Programme Area: Light Duty Vehicles

Project: Economics and Carbon Benefits

Title: Detailed Report on Computer Modelling

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 a detailed report on the modelling work undertaken in the Economics and Carbon Benefits project. It should be read as a supplement to the final Economics and Carbon Offset Analysis Final Report.

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.

ITS

University of Leeds

energy technologies institute

ETI PiVEIP E&CB Analysis

Report on the Economics and Carbon Benefits Modelling

WS3/ITS/02

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Table of Contents

List of Figures

Executive Summary

This deliverable summarises the modelling work done within Sub-project 3 of the PiVEIP project. It includes a summary key features of the models, a description of the themed scenarios introduced in WS3/ARUP/10, an analysis of the results for the base case scenario and of all other themed scenarios, a description of the policy optimisation process and of the "optimal" policy package which it identified, an analysis of the sensitivity tests which were specified in WS3/ARUP/10, and an analysis of the trade-off between Exchequer expenditure and 2050 emissions of CO2. It also includes a section summarising the conclusions and recommendations which we draw from the modelling work. The full results are included in a companion document.

The descriptions of results for individual scenarios, sensitivity runs and policy packages are illustrated with tables and graphs produced by the Economics and Carbon Benefits Model (ECBM) and particular attention is drawn to:

- whole life emissions from the vehicle parc (including the achievement, or otherwise, of target reductions). The whole life emissions are also subdivided into emissions associated with usage and emissions associated with production and scrappage;
- Exchequer spend and revenues;
- the sustainability of the market for PiVs; and
- the deployment and sustainability of public charge points.

The base case scenario demonstrates a switch from gasoline towards diesel with limited uptake of PiVs; PiVs make up only 19% of the parc by 2050 and BEVs only make up 0.6%. These PiVs are supported by a gradual deployment of charge points in response to electricity drawn which is sustainable in terms of profit (or notional profit). By 2050 there are 135,000 non-domestic charge points in place. The increased efficiency of the fleet and the modest shift towards PiVs creates a dramatic reduction in fuel duty receipts from around £17bn down to £9bn in 2050. However, this fall is fully offset by the revenue preserving tax introduced in 2017.

Despite a growth in the parc and in VKT, whole life emissions fall from around 90 Mt in 2010 to 47.8 Mt in 2050. This fall is due to a gradual improvement in new car average emissions. Emissions associated with vehicle use fall from 78.1 Mt in 2010 to 25.4 Mt by 2050 which is still around 9Mt above the 80% reduction target of 16.34 Mt. Production and scrappage accounts for 22.4Mt in 2050 or 46% of the whole life emissions, a much higher proportion than the 13.6% in 2010. Emissions associated with production and scrappage are, by 2050, 60% greater than in 1990 and so are a significant cause for concern.

The other themed scenarios show the effect of changes in scenario and policy variables to represent themes such as most/least favourable conditions for PiV sales, minimised emissions, green emphasis, impact of high/spiked oil prices and a variety of GDP growth assumptions. Analysis and cross-comparison of their results demonstrates which scenario/policy groupings have a significant impact. The analysis shows that the PiV share in 2050 could range from just over 1% (least favourable) to 93% (min emissions); emissions associated with use ranged between 10.9 Mt (min emissions) to 26.8 Mt (High UK GDP) while emissions associated with production and scrappage ranged from 12Mt (green emphasis) to 31.3 Mt (High UK GDP). It is clear that assumptions about consumer behaviour and about the showroom on offer have more impact on PiV share and emissions than do the policy variables. In fact it is clear that the 80% reduction target for in use emissions could be met with favourable behavioural and fleet assumptions without any change to current policies even under the high growth scenario.

The themes also demonstrate the effect on exchequer revenues and spend. The net spend ranges from -£876bn (High UK GDP) to -£731bn (least favourable to PiV sales). It is clear that, while growth in the parc and in VKT generate revenues for the Exchequer, any move towards a greater share of PiVs would increase net spend either through increased spend or decreased revenues. The effect of reduced revenues could be offset to a significant extent by the win-win policies of increased Vehicle Excise Duty and fuel duty and by retaining the revenue preserving fees.

The description of **the optimisation work** begins with a brief outline of its theoretical underpinnings and past applications before describing the process used in the current project. As agreed with MEDAG, the method is used to identify the combination of policies which succeeds in achieving a target reduction in emissions by 2050 at lowest net cost to the Exchequer (where cost to Exchequer includes the value of emissions over the 41 year period). It is noted that the components of the package vary depending on the stringency of the target. The optimal policy package in the base scenario is summarised and its performance with respect to the objective function and other key indicators produced by the ECBM is discussed. It is noted that key components of the package are concerned with minimising expenditure (or raising revenue) rather than with promoting uptake of plug-in vehicles and that the most cost-effective way to achieve the target reduction in emissions involves significant increases in fuel tax and Vehicle Excise Duty, stringent limits on average fleet emissions and subsidies to promote installation of more charge points than would be justified on a purely commercial basis. Interestingly, the provision of subsidy to purchasers of plug-in vehicles appears not to be justified.

The analysis of results obtained from **the sensitivity analyses** specified in WS3/ARUP/10 is structured around key indicators and, for each one, identifies the input variables which have most (and least) impact on that indicator. One hundred and three sensitivity analyses were carried out to test the effect of individual variables in the overall system model. A number of variables and model characteristics were identified as having particularly significant effects on the results across a range of sensitivity analyses.

Consumer behaviour variables have significant effects on the system. Recharge behaviour, attitudes to the idea of plug-in vehicles and the value that consumers place on the availability of charging infrastructure are particularly critical.

Because consumers put a high value on the availability of charging infrastructure, variables that significantly affect deployment of charge points have a large effect on system performance. The two most significant are fixing the deployment of charge points and setting a high level of service coefficient, so that deployment proceeds ahead of demand. Both these cases also rely on government subsidy of the resulting shortfalls in charge point profits.

Electricity price variables generally have relatively small effects except where they affect charge point deployment, because the value consumers place on infrastructure results in significant effects on PiV take-up. The variables with the largest effect are free electricity at workplaces and retailers, likely charge point utilisation and regulation of infrastructure costs.

Government policies generally have small effects on the system. However, it is important to note that fleet average emissions legislation is present in all runs, in one form or another, and is a significant driver towards lowering average emissions. Also, government subsidy of charging infrastructure is a precondition of the high deployment cases discussed above.

Vehicle characteristics have mostly moderate effects on plug-in vehicle take-up, with the most important factors being vehicle price and residual values.

The increase in the vehicle parc and total vehicle kilometres travelled resulting from increased GDP growth is a significant driver of emissions but has relatively little impact on other model outputs.

Analysis of the trade-off between net expenditure by the Exchequer and emissions of CO_2 in 2050 identifies a set of policy packages which perform better (in that they achieve greater reduction in emissions or involve lower net expenditure by the Exchequer) than any others. The characteristics of these packages are discussed. It is noted that the expenditure required to achieve a given reduction in emissions increases as the target reduction becomes more ambitious. The trade-off is also examined in other scenarios and it is noted that the same, or similar, policy package provides the “best” result in several different scenarios.

The conclusions from our analyses will be further discussed along with conclusions from earlier stages in our work in our Final Report (WS3/ARUP/19). Meanwhile, our overall conclusions from the work presented here are as follows:

- PHEVs and REEVs become competitive with conventional vehicles and sell in large numbers in most scenarios.
- BEVs remain more expensive than competitor vehicles and only sell in large numbers if all circumstances are favourable.
- PiV sales are highly dependent upon the perceived availability of charging points at home, at work and at public locations. More research is required on this aspect.
- The success of the business case for public charging point installations is dependent upon the assumed charging behaviour of consumers. Further research is required to provide data on this aspect.
- Inclusion of network reinforcement, network intelligence and public charging points within the Regulated Asset Base encourages public charge point installation. This leads directly to increased PiV sales.
- The subsidisation of charge point installation is a more cost effective use of government resources than subsidisation of PiV purchase. Government subsidy of PiV purchase can have a significant effect in the short term, but its lasting effect is negligible.
- No amount of public subsidy for PiV purchase and charge point installation can compensate for a poor showroom offer or overcome negative public attitudes towards PiVs.
- Loss of revenue from fuel duty becomes a very significant issue for public finances even when PiV shares are low, the annual VKT is significantly increased and/or fuel duties are raised.
- CO_2 emissions in 2050 are highly dependent upon assumptions about the size of the UK car parc and about the total vehicle kilometres travelled.
- It is possible to achieve the 80% reduction target for in-use emissions by 2050 without any change in government policy even under high growth assumptions provided that consumer behaviour, electricity supply/pricing behaviour and showroom on offer are all maximally favourable to PiV sales.
- It is not possible to achieve an 80% reduction in whole life emissions by 2050 in any of our scenarios. This is because emissions associated with production and scrappage are rising, due to growth in the fleet, to becoming a greater problem than in-use emissions by 2050.
- In the base scenario, policy actions, notably including significant subsidy to the deployment of charge points, can, by 2050, achieve at least 77% reduction on the 1990 values of emissions associated with vehicle use.
- The trade-off between net expenditure by the Exchequer over 41 years and reduction in CO_2 emissions in 2050 demonstrates diminishing returns on the expenditure. In the base case, the cost per Mt reduction moves from about £4 bn to about £200 bn. These figures may, at first reading, appear high but it should be noted that the expenditure is spread over 41 years and that the reduced emissions in 2050 will have been preceded by proportionate reductions in the intervening years.
- The trade-off curve demonstrates a sharp inflection at around £30 bn per Mt at a point where total whole life emissions are 42 Mt and the emissions associated with vehicle use are about 19.5 Mt – which still exceeds 16.3 Mt (the desired 80% reduction on 1990 levels of such emissions).

- The DECC values of carbon are not high enough to give the Exchequer a purely financial justification for achieving the 80% reduction in the 1990 emissions by 2050 because the revenue to the exchequer of a non-PiV in terms of fuel duty, VED and other taxes outweighs the value of carbon saved in changing that vehicle to a PiV of any type.
- The trade-off graph can be used to assess the implications of imposing a more stringent target (or different implicit value of carbon). From the graph we can conclude that it is possible to achieve further reductions in emissions close to the 80% reduction target by including generous subsidies to PIV purchase and to charge point deployment (over and above those in the optimal policy). Despite this much higher investment, the net spend to the exchequer is still reduced by around £80 bn relative to the base.
- Widespread deployment of PiVs would not significantly affect the grid demand requirements.

More detailed conclusions are included under three headings:

- Conclusions on policy
- Conclusions on modelling , and
- Recommendations for further work in Phase Two of the PiVEIP project.

Glossary

The following abbreviations are used throughout this report.

- BEV Battery electric vehicle.
- CP Charge point.
- CPC Charge point costs.
- CRM Consumer response model.
- ECBM Economics & Carbon Benefits Model
- GDP Gross domestic product.
- ICE Internal combustion engine.
- LEV Low Emission Vehicle
- NIC Network intelligence costs.
- NRC Network reinforcement costs.
- PEP Public electricity premium, the cost of electricity from non-domestic charge points over-and-above the consumer electricity price.
- 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.
- PVA Perceived value of access to charging infrastructure.
- 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.
- VAT Value Added Tax
- VED Vehicle Excise Duty
- VKT Vehicle kilometres travelled per year.

1 Introduction

1.1 Background, Scope and Structure

Sub-Project 3 (SP3) of the PiVEI project is concerned with the overall evaluation of the economics and carbon benefits of the plug-in vehicle market. It thus includes consideration of the overall vehicle market together with the generation of electricity used to power plug-in vehicles and the economics of the provision of non-domestic charge points. It puts particular emphasis on the impact of government actions on the economics and carbon benefits.

This deliverable contains results of the analyses conducted in SP3 using the Consumer Response Model (described in 1.2 below) and the Economics and Carbon Offset model. The analyses include the base run, themed scenarios and sensitivity analyses defined in our Scenario Development Report[1] together with work to identify the optimal policy package in the base scenario and an exploration of the trade-off between 2050 Emissions of CO2 and Total net relevant expenditure by the Exchequer over the period 2010-2050.

Section 1 of the report continues with a summary of some key features of the Consumer Response Model which help explain some of the results which we find in subsequent sections. This is followed by a description of the themed scenarios.

Section 0 of the report describes the results for the base scenario. This description provides the context for descriptions in subsequent sections.

Section 3 of the report describes the results for each of the twelve themed scenarios – using the results of the base scenario as a reference point and comparing results for groups of themes where appropriate.

Section 4 describes the optimisation work and includes a description of the method and a description of the optimal package which it identifies. This section also contrasts the optimal policy package with the “base” scenario.

Section 5 of the report describes the results of the sensitivity analyses and is structured to discuss “families” of input variables.

Section 6 explores the trade-off between cost to the Exchequer and the reduction in CO2 emissions achieved by 2050.

The final section of the report includes a summary of conclusions and recommendations which flow from the results outlined in the preceding sections.

The full set of detailed graphs output by the ECBM, including many which have not been included in this report, are available as an addendum to this document (the addendum is presented as a separate document to avoid the main report becoming unmanageably large) and is referred to in Appendix A. The “raw” output from the runs of the Consumer Response Model which were drawn on in this phase of the work is available in WS3/ITS/01.

[1] WS3/ARUP/10

1.2 Overview of Model

A description of the overall modelling system, detailing how the individual models interact, is included in WS3/ARUP/10 along with a list of caveats on interpretation of results. Readers are encouraged to consult that report if they wish to be fully informed. However, to assist readers' immediate understanding of the results of the modelling work, some important aspects of the system are described briefly below.

The Consumer Response Model (CRM) is at the heart of the overall modelling system. Most of the CRM is, and always was, concerned with consumers' purchase decision; i.e. with estimation of the number of each type of vehicle sold each year. The consumer purchase decision is made from a "showroom" which evolves over time as specified by other work packages in SP1. The choices are assumed to be restricted to a given class of vehicle and are driven by vehicle attributes (such as range, price running costs, and performance which are specified as part of the showroom offer) and charge point availability combined with response coefficients that put a financial value on those attributes. The coefficients were derived from consumer surveys conducted within SP1.

The original focus of the CRM was expanded, through co-operation between SP1 and SP3, to include some other important aspects of the overall system. Namely:

- the usage and deployment of non-domestic charge points, and
- changes in the number of kilometres driven per car in response to changing costs per kilometre.

Other important aspects of the overall modelling system, developed by SP3 and fed as input to the CRM, include:

- assumptions about the way in which growth in the UK GDP affects growth in the overall size of the GB car market and in total vehicle kilometres
- assumptions about the effect that different electricity generation mixes, and different base-load demands for electricity, have on the price of electricity used in PiVs and on the emissions associated with the generation of that electricity.

The model also makes use of information provided by SP2 on the costs associated with the deployment of charge points.

Of the aspects noted above, the reader will find it particularly useful to appreciate:

i. The importance, in the CRM, of perceived access to charge points
ii. Limitations on the representation of the showroom and of consumers' willingness to choose different classes of vehicle
iii. Assumptions about charge point deployment
iv. Assumptions about consumer recharge behaviour
v. Assumptions about the effect of UK GDP on the size of the car parc and on total vehicle kilometres.

We will address each of these in turn in the following subsections.

1.2.1 The importance of access to charge points

The consumer surveys suggested that people's willingness to purchase PiVs was very dependent on the availability of public charge points; people without access to domestic charge points appeared unlikely to purchase PiVs and, even those with access to domestic charging appeared to require ready access to non-domestic charge points before they would choose a PiV in preference to other power-trains. This is reflected in the CRM and the requirement for access to non-domestic charge points is assumed to persist through to 2050 (even though, in reality, this barrier might be overcome if and when people realise that they rarely or never need access to such charge points). This means that the CRM's forecast of the uptake of PiVs is extremely dependent on the perceived availability of non-domestic charge points.

The perceived availability of non-dometic charge points is dependent on two mechanisms; the assumed deployment – see Section 1.2.3 below – and assumed perception of access associated with a given deployment. The assumed perception of access associated with a given deployment is based on a formula within the CRM – a formula which is, in the absence of observable data, based on key assumptions such as the distribution of a given stock of non-domestic charge points across the country and the way in which the usage of a given number of charge points affects their perceived availability.

1.2.2 Limitations on the representation of the showroom and of consumer flexibility

The showroom offer is based on work by Ricardo but is not assumed to vary in response to the evolution of the market. For example, the availability, specification and price of models does not change in response to the rate of growth in demand. Nor is there any upper limit on the number of any given model that can be purchased in any given year.

Consumers are assumed to have a given class of vehicle in mind when they enter the showroom and this does not depend on the relative attractiveness of the different classes (e.g. super-mini versus mini). This restricts the effectiveness of policy measures which might, deliberately or otherwise, affect people's choices (e.g. favourable tax treatment of Low Emissions Vehicles (LEV) does not prompt people to migrate away from classes of vehicle which include few, if any, LEV models).

The modelling work has accepted the vehicle attributes (performance, price, running costs, etc.) as specified by Ricardo. Some of these attributes might not be as the lay reader might expect, for example, the running costs of BEVs are not much less than those of conventional vehicles – because, although their fuel costs are lower, their insurance costs are higher – in line with their purchase price.

1.2.3 Assumptions about non-domestic charge point deployment

The deployment of non-domestic charge points is governed by a model which replicates a market in which supply generally reflects demand subject to the charge points bringing in sufficient revenue, or other benefits, to cover their costs.

The profitability of charge points is calculated each year. If, in the light of costs and expected revenues, charge points are not expected to be profitable in a given year, then the deployment of new charge points in that year is reduced. The number of charge points to be installed in any year cannot be negative, so the total number of charge points can only reduce due to natural wastage. If charge points are profitable, then additional charge points are installed such that predicted demand can be satisfied by each charge point supplying a specified number of kWh/day.

Consequently the deployment of non-domestic charge points is linked to demand, the price premium that is charged for electricity, the value of any additional benefits to the supplier (e.g. additional sales at a retail outlet) and the cost of running a charge point. These factors are in turn dependent on a number of variables.

Although we believe this model to be reasonable, there is no data to verify it.

1.2.4 Assumptions about consumer recharge behaviour

The amount of recharging that drivers carry out in different locations is modelled with a series of look-up tables which, in the absence of observable data, reflect reasonable assumptions about what may happen.

There are separate look-up tables for private and company car drivers. Each look-up tables categorises drivers depending on their access to domestic, workplace, retail and public charge points and for each driver category specifies the percentage of recharging that takes place in different locations.

For any particular analysis, the recharge behaviour is fixed. Thus recharge behaviour does not vary in response to the cost of recharging, although drivers can be re-categorised if the availability of workplace, retail and public charge points changes.

Different look-up tables are defined for particular sensitivity analyses where recharge behaviour is expected to change significantly, for example if workplaces and retail locations offer free recharging.

1.2.5 Assumptions about the influence of GDP on the car parc and on kilometres travelled

Past data has shown there to be a relationship between the growth UK GDP and the growth in the GB car parc. The relationship is discussed in WS3/ARUP/10 but, in brief, it suggests that the rate of growth in the car parc is positively correlated with the growth in GDP but that its growth is less than proportionate and is constrained by the increased congestion which would otherwise occur. Past data similarly shows that total vehicle kilometres travelled (VKT) also grows with GDP but much less than proportionately – the saturation effect is much more apparent for VKT than it is for the size of the car parc. The net effect is that the distance travelled per vehicle actually *reduces* as GDP increases.

These relationships have been built into the scenario data and, quite naturally, have a considerable impact on total emissions – particularly those associated with the production and scrappage of vehicles.

1.2.6 Calculation of CO2 emissions

In calculating the CO2 emissions due to PiVs' usage of electricity, we have considered three electricity CO2 intensity factors; average, marginal and tapered. The average factor is best suited to situations in which the grid has time to increase its stock of power stations to manage the additional load. The marginal factor is best used when a sudden increased load is applied to the grid and the operators have to switch on a standby, or marginal, power station. We also considered a tapered factor, which transitioned from marginal to average between 2010 and 2030. In practice, although important when compared directly, the differences were negligible when compared to the overall in-use CO2 emissions of the fleet including fossil fuel emissions. As a consequence, we have reported only using an average emission factor.

1.3 Description of the Themed Scenario Input Assumptions

1.3.1 Introduction

The themed scenarios explore PiV uptake and carbon emissions under a range of different potential future states. The future states are defined by unique combinations of input assumptions. Some scenarios are related to "external" factors such as high or low growth in the UK GDP and different oil price futures, while others are purposely defined to consider extreme cases such as futures in which PiV sales are maximised/ minimised or in which carbon emissions are minimised. The following themes were identified during the scenario development process reported in WS3/ARUP/10 :-

- T0 Base (in which all variables are set to "Most likely" or "Do nothing" levels)
- T1 All circumstances are maximally favourable to PiV sales
- T2 All circumstances are minimally favourable to PiV sales
- T3 Government incentives as announced but all other factors are maximally favourable to PiV sales
- T4 Government incentives as announced and all other factors are minimally favourable to PiV sales
- T5 High rate of growth of UK GDP
- T6 Low rate of growth of UK GDP
- T7 High rate of growth in the global economy
- T8 Medium rate of growth in the global economy with a green emphasis
- T9 Medium rate of growth in the global economy with high oil price
- T10 Medium rate of growth in the global economy with oil price spike
- T11 Low rate of growth in the global economy
- T12 Minimised carbon emissions

The initial specification of each themed scenario is described in WS3/ARUP/10. For some scenarios, e.g. T5 and T6 (which simply envisage different rates of growth in UK GDP), and T7, T9, T10 and T11 (which simply envisage different rates of growth in the global economy – with commensurate commodity price levels), this was relatively simple, for others, a degree of judgement was required. For example, given the complex interactions encapsulated in the Consumer Response Model (CRM) and its associated algorithms, it was not always clear which settings of some of the behavioural parameters would maximise (or minimise) PiV sales in T1, T2, T3 and T4. Nor was it clear what settings would best represent a "green emphasis" in T8 or minimise carbon emissions in T12. It was therefore always intended that we would examine the results of the sensitivity tests from the base case to check our assumed values. This was done and some additional sensitivity tests were then run for certain parameters to check the "best" values to maximise/minimise PiV sales in T1, T2, T3, T4 and to minimise emissions in T12.

The following sections include tables which summarise the settings used for each variable in the base run (T0) and in each of the themed scenarios. In these tables "M", "L" and "H" indicate use of the Medium, Low and High values respectively. The actual values implied by these labels, and for others appearing in the tables, can be found in WS3/ARUP/10.

The following sub-sections set out the basic assumptions for each theme and highlight where variables were not as suggested/expected in WS3/ARUP/10 (variables whose values differ from those set out in WS3/ARUP/10 are shown in red in the appropriate table).

1.3.2 Commodity prices

WS3/ARUP/10 describes the base, high and low trajectories for prices for Oil, Gas, Coal and Carbon. For each theme we then identified the following changes compared to the base as shown in Table 1.

Table 1. Commodity Prices

Code		Oil	Gas & Coal	Carbon Credit
T0	(Base)	M	M	M
T1	Maximally favourable to PiV sales	H	L	L
T2	Minimally favourable to PiV sales	L	H	H
T3	Govt incentives as T0 otherwise maximally favourable to PiV sales	H	L	L
T4	Govt incentives as T0 otherwise minimally favourable to PiV sales	L	H	H
T5	High rate of growth in UK GDP	M	M	M
T6	Low rate of growth in UK GDP	M	M	M
T7	High rate of growth in the global economy	H	H	H
T8	Medium rate of growth in the global economy with a green emphasis	H	H	H
T9	Medium rate of growth in the global economy with high oil	H	M	M
T10	Medium rate of growth in the global economy with oil spike	S	M	M
T11	Low rate of growth is the global economy	L	L	L
T12	Minimum carbon emissions	H	H	H

Note: "S" indicates a price spike

T1 and T3, which require settings to maximise PiV sales, have high oil prices which should adversely affect non-PiV sales combined with low gas, coal and carbon prices which should mean low prices for electricity (see later for generation mix). T2 and T4, which require settings to minimise PiV sales, have settings opposite to those in T1 and T2.

T5 and T6 have the same settings are as for the base (it is assumed that UK GDP growth rates do not affect commodity prices).

T7, the high global growth scenario, has all commodity prices set as high due to high demand around the world. T8, medium growth with green emphasis, also has all prices set as high. This is partly due to an assumed high price of carbon, which implies investment is needed to deliver commodities with lower carbon footprint, but it is also linked to the assumed target for the generation mix (super ambition scenario) which implies high prices.

T9 and T10, the high oil and oil spike scenarios (indicated by "S"), have medium gas, coal and carbon prices but oil prices as specified.

T11, the low global growth scenario, has low prices due to low demand around the world. Finally T12 has high commodity prices because these were expected to minimise emissions and did so.

1.3.3 UK GDP variables

WS3/ARUP/10 defined the variables related to UK GDP as the size of the UK car parc, annual vehicle kilometres travelled (VKT) and whether or not people are less sensitive to prices. A high rate of GDP growth results in a large car parc, higher VKT by 2050 and reduced sensitivity to prices (due to higher personal incomes). The parc sizes in 2050 for the low, base and high GDP cases are 33.8, 45.3, 60.6 million vehicles with associated VKT of 405, 453 and 484 bn vehicle kilometres respectively.

Table 2 Tests related to the UK GDP

Code	UK vehicle parc	Annual VKT	Reduced sensitivity to prices
T0 (Base)	M	M	M
T1 Maximally favourable to PiV sales	H	H	H
T2 Minimally favourable to PiV sales	L	L	N
T3 Govt incentives as T0 otherwise maximally favourable to PiV sales	H	H	H
T4 Govt incentives as T0 otherwise minimally favourable to PiV sales	L	L	N
T5 High rate of growth in UK GDP	H	H	H
T6 Low rate of growth in UK GDP	L	L	L
T7 High rate of growth in the global economy	H	H	H
T8 Medium rate of growth in global economy with a green emphasis	L	L	L
T9 Medium rate of growth in the global economy with high oil	H	H	H
T10 Medium rate of growth in the global economy with oil spike	L	L	L
T11 Low rate of growth is the global economy	L	L	L
T12 Minimum carbon emissions	L	L	L

To maximise PiV sales (T1 and T3) we have naturally assumed a high growth scenario and a high reduction in sensitivity to prices (PiVs being generally more expensive, reduced sensitivity to prices should help sales). To minimise PiV sales (T2 and T4) we use the opposite settings; a low growth scenario and no reduction in sensitivity to prices.

Settings for T5, T6, are obvious (the GDP growth rates are specified).

Settings for T7, T9, T10 and T11 are as per the base (the GDP growth rates are medium).

In T8, despite its medium global growth rate, we have set UK growth in parc and VKT to low due to the green emphasis – people are assumed to choose other forms of transport over the car and/or growth in the UK economy is assumed to be sluggish.

T12 has a low growth assumed in order to minimise emissions.

1.3.4 The vehicle showroom

Table 3 shows the assumed attributes for development of the fleet for each themed scenario.

Table 3 : Showroom attributes (B= BEV, P= PHEVs and REEVs, N = Non-PiVs – including mild and full hybrids, ICE with or without stop-start , hydrogen and fuel cell – as appropriate)

	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
	B&P&N	B&P&N	B&P&N	P&N	B&P	B&P	B&P	N	B&P&N	B&P&N
T0	M	M	M	M	M	M	M	M	M	M
T1	L	L	L	H	H	H	H	L	H	L
T2	H	H	H	L	L	L	L	H	L	H
T3	L	L	L	H	H	H	H	L	H	L
T4	H	H	H	L	L	L	L	H	L	H
T5	M	M	M	M	M	M	M	H	M	M
T6	M	M	M	M	M	M	M	H	M	M
T7	L	L	L	L	L	H	H	H	H	L
T8	H	H	L	L	L	H	H	H	H	L
T9	M	M	M	M	M	M	M	M	M	M
T10	M	M	M	M	M	M	M	M	M	M
T11	H	H	H	H	H	L	L	L	L	H
T12	L	L	L	L	H	H	H	H	H	L

To maximise sales of PiVs (T1 and T2) we have low purchase prices with low battery prices, fossil fuel consumption is set as high, max electric range and performance of BEV and PiVs are set high while performance of other vehicles is set low. Average life for PiVs is set high as this affects the residual values and production and scrappage values are set low. Concerning electricity consumption per 100km, it was originally thought that a low consumption per 100 km would cause greater PiV sales due to lower operating costs per km in electric mode. However, the sensitivity tests indicated the opposite result. We deduce that this counterintuitive result is due to the fact that, since the number of charge points installed responds to amount of electricity drawn in the previous period, higher consumption leads to more charging points and, since charge point availability significantly affects purchase of PiVs, high consumption is beneficial to sales.

To minimise sales of PiVs (T2 and T4) we simply use the opposite of T1 and T3.

T5, T6, T9 and T10 have medium growth in the global economy and hence, by definition, have medium fleet development and prices.

T7, the high global growth scenario implies, by definition, an advanced fleet at low costs for both PiVs and ICEs.

T8 has a similarly advanced fleet development but with higher prices because we have assumed the green emphasis means manufacturers respond to tighter regulations and offer an advanced fleet but that, given the medium rate of growth in the global economy, they can only do so at higher prices.

T11 has low growth in the global economy and so, by definition has poor fleet development in terms of efficiency, performance and emissions with higher prices (required due to lower volumes being sold).

Finally, for T12, to minimise emissions we assumed a low cost, highly advanced fleet with low production and scrappage emissions.

1.3.5 Electricity generation assumptions

Table 4 shows the scenario variables for electricity generation, price and supply of charge points for each themed scenario.

Table 4: Electricity generation

Theme	UKERC Base Load	UKERC - associated theme
T0 (Base)	M	CAM
T1 Maximally favourable to PiV sales	H	CLC
T2 Minimally favourable to PiV sales	L	CCSP
T3 Govt incentives as T0 otherwise maximally favourable to PiV sales	H	CLC
T4 Govt incentives as T0 otherwise minimally favourable to PiV sales	L	CCSP
T5 High rate of growth in UK GDP	H	CAM
T6 Low rate of growth in UK GDP	L	CAM
T7 High rate of growth in the global economy	H	CAM
T8 Medium rate of growth in the global economy with a green emphasis	L	CSAM
T9 Medium rate of growth in the global economy with high oil	M	CAM
T10 Medium rate of growth in the global economy with oil spike	M	CAM
T11 Low rate of growth is the global economy	L	CAM
T12 Minimum carbon emissions	L	CSAM

The four UKERC carbon reduction scenarios for the installed electricity grid capacity to 2050 were defined as follows:-.

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

The assumed base demands are related to assumed UK growth rates in GDP. The combination of base load and UKERC theme produces the base electricity price as reported in WS3/ARUP/10.

1.3.6 Charge point deployment and electricity prices

The basic price of electricity is determined by the generation mix and demand assumptions described above. However, the price of electricity drawn from charge points and the deployment of charge points, is affected by other factors – as described in WS3/ARUP/10.

Our assumptions about these factors under the themed scenarios are set out in Table 5.

Table 5 Electricity price and supply scenarios.

Theme	Electricity Price (EP)						Supply & Price of Charge Points (CP)	
	Costs for NR, NI & CP	Required rate of return on capital	Employers & Retailers Action		Likely utilisation	Peak/Off Peak Elec Price Ratio	Domestic Avail	Non-domestic max utilisation
			Charge for Elec?	Notional Value				
T0 (Base)	M	M	FP	M	M	M	M	M
T1 Maximally favourable to PiV sales	L	L	F	M[2].	M	H	H	H
T2 Minimally favourable to PiV sales	H	H	FP	L	H	L	L	L
T3 Govt incentives as T0 otherwise maximally favourable to PiV sales	L	L	F	M.	M	H	H	H
T4 Govt incentives as T0 otherwise minimally favourable to PiV sales	H	H	FP	L	H	L	L	L
T5 High rate of growth in UK GDP	M	M	FP	M	M	M	M	M
T6 Low rate of growth in UK GDP	M	M	FP	M	M	M	M	M
T7 High rate of growth in the global economy	M	M	FP	M	M	M	M	M
T8 Medium rate of growth in the global economy with a green emphasis	L	L	F	M.		H	H	H
T9 Medium rate of growth in the global economy with high oil	M	M	FP	M	M	M	M	M
T10 Medium rate of growth in the global economy with oil spike	M	M	FP	M	M	M	M	M
T11 Low rate of growth is the global economy	M	M	FP	M	M	M	M	M
T12 Minimum carbon emissions	L	L	F	M.		H	H	H

Note: In Table 5 electricity charge F means " Employers and retailers offer free electricity to their employees and customers respectively" and electricity charge FP means that " Employers and retailers charge the full price (CEP+PEP)"

For T1, costs and rates of return required are low compared to base and employers and retailers provide free electricity at their charge points (which means the notional value is not applied). Likely utilisation is linked to the charge point deployment formula and we assume the base value is the lowest feasible value. We assume that to increase PiV sales there will be a higher peak/off peak price ratio which benefits PiV users who can charge at night. Domestic availability is high along with non-domestic maximum utilisation. This last variable was one of those which were changed following the sensitivity analysis – again higher utilisation drives the demand for charge point installation which reduces the penalty on charge point availability. T3 is set the same as T1

T2, which aims to minimise PiV sales, is the opposite of T1 as usual apart from likely utilisation which is set as high, a higher utilisation implies fewer charge points are installed in our charge point deployment formula described in WS3/ARUP/10. T4 follows T2 as usual.

T8 and T12 which have a green emphasis and aim to reduce emissions respectively have the same assumptions as T1 as we assume more PiV sales will also fit with the green emphasis and help minimise emissions.

All other themes are assumed to have the same settings as the base.

[2] The notional values do not affect deployment in scenarios where retailers and employers do not charge for use of charge points (i.e. when "charge for elec" is set to "F")

1.3.7 Consumer behaviour

Table 6 shows the scenario variables related to consumer behaviour for each themed scenario.

Table 6 : Variables related to consumer behaviour

	Segment Pref	% Private	Purchase sensitivity to PiV idea	Range	Price	CP availability	Use sensitivity	Recharge behaviour Patterns	Company Patterns	Off peak
T0 (Base)	B	C	B	B	B	B	E	B	B	Y
T1 Maximally favourable to PiV sales	SM	HP	L	L	L	L	E	FWR	B	Y
T2 Minimally favourable to PiV sales	L	C	H	H	H	H	I	PR	PR	ND
T3 Govt incentives as T0 otherwise maximally favourable to PiV sales	SM	HP	L	L	L	L	E	FWR	B	Y
T4 Govt incentives as T0 otherwise minimally favourable to PiV sales	L	C	H	H	H	H	I	PR	PR	ND
T5 High rate of growth in UK GDP	B	C	B	B	B	B	E	B	B	Y
T6 Low rate of growth in UK GDP	B	C	B	B	B	B	E	B	B	Y
T7 High rate of growth in the global economy	B	C	B	B	B	B	E	B	B	Y
T8 Medium rate of growth in the global economy with a green emphasis	SM	HP	L	L	L	L	E	FWR	B	Y
T9 Medium rate of growth in the global economy with high oil	B	C	B	B	B	B	E	B	B	Y
T10 Medium rate of growth in the global economy with oil spike	B	C	B	B	B	B	E	B	B	Y
T11 Low rate of growth is the global economy	B	C	B	B	B	B	E	B	B	Y
T12 Minimum carbon emissions	L	HP	L	L	L	L	E	FWR	B	Y

(see WS3/ARUP/10 for definitions of codes in table 6)

For T1 and T3 it was found from the sensitivity tests that a preference for smaller vehicles and a high proportion of private purchasers would increase PiV sales compared to the base values. Assuming a low sensitivity to the PiV idea, range, price and charge point availability also logically increases the share of PiV sales. Sensitivity to use was set as in the base after further tests showed it to be beneficial to PiV sales (ignoring sensitivity to use is detrimental to PiV sales). The logic behind this is that, since electricity if offered free at retail and workplace charge points and since electricity costs are low, this creates more demand for electricity which stimulates the installation of more charge points, and this in turn encourages higher sales of PiVs.

For T2 and T4 we generally have the opposite to T1 – with charging patterns set as favouring public rapid charge points (PR) which are generally not going to be installed in a failing scenario. The off-peak recharge behaviour is also set with no delayed charging (ND) to minimise sales of PiVs.

T8 follows T1 as we assumed the green emphasis also wishes to see increased share of PiVs. Note that for T12 most variables are also as T1 with the exception of the segment preference where it was found that using a preference for larger vehicles actually reduced total emissions. This is thought to be due to the relative improvements in emissions between model types on offer.

Settings for all other scenarios (T5, T6, T7, T9, T10 and T11) are retained at the base (T0) levels.

1.3.8 Policy variables

As noted above, the base case generally assumes medium or median values for "external" factors and "as now/as announced" settings for the policy levers. Important exceptions include:

- The assumption that a revenue preserving tax would be introduced, as a levy on each vehicle, to replace tax revenues lost due to falling sales of petrol and diesel.
- The assumption that Network Reinforcement and Network Intelligence will be designated as regulated assets (while Charge Points are not).
- The exemption from congestion charges in London is not assumed to apply to PiVs unless they are also LEVs [3]

Table 7 shows the values used for each of the available policy levers in each of the themed scenarios. It will be seen that, only themes T1, T2, T8 and T12 were set to differ from the base. Settings for these policy levers were anticipated in WS3/ARUP/10 and were to be confirmed by examining the results from the sensitivity analyses. There were two cases where we found it necessary to depart from the anticipated values. Firstly, detailed investigation suggested that PiV sales were maximised if the vehicle purchase and ownership taxes were banded according to well-to-wheel emissions (rather than tailpipe emissions). This unexpected result implies that the WTW scale was actually more disadvantageous to some ICE models than we had anticipated.[4] Secondly, it transpired that PiV share would be maximised if the congestion charge was extended to other major cities with the exemption lever activated. These settings were therefore adopted for T1 (and the opposite ones were adopted for T2)[5].

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[3] This change was necessitated by a misunderstanding between SP3 and Element Energy which did not come to light until after the bulk of the CRM runs had been completed. We had intended the Base to include an exemption for all PiVs up until 2014 and, anticipating a decision that has not yet been taken, for the PiV exemption to end in that year.

[4] Our expectation, backed up by the single dimension sensitivity analyses, was that a tailpipe scale would be more beneficial to PiV sales but, in the context of other changes which favoured PiV sales, the WTW scale actually proved better.

[5] This unexpected result is attributable to the fact that, because of a coding error in the CRM, activation of the exemption lever was giving a benefit to PiVs and, quite naturally, this effect was maximised if congestion charges were extended to other major cities.

Table 7 : Values for policy levers

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. Network 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										

Levers marked with question marks are dummy variables - a “Y” in the table indicates “yes”, “na” on line A2 indicates that there was no budget cap.

For T1 which aims to increase the sales of PiVs the policies were as for the base case except for the following:-

- Maximum subsidies were allowed until 2025 with an unlimited budget
- Capital allowances for company cars were only allowed for cars which emit less than 42 g/km (beyond 2013) – more inclusive limit actually harms the uptake of PiVs because, it benefits a number of non-PiVs and thus reduces the PiV share.
- VED rates were set by well to wheel and doubled
- Fuel duty was doubled
- No revenue preserver charge is applied
- Congestion charges are applied in all major cities in the UK with no exemptions, other than for PiVs[6] – the removal of subsidies from non-PiVs is clearly beneficial to PiV uptake
- The number of initial charge points deployed were doubled
- The level of service coefficient was increased (but limited) to 1.1 – this results in more charge points being deployed
- The government is assumed to meet any shortfall in revenues from charge points (charge points are not regulated in the base and in T1)
- Emissions regulations are strengthened to 25 g/km by 2050 and based on tailpipe.

For the theme T2 which aims to minimise PiV sales the policies were as the base apart from the following:-

- No subsidies to PIV purchases were given
- Beyond 2020, company car taxation is set by WTW emissions (which is less favourable to PiVs)
- VAT is increased to 20% on domestic electricity used for charging purposes
- Fuel duty is reduced by 50%
- A revenue preserver charge is applied but based on use
- There are no regulated assets and no grants or capital allowances
- Only 25% of the initial charge points are deployed compared to the base
- Maximum price consumers are assumed to pay for electricity is set at half the equivalent price of conventional fuel
- The government does not meet any shortfall
- Emissions regulations are relaxed aiming at 50 g/km WTW by 2050

For themes T8 and T12 the policy is the same as for T1 with the exceptions that a revenue preserver charge is applied to use and that charge points are now a regulated asset.

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[6] As already noted, the exemptions policy was not coded as we had originally intended (i.e. as described in WS3/ARUP/10. In the current document we describe the policy as it was coded at the time that we conducted the bulk of our work. We understand that the CRM code has now been corrected to represent the policy as originally intended.

All other themes have policy levers set as in the base. This is particularly important to note for T3 and T4 which are the same as T1 and T2 in all other aspects. This allows us to compare the base policy contribution compared to (un)favourable policies in T1 and T2.

2 Results for the Base Scenario (T0)

2.1 Share of New Sales and of Parc

In the base case there is a switch from gasoline towards diesel with limited uptake of PiVs. Taken together, PHEVs and REEVs , whether gasoline or diesel, make up only 19% of the parc by 2050 and BEVs only make up 0.6%. Figure 1 a,b shows the sales in thousands and percentage of the parc from 2010 to 2050. It should be noted that the emissions regulations begin to take effect in the form of penalties and credits on purchase price from around the year 2022 which, along with the introduction of more PiV models in each segment beyond 2020, accounts for most of the push towards PiVs. The reason for the trends in gasoline and diesel sales are complex. It is noticeable that just before 2040 there is a move from gasoline to diesel with gasoline sales dropping. However after 2040 gasoline sales begin to rise again suggesting they are becoming first less attractive and then more attractive relative to diesel models. We note that the Ricardo road map interim report shows that the introduction of improved models (giving better fuel consumption and lower emissions) is generally earlier for diesel than for gasoline. The fuel consumption prior to 2040 favoured diesel but this was reversed beyond 2040 when new gasoline models were introduced. There was also a tendency for gasoline models to have improvements in performance before improvements in emissions. We also note that, in the period leading up to 2040, there was a purchase price differential in favour of diesel models which then reversed beyond 2040. Finally there is an interaction with the penalties as emissions regulations are not met in the later years. Although we do not have access to sufficient data to confirm that it is true, we deduce from the above analysis that diesel models were given higher credits (or lower penalties) than gasoline models because their emissions were improved earlier.

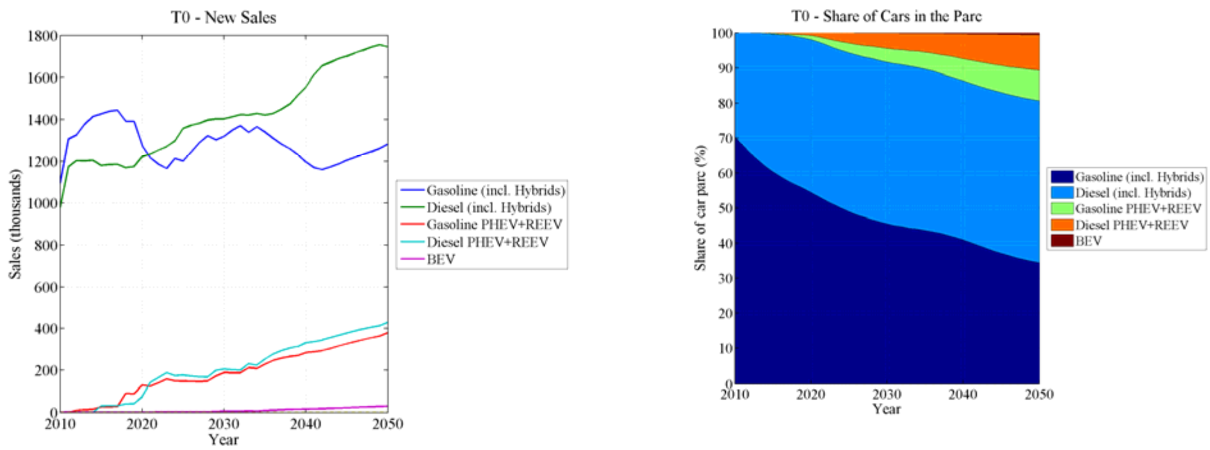


Figure 1(a), (b) : Total new sales and share of cars in the parc T0
(Note that “Hybrids” refers to non-plug-in hybrids)

2.2 Charge Point Deployment and Profit

The majority – around 85% - of recharging occurs at home. The availability of domestic charging is thus fundamental to the uptake of PiVs. The base-case assumption is that this is limited to 80% of the people who have access to off-street parking at or near their home. This assumption clearly constrains the uptake of PiVs.

Figure 2 shows the number of non-domestic charge points in place by type from 2010 to 2050. Figure 3 provides information on their profitability. Initially charge points have a fixed rate of deployment. When these come to the end of their life the amount of electricity drawn per charge point along with profit or notional profit determine whether or not they are replaced; more charge points if the demand and profits justify it. Notice, from Figure 3a, that the net profit oscillates around the zero profit line. This is because a zero net profit represents the case where the operators are making their required rate of return. This behaviour is as expected and demonstrates that the charge point deployment formula is working as intended.

Figure 2 shows that deployment of on-street and car-park charge points takes off quite rapidly after 2020 with a further acceleration around 2035. As can be seen from Figure 3a the profits for these categories of charge points are initially negative. As profits for car park and on-street become positive then more charge points are deployed beyond 2020 with around 50k car park and 60k on street points by 2050.

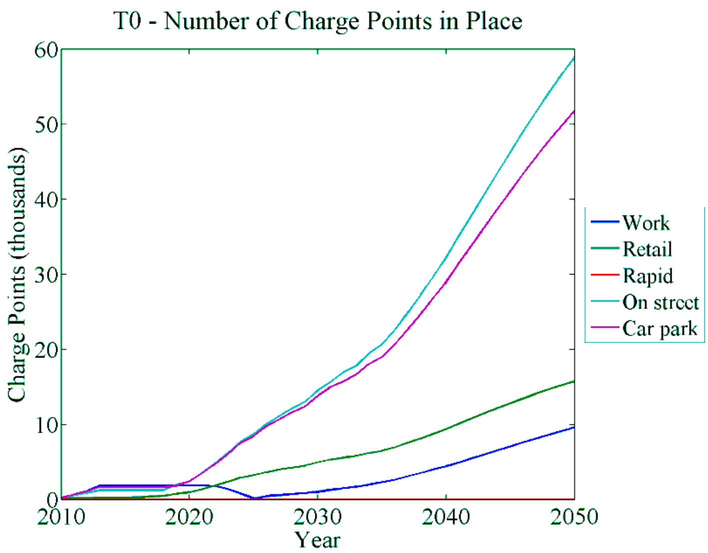


Figure 2 : Number of charge points in place T0

The deployment of rapid charge points is never very significant. This reflects the input assumptions about demand for rapid charging. Figure 3a indicates that they are never profitable and, in the absence of a business case for rapid charge points, the initially installed points are not replaced when they come to the end of their life.

Deployment of work place charge points falls after about 2022 but begins to recover again after 2025 – reaching about 10k by 2050. This reflects the fact, illustrated in Figure 3b, that the notional profit on such charge points is negative until 2025. After 2025 the positive, albeit small, notional profit allows more work place charge points to be installed as demand from PiVs increases with increased PIV share.

Deployment of charge points at retail locations rises steadily from about 2018 to around 16k in 2050. Figure 3b shows that the retailers' notional profit for such charge points increases and this might suggest that more could have been installed without making a loss. However we are happy that the deployment rate is reasonable and that the notional profit per charge point is only around £430 per point per annum.

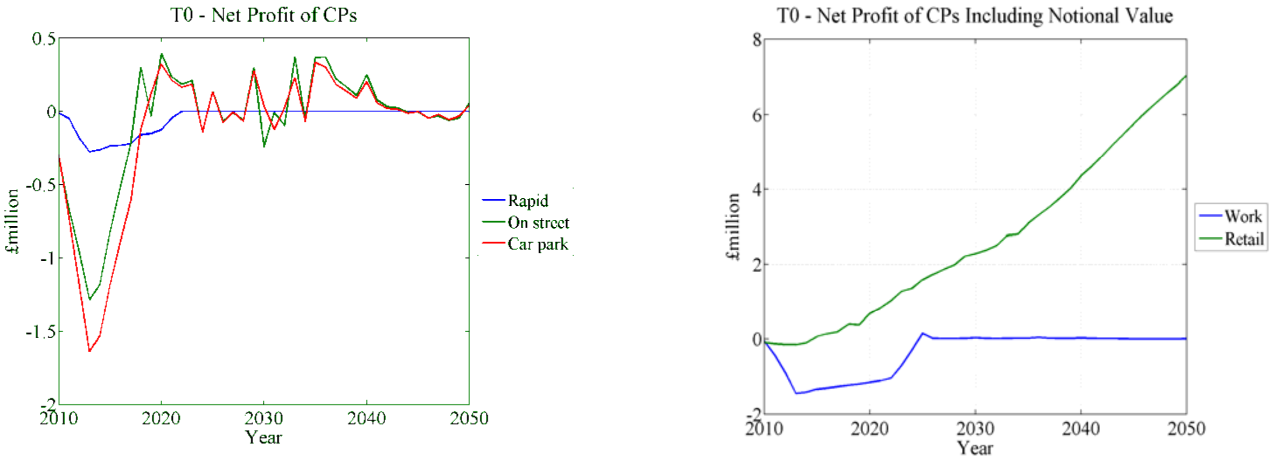


Figure 3a,b : Net profit and notional profit for charge points T0

2.3 Exchequer Spend and Revenue

Figure 4 shows the Exchequer spend and revenues for the base case. Spend is dominated by the loss in corporation tax as companies take advantage of the capital allowances. The spike in corporation tax is due to the first year losses as companies take advantage of the capital allowances for new low emission models which appear in the showroom between 2017 and 2022. Whilst sales are increasing relative to high emission vehicles then the delayed tax receipts in years 2-5 are not enough to outweigh the losses from year 1 write-down. Note that in the base case the allowances can be applied to any vehicle meeting the 95g/km limit – so this is not restricted to PiVs. Over time, non-PiVs become more efficient and are thus eligible for the allowance and the loss in corporation tax is thus likely to occur even without a policy to support the introduction of PiVs.

Whilst there are some subsidies in 2011 these only amount to £11.8m (they are shown in Figure 4c along with subsidies for charge points). It should be noted that these subsidies are spent on BEVs only as there are no PiVs on offer in 2011. There are also some subsidies to charge points which rise steadily to a value of £2.8m per annum by 2050. Figure 4b shows how fuel duty collected is reduced over time, partly due to the shift to PiVs and partly due to the increased efficiency of the non-PiV fleet. When fuel duty collected drops below the 2010 value then the revenue preserving tax kicks in; this happens in 2017 and the revenue preserver ensures that fuel duty plus revenue preserver sums to the 2010 value of around £17.4b. VAT receipts are seen to increase steadily to around £15b p.a. by 2050. VED and company car tax remain quite stable over time despite the increase in parc size – from around 28 million to around 45 million vehicles. This is because the average VED per car is reduced from £125 in 2010 to £98 in 2050 (the reduction in new vehicles' average emissions per km means that, over time, a greater share of vehicles attract low – or zero – VED). A similar argument applies to company car tax.

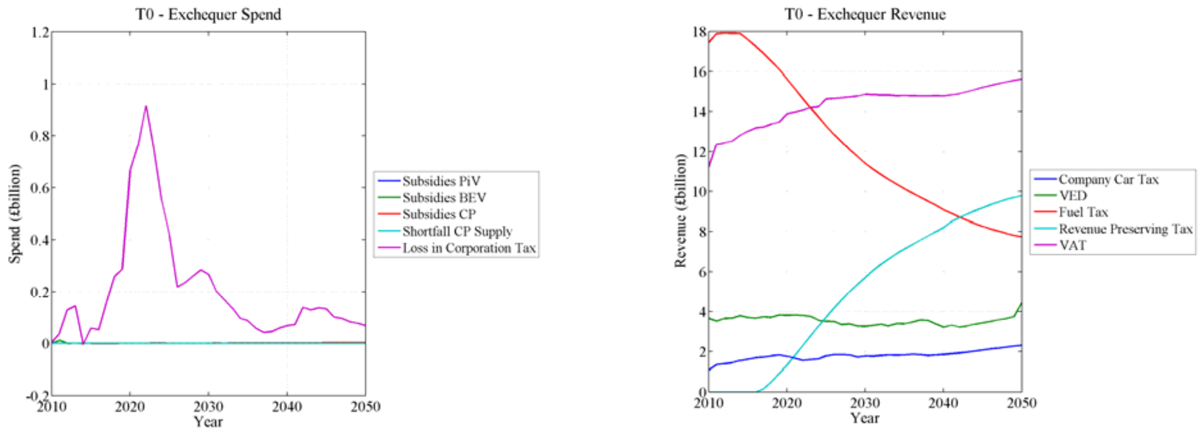


Figure 4a,b : Exchequer spend and revenues T0

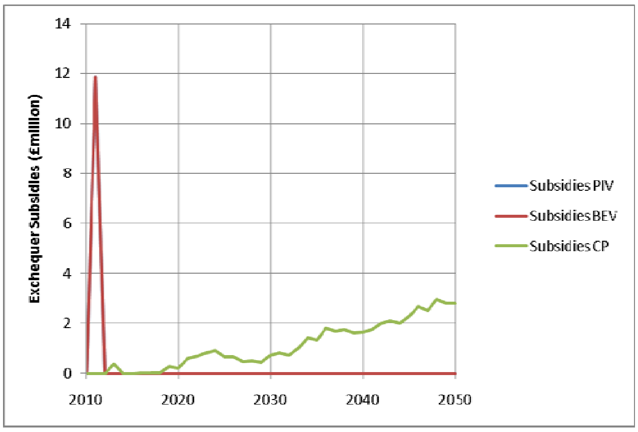


Figure 4c : Exchequer subsidies T0

2.4 Emissions

The in-use emissions of PHEV/REEVs are around half those of conventional vehicles and the in-use emissions of BEVs are negligible in comparison to conventional vehicles even though these are declining over time (see Figure 5). The increasing proportion of PiVs leads to a reduction in the average emissions of the UK parc decrease and in total in-use emissions.

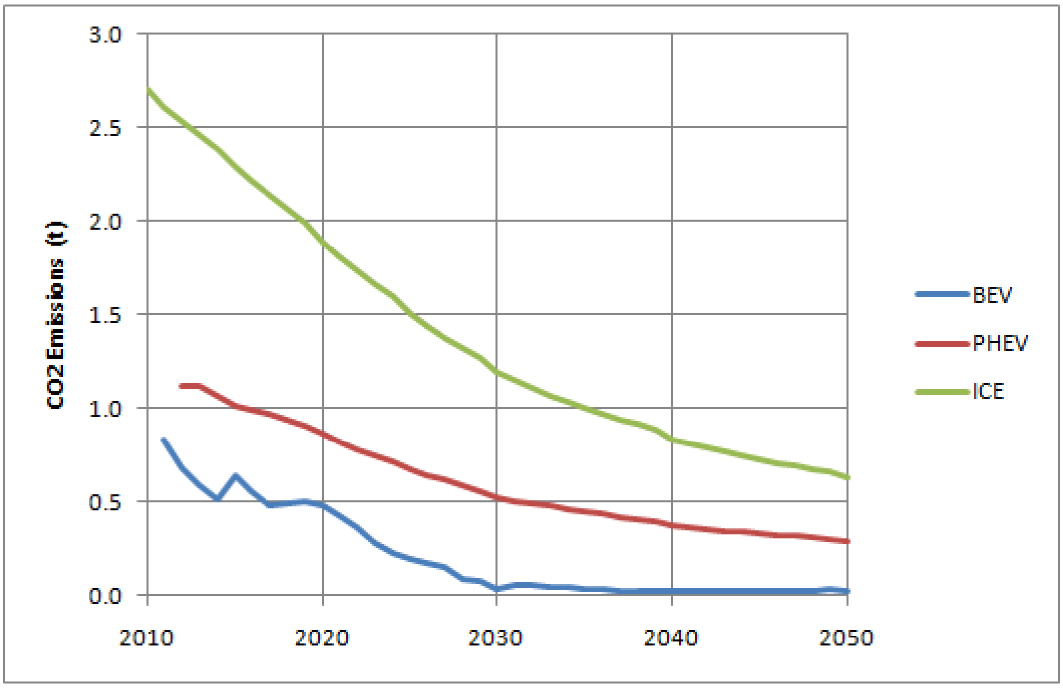


Figure 5 Average annual CO2 emissions per vehicle by vehicle type in base case

Figure 6 shows how the new car average emissions are affected by the fleet average emissions targets. Although the average is below the target for most of the period, the improvement slackens after about 2040 and the target is not being met beyond 2045. Clearly the price adjustment mechanism envisaged in the CRM is insufficiently strong to ensure achievement of the target (Figure 7 indicates the penalty beginning to take effect).

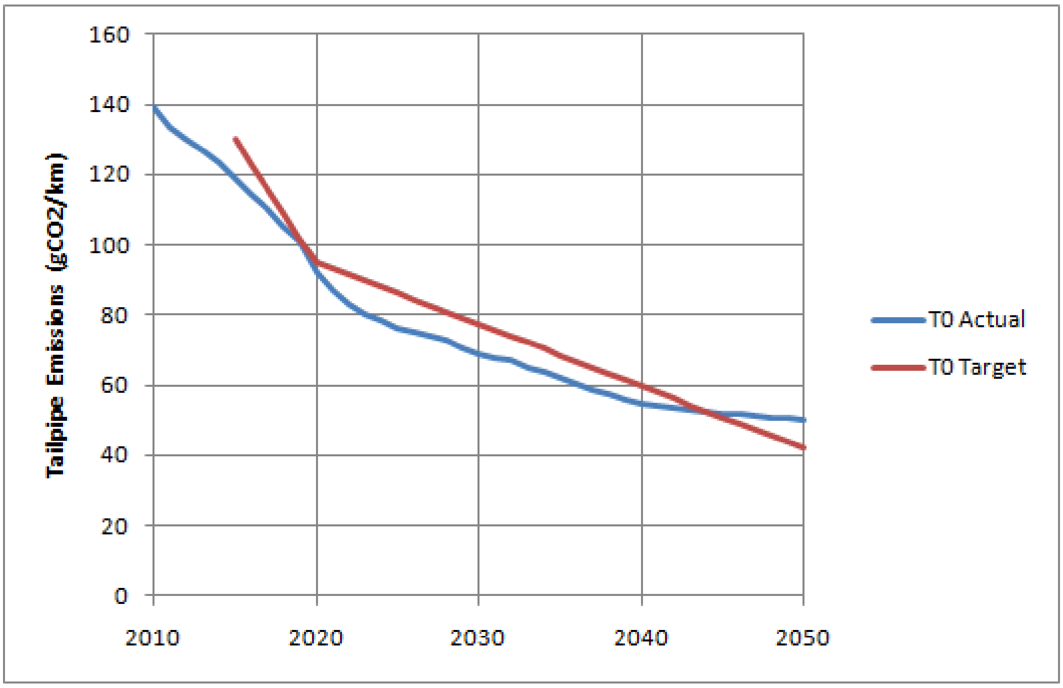
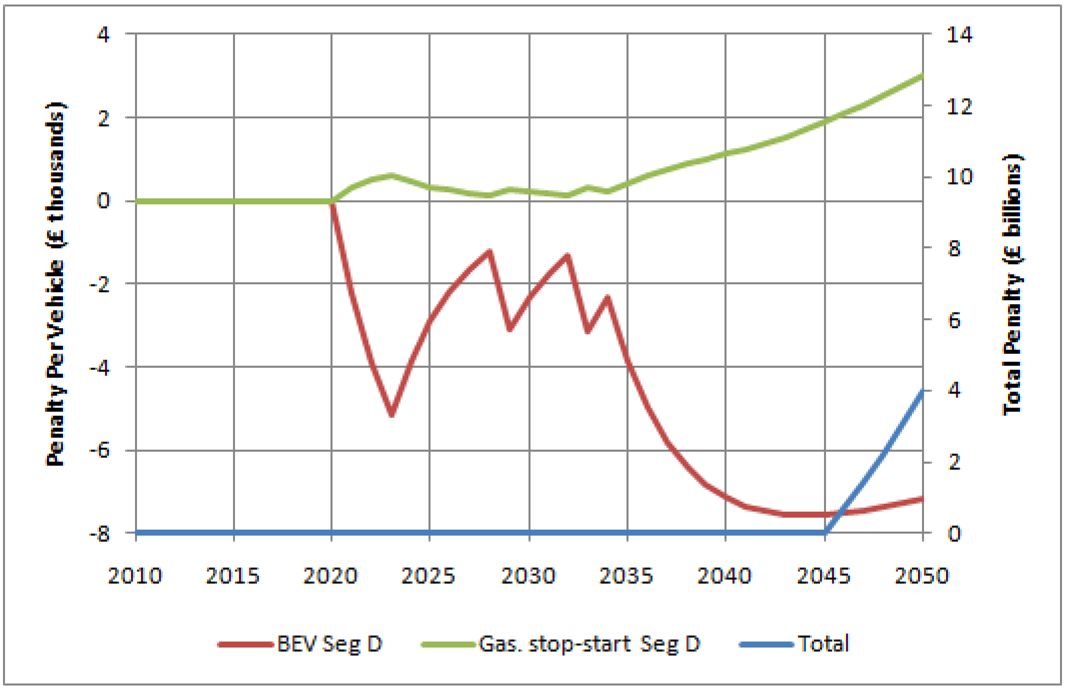


Figure 6 UK new car average emissions compared to fleet average emissions targets



Penalty PerVehicle (£ thousands)
Total Penalty (£ billions)
4
2
0
-2
-4
-6
-8
14
12
10
8
6
4
2
0
2010
2015
2020
2025
2030
2035
2040
2045
2050
BEV Seg D
Gas. stop-start Seg D
Total

Figure 7 Example manufacturer applied penalties and total fleet average emissions penalties applied in base case

Figure 8 a,b shows the average CO_2 emissions (distinguishing those associated with vehicle usage and with production and scrappage) by vehicle type and for all vehicles from 2010 to 2050. Firstly we can see that emissions for all vehicles are on a downward trend due to improvements in efficiency (driven, in part by the fleet average emissions regulations which require new vehicle average emissions of 42 g/km by 2050). Thus even the non-PiVs would contribute significantly to the reduction in total emissions despite the increased car parc and VKT. Total emissions are reduced from around 90 Mt to 47.8 Mt in 2050 which is a reduction of almost 50% compared to 2010. The in use emissions are reduced from 78.1 Mt to 25.4 Mt by 2050 despite the increased parc and VKT. Notice also the increasing contribution from PiVs as take up increases. Production and scrappage accounts for 22.4Mt in 2050 or 46% of the total emissions, a much higher proportion than the 13.6% in 2010.

The 1990 values for emissions were 81.7 Mt and 14 Mt for in-use and production and scrappage respectively. Thus to meet the 80% reduction target in use emissions should be reduced to 16.34 Mt by 2050. The base case is far from meeting this target for in use emissions. The production and scrappage emissions have actually increased 60% compared to 1990 by 2050 and so are a significant cause for concern.

Note that whilst we also calculated emissions based on a marginal and taper basis for electricity based emissions, these were very similar to the average emissions. For example the value of whole life emissions throughout the study period was only 0.25% higher on the marginal basis than on the average basis. Full graphs of marginal and taper based emissions are included in the separate addendum document.

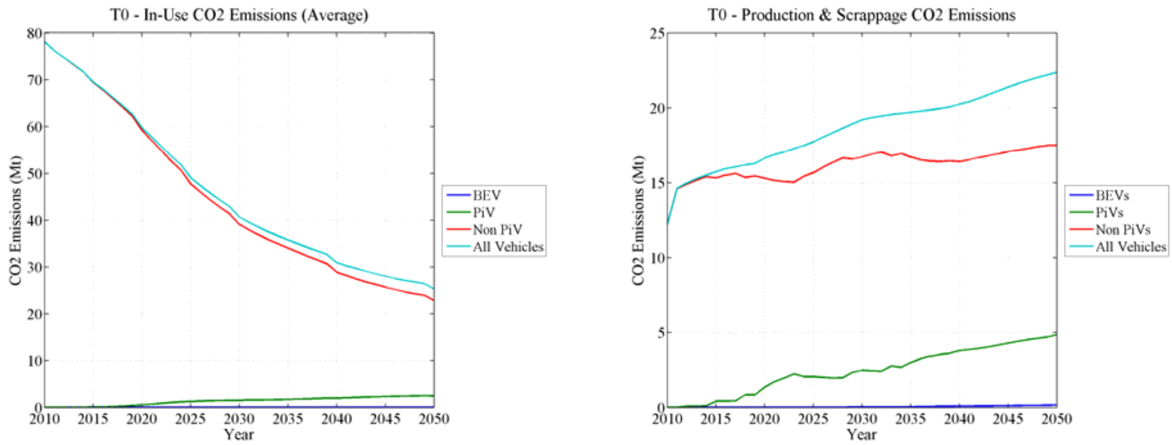


Figure 8 (a), (b) : In use and production and scrappage emissions T0.

2.5 Effect on Grid demand

Figure 9 a,b shows the additional predicted demand on the grid due to PiVs together with a typical winter weekday grid base load for the base scenario. It can be seen that the additional requirement for grid generation is insignificant in 2030 and in 2050 (increase in the base load by 2050 actually means that the load associated with PiVs contributes a smaller proportion of overall demand in 2050 than it does in 2030).

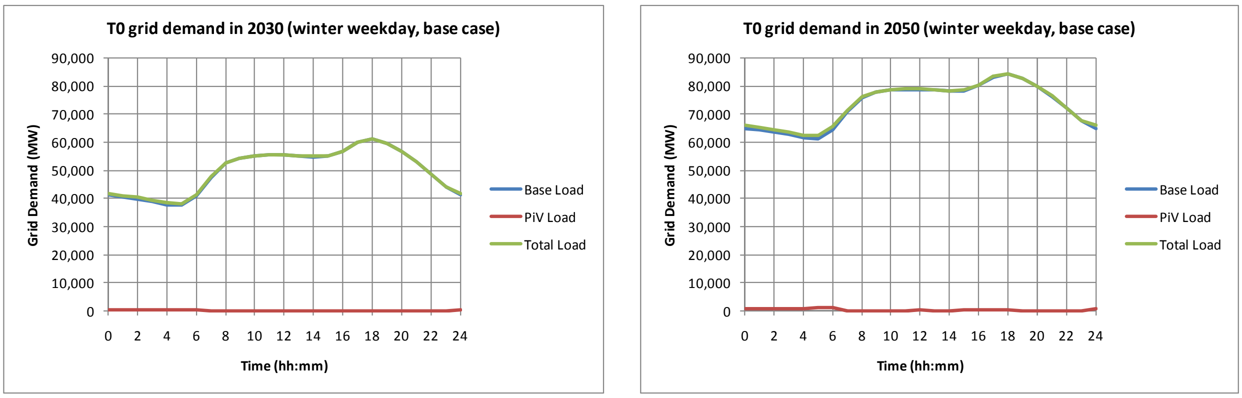


Figure 9 (a), (b) : Grid load in 2030 and 2050 T0.

The predicted PiV daily demand profile is dependent upon the assumed charging behaviour described in WS3/ARUP/10, which is in turn dependent upon time, length and destination of journey together with assumptions on access to charging facilities at home, work and in public. In particular, home charging is assumed to take place 50% immediately on completion of journey, and 50% overnight.

Ideally, to minimize the need for additional generation capacity, PiVs should charge during the troughs in the base demand overnight and midday. This can be incentivized by using differential tariffs to encourage off-peak charging. The CRM does not currently have the capability to simulate the moving of charging behaviour to minimize electricity costs. The best profile for generation may not be optimum for network reinforcement. Local hotspots are likely to occur if overnight recharging is concentrated on a network designed for domestic loads in a residential neighbourhood.

3 Results for the Themed Scenarios

The following sections describe the outcome of the 12 themed scenarios, followed by comparisons between each theme and the base scenario (T0) and the between relevant pairs of themes. In all the figures which follow, the dashed lines are from the base T0 while the solid lines are from the theme under discussion.

3.1 T1 Maximised Sales of PiVs

All scenario and policy variables are set to maximise sales of PiVs as described above.

3.1.1 Share of sales and parc in T1

As can be seen in Figure 10 a and b, PiV sales are high - with sales buoyant as the models become available[7]. By 2017 sales of gasoline plug-ins peak at 1.6 million, this is because some gasoline models become available prior to diesel plug-ins. Beyond 2020 the sales of plug-in hybrids settle down and sales of BEVs begin to take off with sales of BEVs increasing to almost 1.8 million p.a. by 2050. The reason for this high share for BEVs will be discussed further in Section 3.13.5. By 2050 non-PiVs make up less than 10% of the parc while BEVs make up 28.8% and plug-in hybrids make up around 60% (approximately half being gasoline and half being diesel).

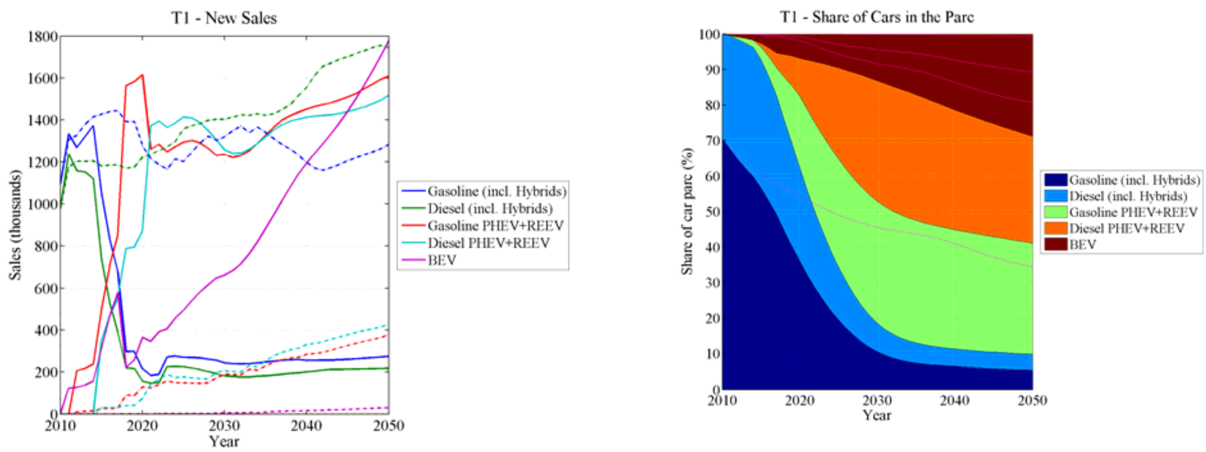


Figure 10 (a), (b) : T1 Total new sales and share of cars in the parc

3.1.2 Charge point deployment and profit in T1

Under T1, the government meets any shortfall in the installation of charge points so the deployment is simply determined by the feedback from electricity drawn per charge point type. As can be seen from Figure 11, each charge point type has a significant number of installations and the number of charge points grows fairly steadily until around 2030-2035, at which point they level out. Further inspection of the pattern of electricity drawn from PiVs (see addendum document) shows that there is a levelling off of demand for electricity which in turn results in a levelling off in the supply of charge points. By 2050 there are around 3 million retail charge points and around 1.6 million other charge points. Installation of rapid charge points do not occur in any significant numbers; there are only around 720 in place by 2050.

[7] It is important to note that the CRM does not include any supply-side constraints – as soon as a model is introduced the model assumes that the supply is potentially infinite. This is clearly unrealistic.

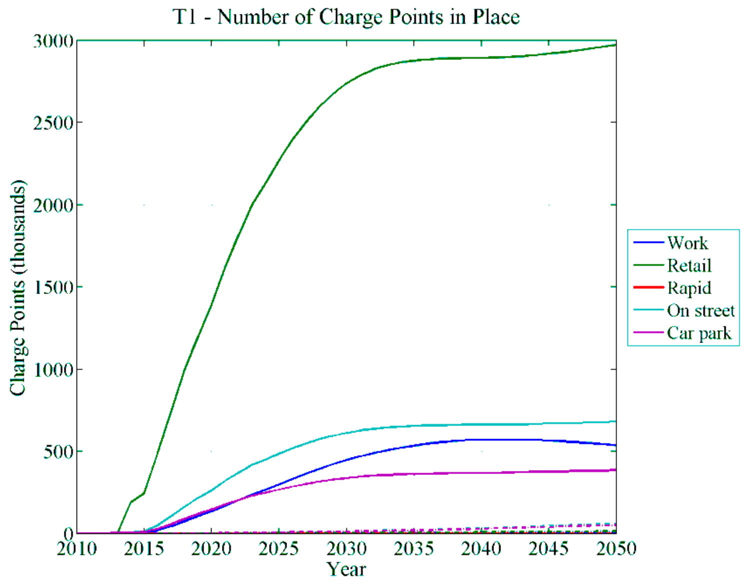


Figure 11 : Number of charge points in place T1

Figure 12 a,b show that, while on-street and car park charge points are highly profitable in the early years, they become highly unprofitable when charge points are being installed at a significant rate and become profitable again when the number of new installations levels off again. This indicates that there is some oversupply during the period of rapid installation. Despite offering free electricity at work and retail points, the notional profit for retail in particular is positive and growing. By 2050 the notional profit is £3bn for retail which translates to around £1000 per charge point. This level appears to be optimistic given the costs per charge point are around £500. Note that the notional profit for work place charge points is running slightly negative by 2050.

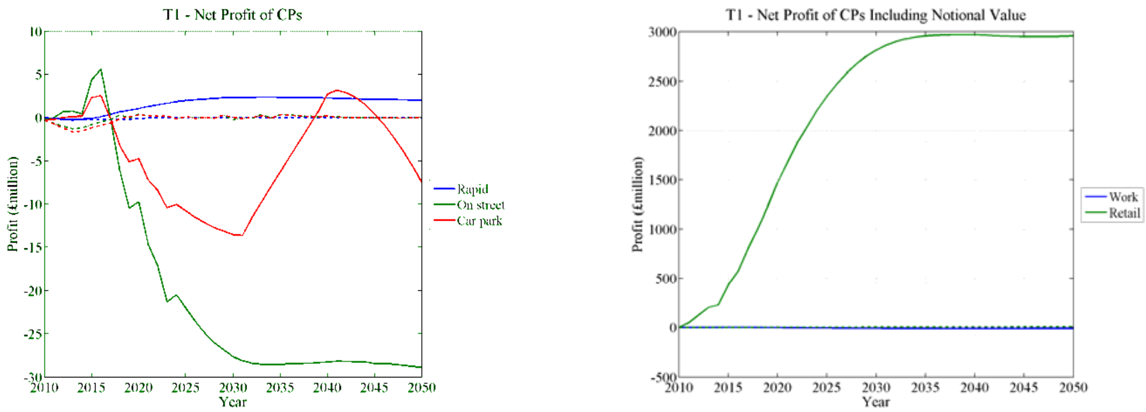


Figure 12a,b : Net profit and notional profit for charge points T1

3.1.3 Exchequer spend and revenue in T1

Figure 13 a is dominated by the subsidies to PiVs . The subsidy peaks at around £13.6 bn in 2022 which means that around 2.72 million vehicles are subsidised in that year. Subsidies for charge point supply peak at £214 million in 2014 when 188 thousand retail charge points are installed in one year[8]. The loss in corporation tax has a different profile to that of the base case; the significant spike which characterised the base case is replaced by variations around £0.5 bn p.a. during the first 20-30 years. The net present value of total Exchequer spend in 2050 is around £75 bn and is dominated by subsidies to purchasers of PiVs.

Fuel tax revenues show an initial increase, associated with the fuel duty increase in 2015, but then decrease significantly to £6.8bn p.a. in 2050 as ICEs fall in number. This scenario has no revenue preserving tax to recoup these losses. VAT is affected by the high growth in the overall fleet with some reduction in receipts from VAT on fuel. Overall though, VAT receipts in 2050 are higher than in the base case, due to the higher parc and VKT. There is significant decrease in VED receipts because more vehicles are in the zero (or low) rated bands. By 2050 the average VED per car is only £28. Overall the net spend by the Exchequer is around £50bn greater than in the base case. This reflects an additional £70bn of expenditure offset by an additional £20bn of revenue.

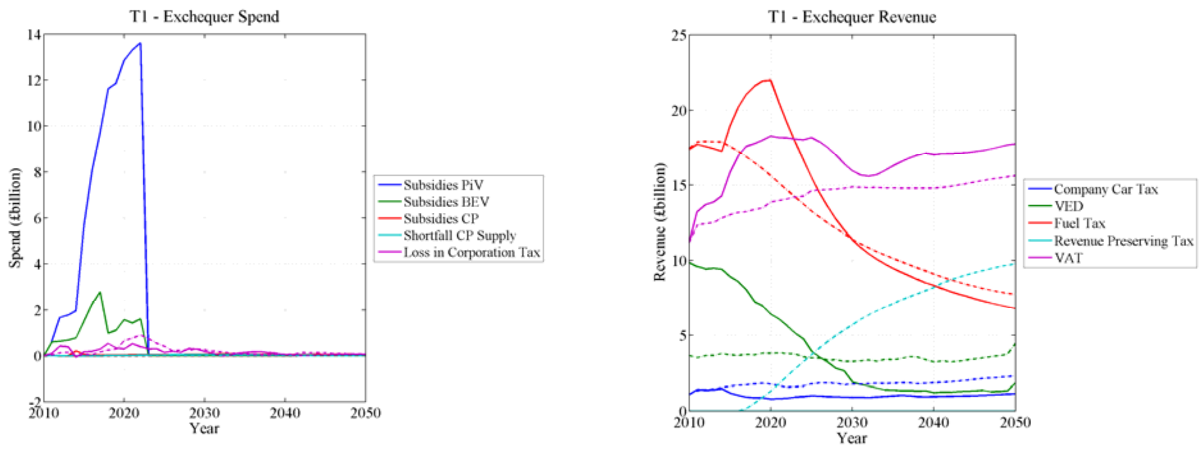


Figure 13a,b : Exchequer spend and revenues T1

3.1.4 Emissions in T1

As expected the significant uptake of Plug-in hybrids and BEVs has a large impact on in use emissions. In Figure 14 a,b the dashed lines show the base emissions while the solid lines are for T1. In use emissions are reduced significantly compared to the base while production and scrappage are increased due to the growth in parc size. Of the total 36.5 Mt in 2050, 23.9 Mt can be attributed to production and scrappage – leaving only 12.6 Mt due to use of vehicles, thus, under this scenario (despite its high growth in VKT), the target of 80% reduction in usage-only CO_2 compared to 1990 levels (16.34 Mt) is more than met.

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[8] Note that the CRM has no constraint on the number of charge points being installed in any one year – it might in practice be impossible to achieve such a high rate.

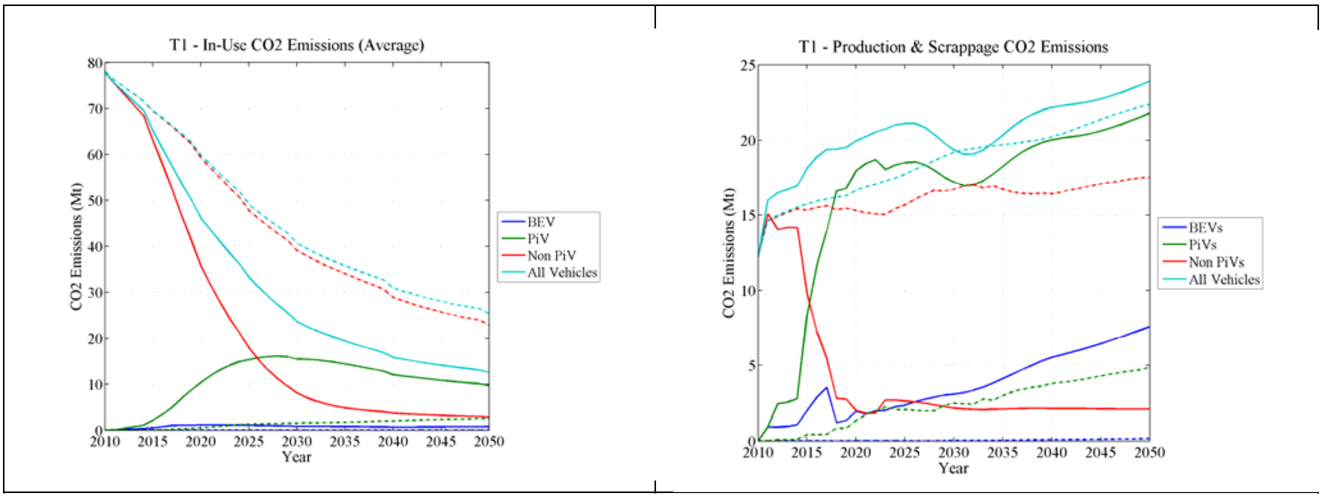


Figure 14 (a), (b) : In use and production and scrappage emissions T1.

3.1.5 Grid load T1

Figure 15 shows the additional predicted demand on the grid due to PiVs together with a typical winter weekday grid base load for T1 in 2020, 2030, 2040 and 2050. It can be compared with Figure 9 which showed the same thing for the base. Although higher than in the base, the contribution of PiVs to total demand is still very small. It grows in absolute terms as a consequence of the increased vehicle numbers – offset by increases in vehicle efficiency – but is not growing as fast as the base load and so constitutes a smaller proportion of overall demand in 2050 than it did in 2020.

Figure 15 Grid load in 2020, 2030, 2040 and 2050 T1

3.2 T2 Minimised Sales of PiVs

Here all scenario and policy variables are set to minimise PiV sales – for example it assumes low rates of growth in the global and UK economies and a poor showroom offer.

3.2.1 Share of sales and parc in T2

Figure 16 a,b shows that, with all variables set against PiV sales, the result is a failed market. By 2050 plug-in hybrids (i.e. PHEVs and REEVs) make up only 1.2% of the parc and BEVs are all but invisible.

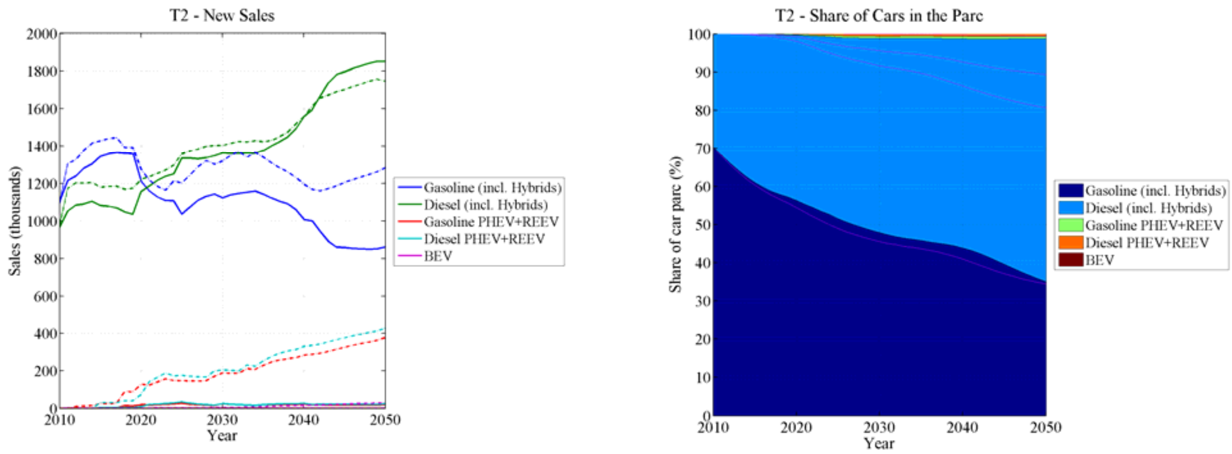


Figure 16 (a), (b): T2 Total new sales and share of cars in the parc

3.2.2 Charge point deployment and profit in T2

Results are shown in Figure 17 and in Figure 18 a and b.

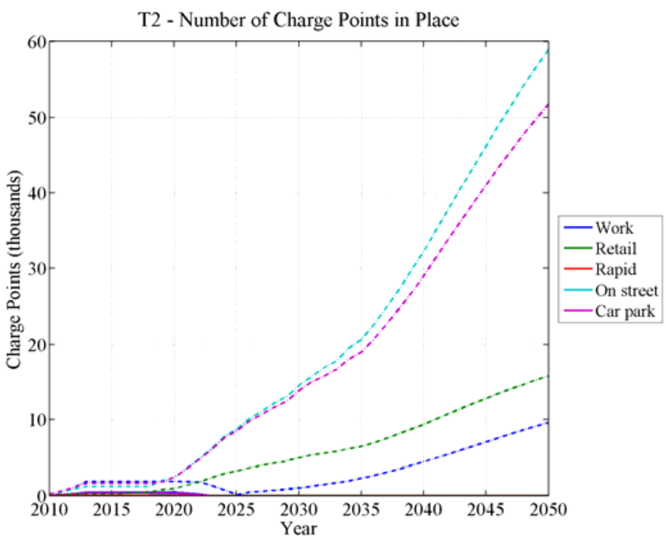


Figure 17 : Number of charge points in place T2

Due to the failing market and the fact that the government does not pay for any shortfall, the majority of the initially deployed charge points are not replaced because profits (real and notional) are negative. While there are some replacements in retail, the numbers are very low (e.g. 17 are replaced in 2023). The massive loss (minus £360 million) per retail point in 2050 reflects the impracticality of a regime under which all network reinforcement and intelligence costs are allocated to a small number charge points (in this case two!). Treatment of network reinforcement and network intelligence as regulated assets seems much more realistic.

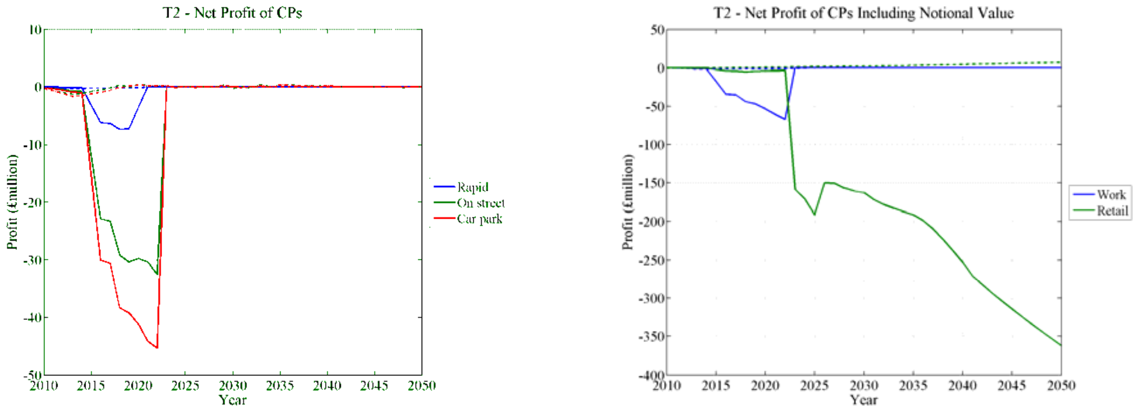


Figure 18a,b : Net profit and notional profit for charge points T2

3.2.3 Exchequer spend and revenue in T2

Since there are no subsidies under T2, the only spend is that which is associated with delayed receipts from the capital allowances on low emission vehicles or with loss in corporation tax. These expenditures exhibit the same pattern as in the base and this confirms our expectation that, with a less stringent limit on eligibility for these allowances, purchases of other (non-PiV) LEVs contribute significantly to the loss in corporation tax and thus that this loss will occur even in a scenario which has a failing PiV market.

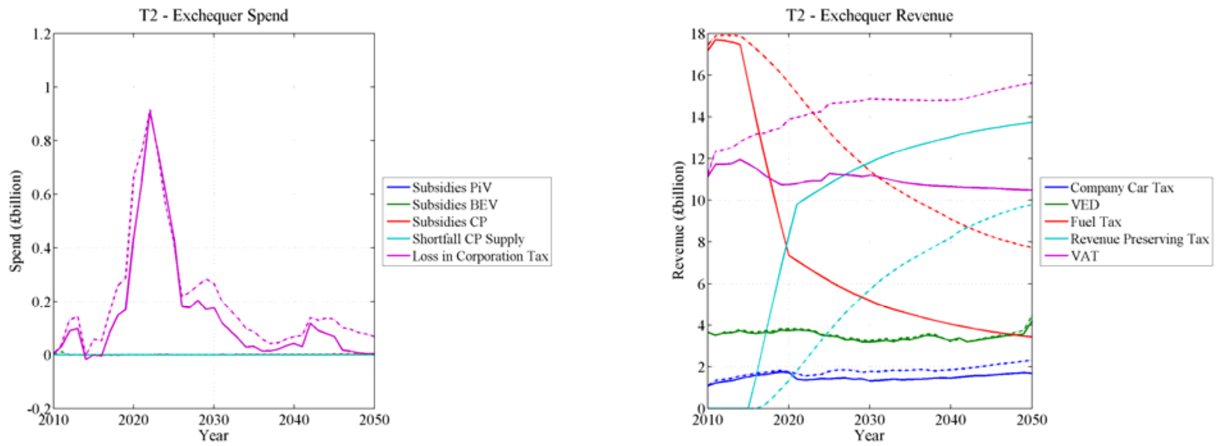


Figure 19a,b : Exchequer spend and revenues T2

In terms of revenues, the most obvious trend is the reduction in fuel duty receipts when fuel duty is halved in 2015 (receipts from fuel duty decrease from £17.4bn in 2014 to £7.3bn in 2020 and, by 2050, have fallen to £3.4bn). However the revenue preserver is in place in T2 and by 2050 the preserver fee amounts to £13.7bn which is around £400 per vehicle p.a. VAT, VED and company car tax remain fairly stable over the period due to the low growth in parc size and limited switch to PiVs. The average VED per car is reduced to £123 per vehicle - compared with a reduction to £98 in the base case. This is due to the fact that the fleet contains more high emission vehicles which attract higher VED. In total, the Exchequer is around £80bn worse off than in the base case over the whole period. This is mainly due to lower revenues associated with the size of the fleet.

3.2.4 Emissions in T2

As expected, the emissions under this scenario are dominated by non-PiVs and are always lower than the base case due to the lower growth in parc size and VKT. The total emissions in 2050 are 43.8 Mt compared to 47.8 Mt in the base. This value is lower than the 46 Mt target used in the optimisation work. Production and scrappage accounts for 19.7 Mt in 2050 which is much lower than in the base. The low growth assumptions has a greater impact on production and scrappage emissions than on in use emissions.

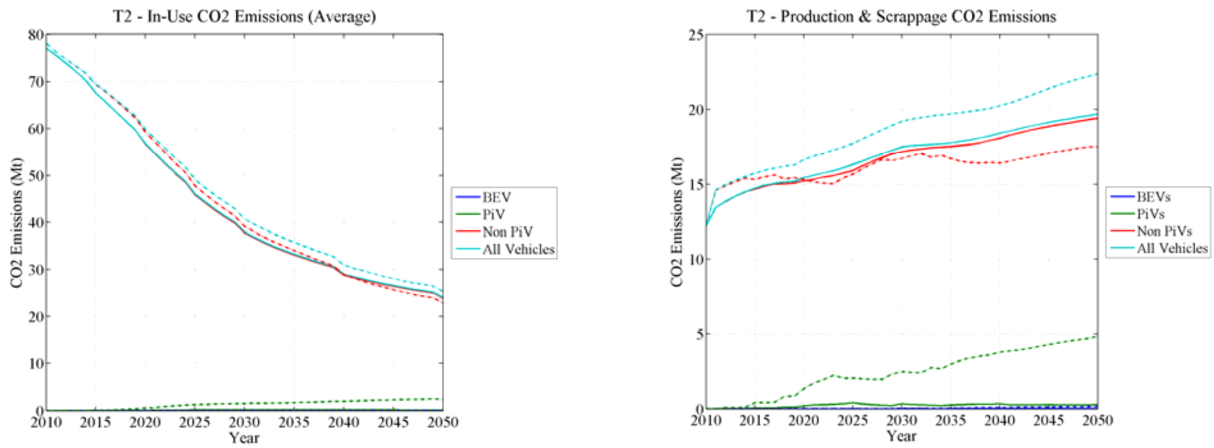


Figure 20 (a), (b) : In use and production and scrappage emissions T2.

3.3 T3 Maximise PiV Sales While Retaining Current Policy

T3 has the same scenario variables as T1 – except that current government policies are assumed to be maintained. The results should therefore be compared with T1.

3.3.1 Share of sales and parc in T3

As expected the 2050 share of PiVs is, at 88.6% (including the 28.7% BEVs), just below the values for T1. The main difference in trajectory is in the early years because the subsidies are not maintained beyond 2011. However, in T2, £312m is spent on subsidising BEV purchases in 2011 compared to £11.8m in the base. The sales are higher than the base because of the lower prices, improved fleet and other behavioural assumptions. The amount spent in 2011 is however around half that spent in T1 on BEVs which demonstrates the consequences of not introducing policy measures such as doubling the number of initial charge points and changes to VED. After 2011 there are no subsidies and so the peak sales for gasoline plug-ins is only 1.4 million in 2020 compared to 1.6 million under T1 assumptions. However when we compare the shares of parc in 2050 we find that T3 has 88.6% versus 90.2% PiV share which equates to only 900,000 fewer PiVs in circulation in 2050. As will be seen later, this is despite a total subsidy spend of only £312 million in T3 compared with £75 bn in T1.

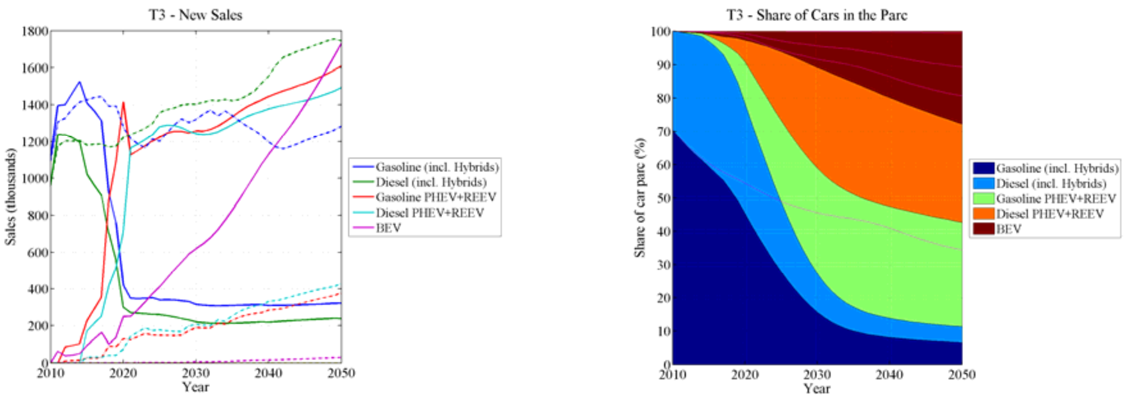


Figure 21 (a), (b) : T3 Total new sales and share of cars in the parc

3.3.2 Charge point deployment and profit in T3

As might be expected there are fewer charge points deployed in T3 than in T1 but it is still a significant number despite the fact that the government does not pick up any shortfall and that the level of service factor is lower (1.0 in T3 compared to 1.1 in T1). By 2050 there are around 2.7 million retail charge points (300k fewer than in T1), with around 1.3 million other public charge points in total compared to 1.6 million in T1.

Since the government is not meeting any shortfall, the net profits should not ideally fall below zero. However the net profit for on-street charge points are consistently negative between 2022-2038 – indicating a degree of overprovision of this type of charge points. We assume this is related to excessive installation in the earlier, profitable, years. Towards the end of the period net profits for car-park charge points increase rapidly and then decrease beyond 2040. By 2050 the notional profit is again around £3b for retail which translates to around £1100 per charge point. This level appears to be rather optimistic. Note that the notional profit for work place charge points is running slightly negative by 2050.

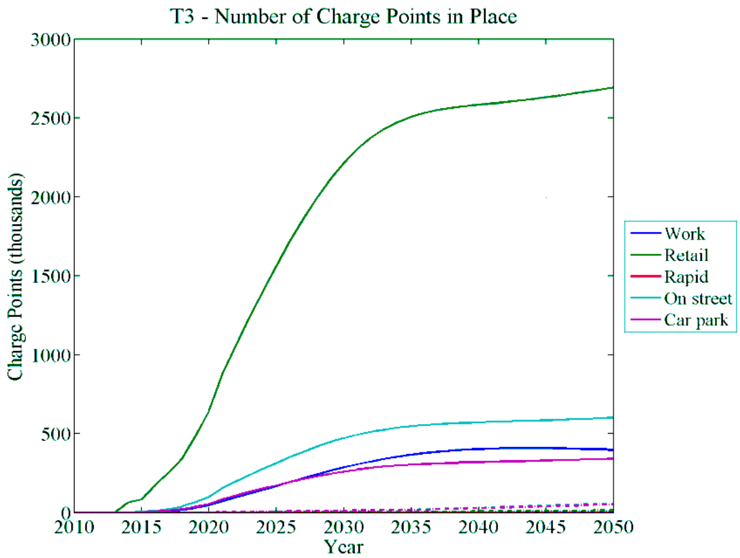
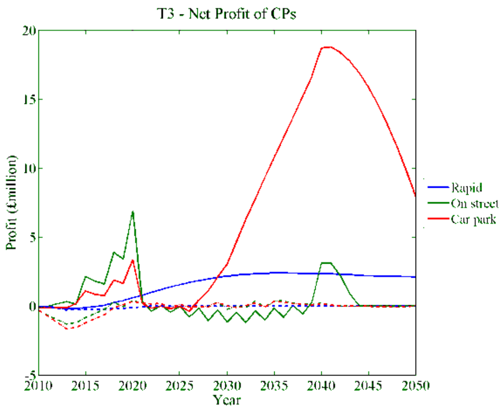


Figure 22 : Number of charge points in place T3



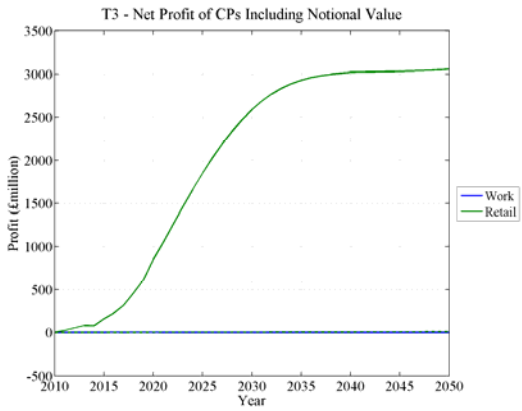


Figure 23a,b : Net profit and notional profit for charge points T3

3.3.3 Exchequer spend and revenue in T3

As mentioned previously the most obvious difference between T3 and T1 is the lack of subsidies for PiV purchases beyond 2011. The value of subsidies to PiV in T3 is around £69bn compared to just over £300 million in T1. The loss in corporation tax is also more in line with the base case than that under T1. Subsidies to charge point installation are around £15 million p.a. (there being no government underwriting of unprofitable charge points).

Although fuel duty revenues are lower in T3 than in T1(due to the rate not having been increased), there is now an income from the revenue preserving tax which rises to around £14bn p.a. by 2050. VED receipts in T3 are significantly lower than in T1 (around £961 million p.a. or £16 per vehicle compared to £1.8 bn under T1) because VED rates has been left at their base values. VAT and company car tax show similar profiles in T3 and T1. Overall the value of Exchequer spend is reduced by around £69bn compared to T1 and while the revenue is reduced by around £34bn, the Exchequer is better off by around £35bn under T3 than under T1. Comparing to the base however, T3 results in a £15bn loss for the Exchequer.

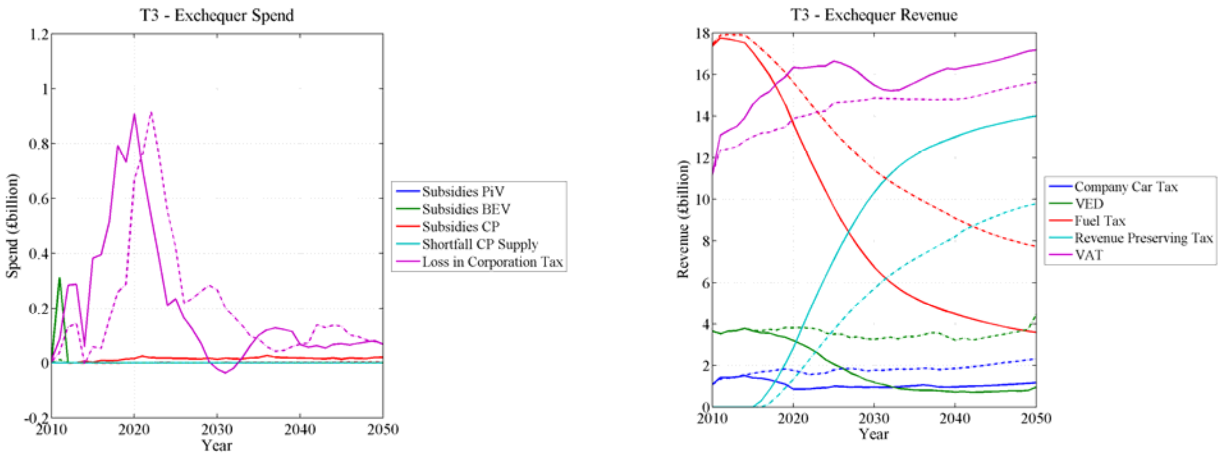


Figure 24a,b : Exchequer spend and revenues T3

3.3.4 Emissions in T3

The emissions trajectory in T3 is similar to that in T1 with a slight lag and with the total 2050 emissions being 37 Mt compared to 36.5 Mt for T1. Once again, the contribution due to production and scrappage is, at 23.9 Mt, relatively high in 2050 and means that emissions due to vehicle use are down to 13.1 Mt (well below the 80% reduction target (16.34 Mt) for use of vehicles despite the large increase in VKT). This implies that, even without any change in current policies, scenario variables being set in favour of PiV sales would be more than sufficient to reduce usage-related emissions by 80% - it is only the production and scrappage contribution which puts the overall target beyond reach.

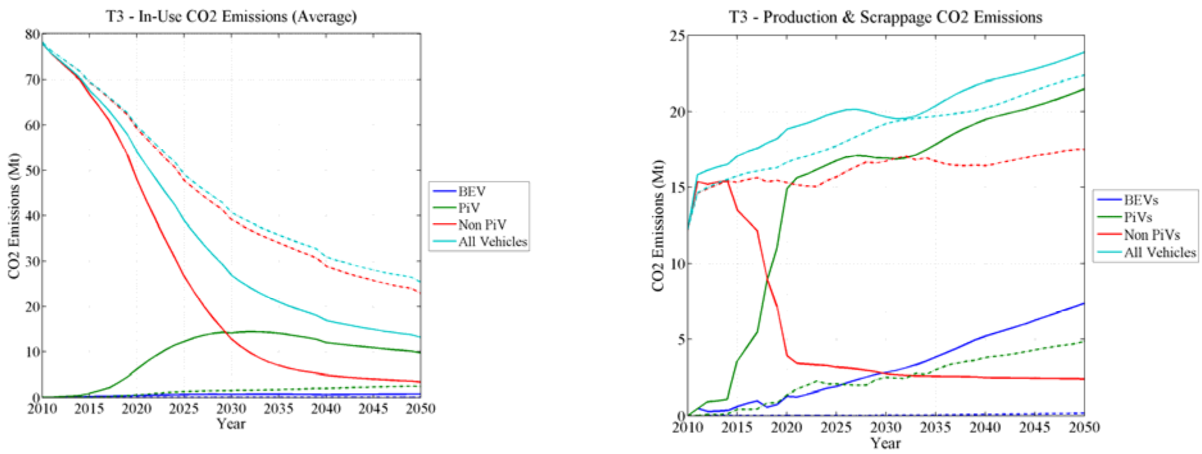


Figure 25 (a), (b) : In use and production and scrappage emissions T3.

3.4 T4 Minimise PiV Sales While Retaining Current Policies

T4 has the same scenario variables as T2 – except that current government policies are assumed to be maintained. The results should therefore be compared with T2.

3.4.1 Share of sales and parc in T4

As expected, T4 is similar to T2 in respect of share and sales but with a slightly higher share of PiVs in the parc by 2050 (1.7% compared to 1.2%). The less unfavourable policy variables in T4 (e.g. four times as many charge points initially installed and some, albeit limited, subsidy for PiVs) do result in higher sales of PiVs – but the effect is limited and the negative scenario variables dominate the outcome.

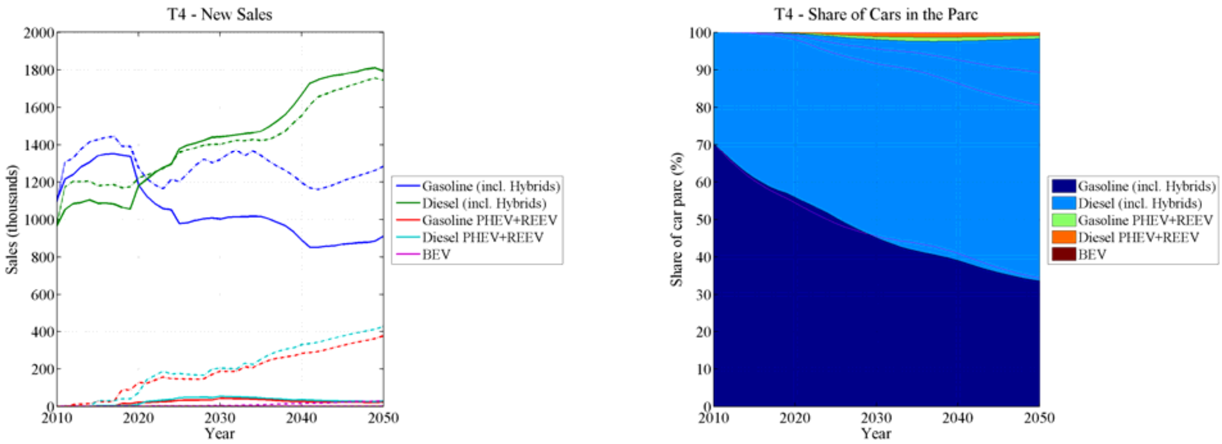


Figure 26 (a), (b) : T4 Total new sales and share of cars in the parc

3.4.2 Charge point deployment and profit in T4

The initial charge point deployment is four times that of T2 and, as can be seen from Figures 27 and 28, there is a profitable market for retail charge points (though it is significantly reduced compared to the base case with only 672 points in place in 2050 compared to around 15,700 in the base). The base also had a viable market for other public charge point facilities which is not the case in T4. This is further evidenced by the profit figures for T4 which confirms the negative profits for all but retail and rapid points and very small profits even for them. Overall T4 must be regarded as a failing market for charge point deployment.

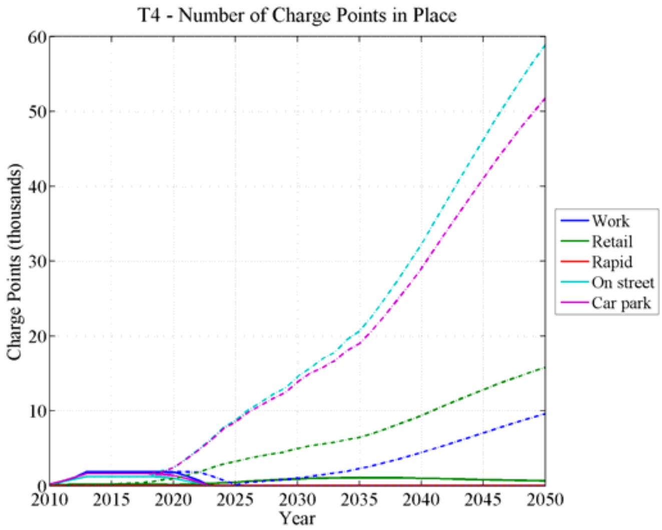
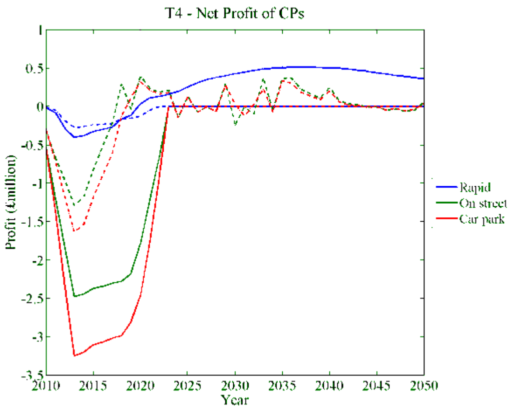


Figure 27 : Number of charge points in place T4



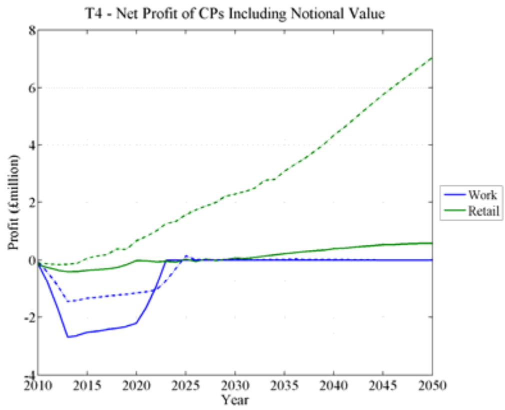


Figure 28a,b : Net profit and notional profit for charge points T4

3.4.3 Exchequer spend and revenue in T4

In general the spend figures are almost the same as under T2, with the exception that £983k is spent on BEV subsidies. Otherwise the loss in corporation tax dominates the spend and is very similar to T2. In terms of revenues, the main difference between T4 and T2 is that, since the fuel duty is not now halved, the curves for fuel duty revenue and revenue preserver tax revenues are significantly different. VAT receipts are generally a little higher while VED and corporation tax receipts are similar to T2. Total revenues are around £22bn higher than T2 over the full period mainly due to higher VAT receipts and some initial gains in fuel duty receipts. The VAT receipts are higher in part because the prices of vehicles are increased in T4 due to tighter emission penalties and in part due to the increased VAT on fuel (fuel duty is not halved in T4).

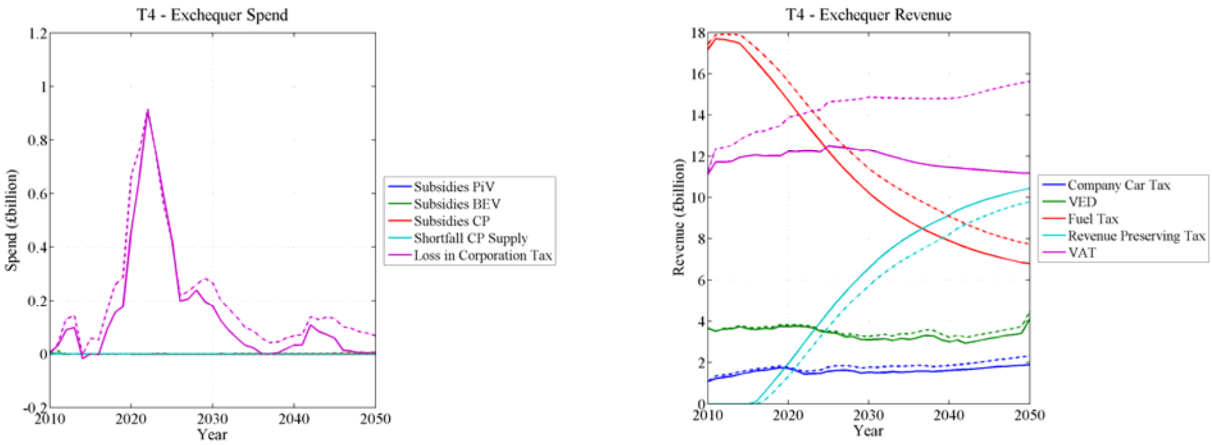


Figure 29a,b : Exchequer spend and revenues T4

3.4.4 Emissions in T4

With the slightly higher share of PiVs in T4 there is a slight improvement in overall emissions compared to T2. Total emissions in 2050 are now 43.5 Mt compared to 43.8 Mt in T2. Again this is only lower than the base case due to the assumed lower parc and VKT in this scenario. The production and scrappage contribution in 2050 is, at 19.7 Mt, the same as in T2.

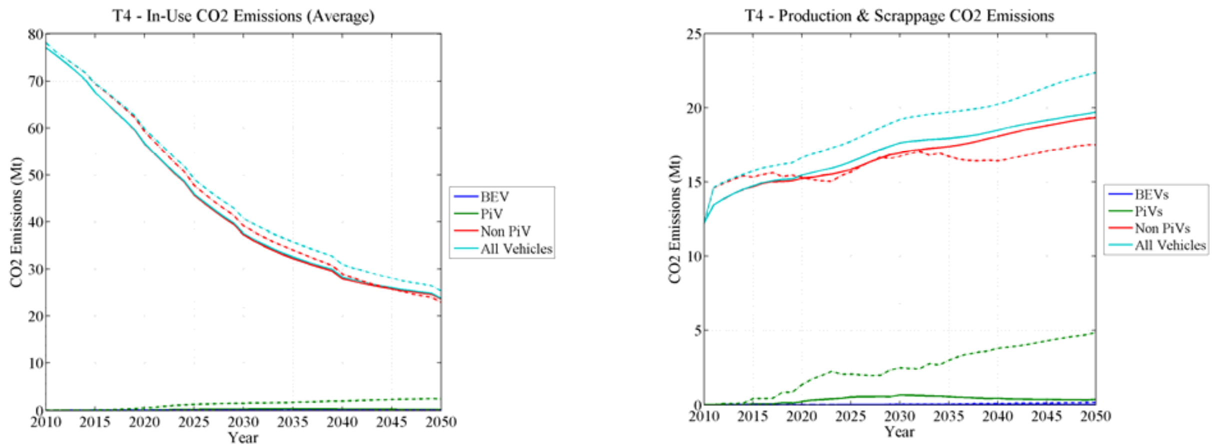


Figure 30 (a), (b) : In use and production and scrappage emissions T4.

3.5 T5 High Growth in UK GDP

Under T5 we have assumed a higher growth in parc size and in VKT. The parc size in 2050 is now 61 million compared to 45 million in the base case T0. VKT in 2050 is 6.8% higher than the base.

3.5.1 Share of sales and parc in T5

The sales figures for T5 exhibit a similar pattern to the base in terms of shares and trajectories but with higher absolute figures due to the higher assumed growth in car ownership. As can be seen in Figure 31, the final share of PiVs is slightly lower than in the base with 18.7% compared to 19.4%. However, the total number of PiVs in 2050 is 11.3 million compared to 8.8 million in the base. This is only a 28% increase while the total fleet has increased by 35.5%. It should be noted that by 2050 the non-PiV fleet has grown by 37% while the PiV fleet has grown by only 28%.

We believe that the relatively poor performance of PiVs is a consequence of two factors which characterise high UK GDP scenarios such as T5; the reduced VKT per car and the reduced sensitivity to prices. The reduced VKT per car reduces the profitability of charge points (see discussion in Section 3.6.2 below) and combines with the reduced sensitivity to prices to erode the value of one of the most attractive features of PiVs – their relatively low running costs.

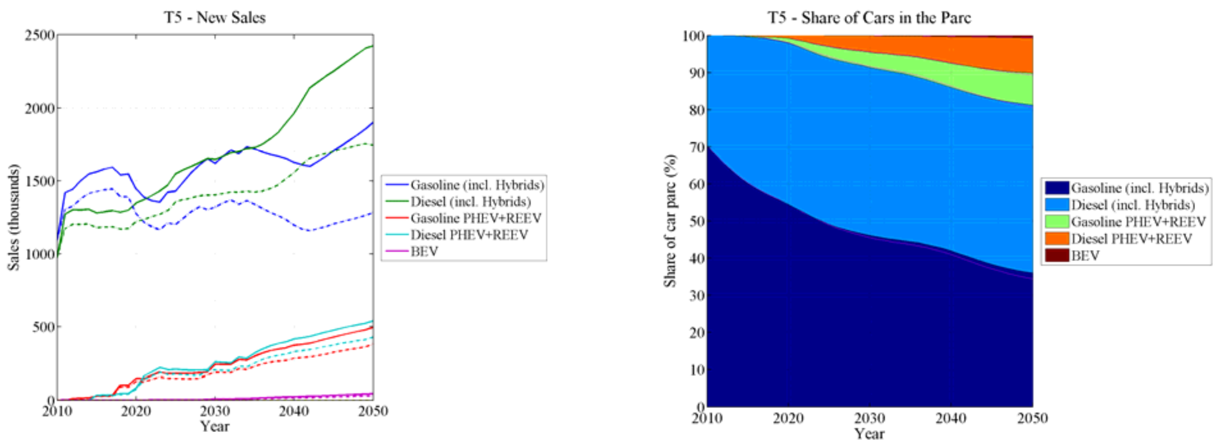


Figure 31 (a), (b) : T5 Total new sales and share of cars in the parc

3.5.2 Charge point deployment and profit in T5

The number of charge points deployed turns out to be similar to the base case but, by 2050, the total is 8% less despite there being more vehicles in circulation. It is thought that this is in part due to the way access to charge point infrastructure has been modelled in the CRM. As noted above, a high rate of growth in UK GDP (as in T5) is associated with a reduction in VKT per car. This results in a reduction the total electricity drawn from each vehicle and, since the CRM assumes that each charge point can only “serve” a fixed number of vehicles, the reduced draw-down per car results in lower revenues per charge point and this in turn results in fewer charge points being installed.

The net profit curves are also similar to the base. The higher population results in more people with access to home charging (this being calculated as a percentage of the parc and as we now have a higher parc size, there are more home chargers). Some of these people choose to purchase PiVs and, having done so, access retail charge points to some extent. Despite this, by 2050 there are fewer retail charge points in T5 than in the base.

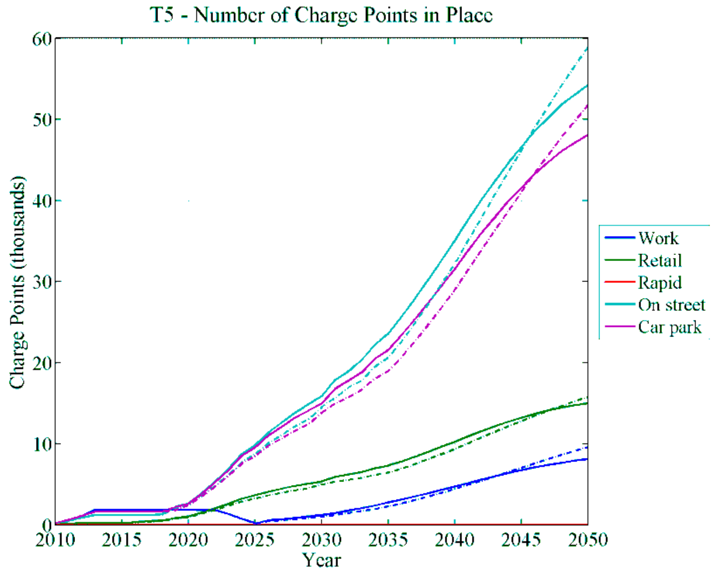


Figure 32 : Number of charge points in place T5

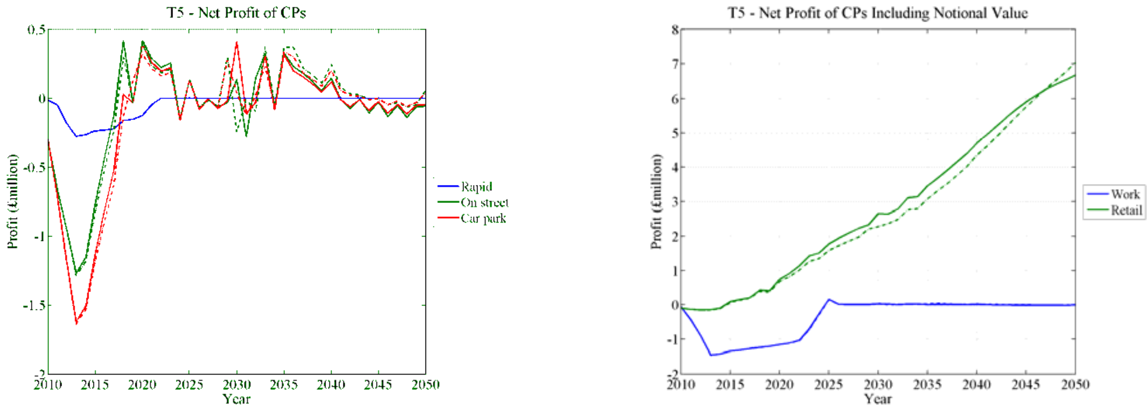


Figure 33 a,b : Net profit and notional profit for charge points T5

3.5.3 Exchequer spend and revenue in T5

The spend in T5, as in the base, is dominated by loss in corporation tax and, since the parc size is higher, the £1.5 bn increase in losses is not unexpected. The subsidy in 2011 also increases by £1m due to increased total sales. Revenues generally increase with the increased parc. For example; VAT receipts increase to around £21bn compared to £15bn in the base and revenues from both Corporation tax and VED are also higher than in the base. There is an initial increase in fuel duty revenue compared to the base case due to the higher rate of growth in parc size. However, as the average fleet becomes more fuel efficient and as the share of PiVs increases, the revenue preserver mechanism begins to kick in and by 2050 the sum of fuel duty plus revenue preserver taxes is, at £17.5 bn p.a., similar to that in the base. In summary, due to the higher growth in parc size, the Exchequer would be around £60bn better off than in the base.

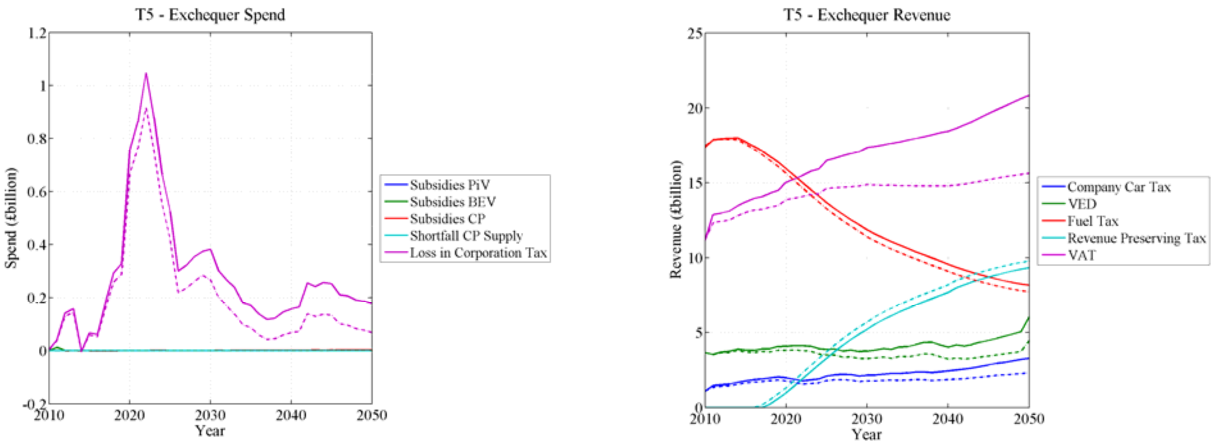


Figure 34a,b : Exchequer spend and revenues T5

3.5.4 Emissions in T5

As may be expected the emissions in T5 are higher than in the base; they reach a total of 58.1 Mt by 2050 which is 8.4% higher than in the base. The contribution from production and scrappage is 31.3 Mt in 2050 (39% more than in the base – due to the growth in parc size). The reduced VKT per car limits the growth in emissions due to use to around 5.5%. Thus we can see that the assumed high growth in UK GDP has a greater impact on emissions from Production and Scrappage rather than on emissions due to use of vehicles.

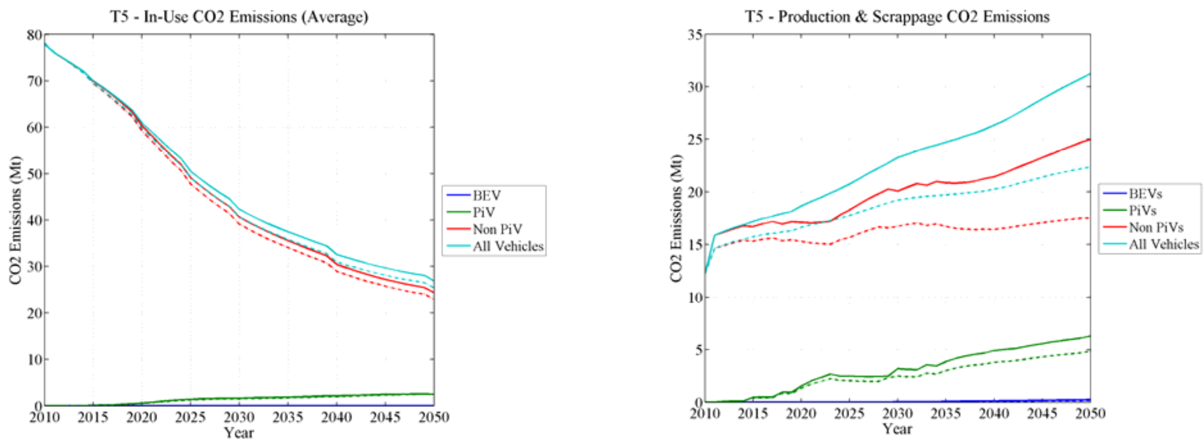


Figure 35 (a), (b) : In use and production and scrappage emissions T5.

3.6 T6 Low Growth in UK GDP

Under the low GDP growth assumptions, the 2050 parc size is now only 34 million compared to the 45 million in the base while total VKT is only 10.6% lower – implying an increase in VKT per car of 20% by 2050 compared to the VKT per car in the base in 2050 (note that this is still a reduction compared to the VKT per car in 2010).

3.6.1 Share of sales and parc in T6

The sales picture under low growth exhibits a similar pattern to the base case but with lower absolute sales as expected. The final PiV share is slightly higher by 2050 at 19.9% versus 19.4% in the base.

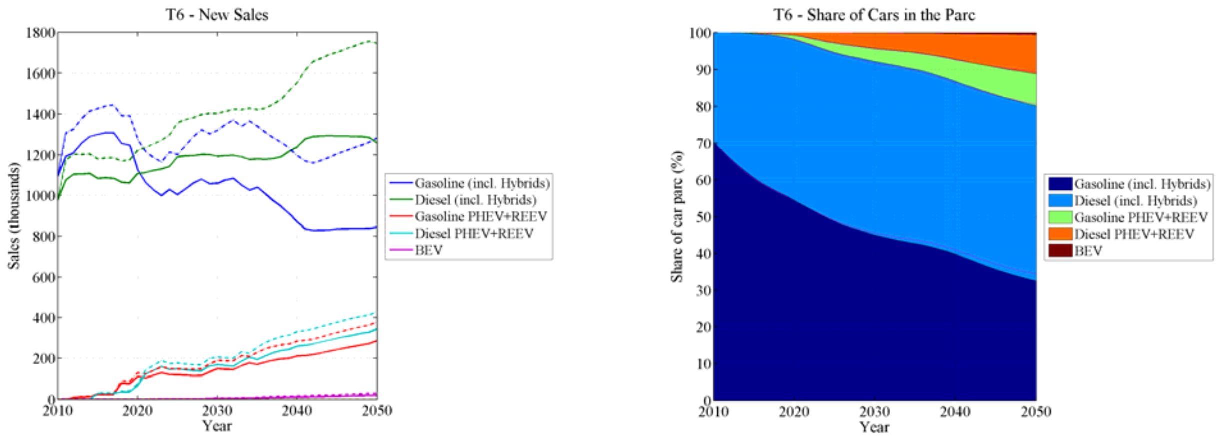


Figure 36 (a), (b) : T6 Total new sales and share of cars in the parc

3.6.2 Charge point deployment and profit in T6

The deployment of charge points is very similar to the base case and in fact by 2050 there are around 1000 additional charge points. As the number of charge points is similar to the base we conclude that the number of PiV owners who make their purchase decision based on access to public charge points is the same as in the base despite there being fewer vehicles in circulation. This is due to the fact that in the CRM, the number of consumers who perceive access to public charge points is a fixed number per charge point – which implies in T6 that the percentage of the parc who "see" each charge point is increased compared to the base case. We can also infer from the model that the number of consumers who base their decision on access to home charge points is reduced by 25% due to the reduced parc size. The total share of PiV consumers has increased slightly whilst in absolute terms the number has been reduced from 8.8 million in the base to 6.7 million in T6. Within this 6.6 million figure the proportion of home chargers will have decreased significantly while the absolute number of public chargers will be similar to the base.

This is backed up by the fact that the total electricity drawn is lower in T6 than in the base despite there being more public charge points. The profit curves in T5 are similar to those in the base – thus tending to confirm the suggestion that the initial deployment of charge points is driving the absolute number of PiV users who purchase a PiV based on public charge point availability. After initial deployment, any further deployment of charge points responds to the electricity drawn from them which is similar in all three cases (base, T5 and T6) and it is only the number of home chargers which varies significantly (in line with the assumed parc size).

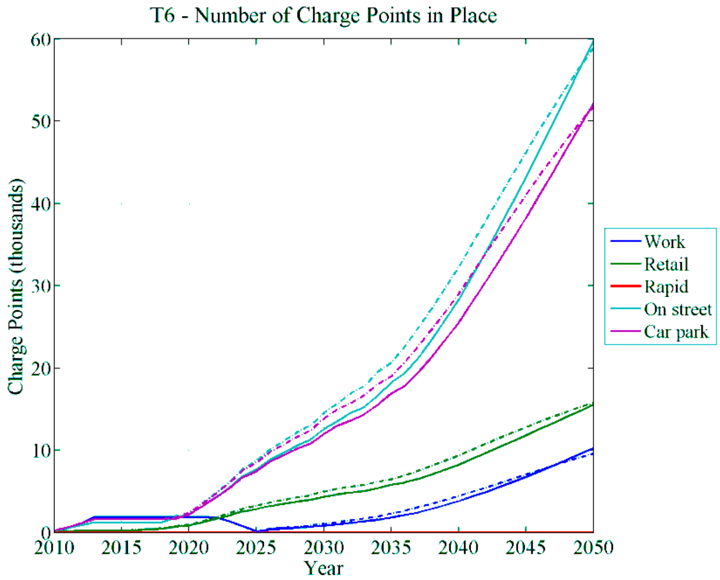


Figure 37 : Number of charge points in place T6

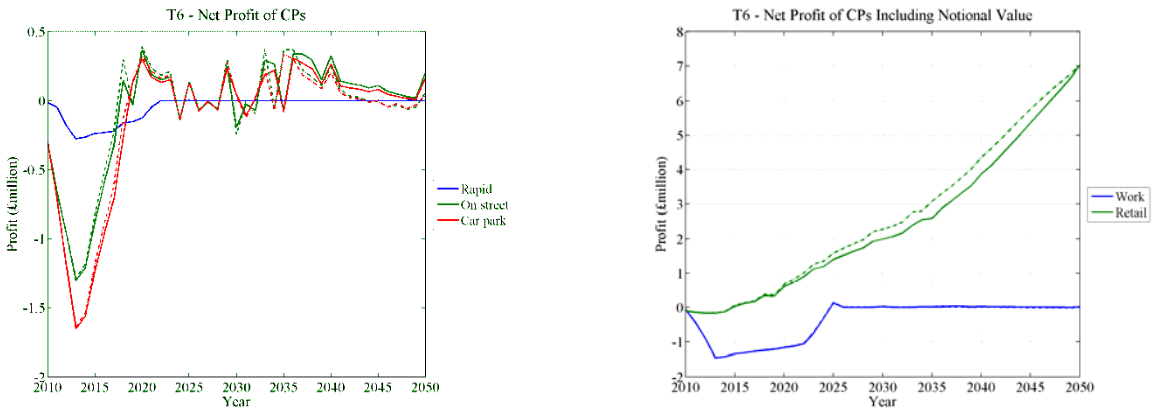


Figure 38a,b : Net profit and notional profit for charge points T6

3.6.3 Exchequer spend and revenue in T6

Compared to the base, the Exchequer spend is reduced slightly (by £50bn over the whole period) due to the lower parc size and hence lower annual sales. This reduction is in line with expectation and reflects reductions in revenues from VED, Company car tax and VAT. The combined revenue from fuel duty and the revenue preserving tax is maintained (the slightly higher income from the revenue preserver tax by 2050 is triggered by the lower fuel duty receipts caused by the lower VKT).

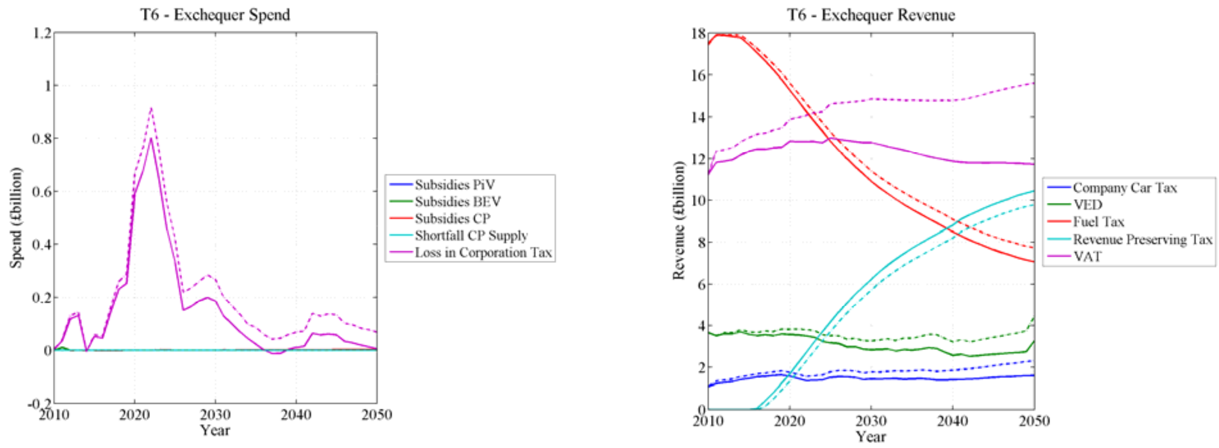


Figure 39a,b : Exchequer spend and revenues T6

3.6.4 Emissions in T6

As expected the emissions are lower than in the base case with a total of 39.1 Mt being emitted in 2050. Of this 40% (15.9 Mt) is due to production and scrappage. Overall the reduction in emissions relative to the base case is around 18%. This is lower than the 25% reduction in parc size as the VKT is only reduced by around 10.6% relative to the base.

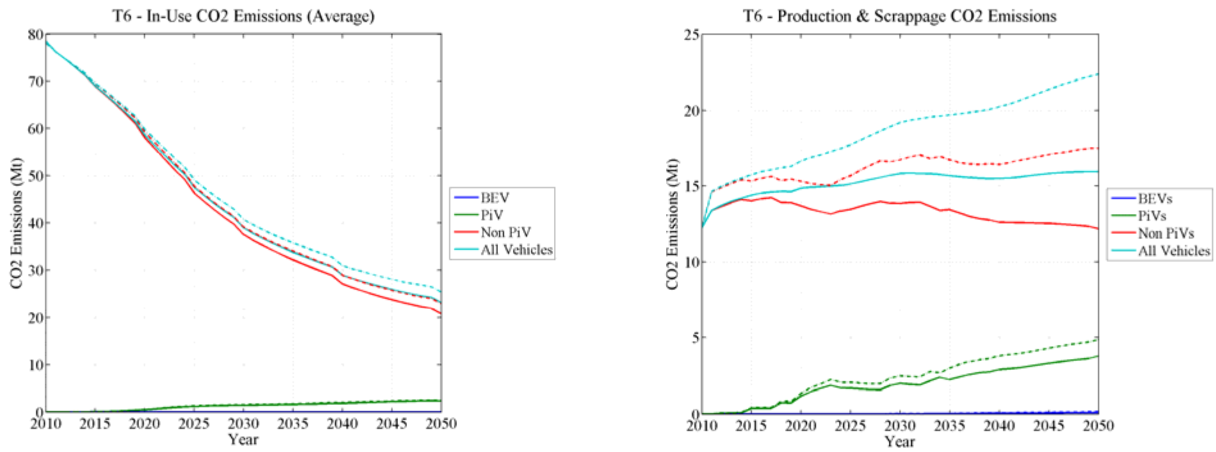


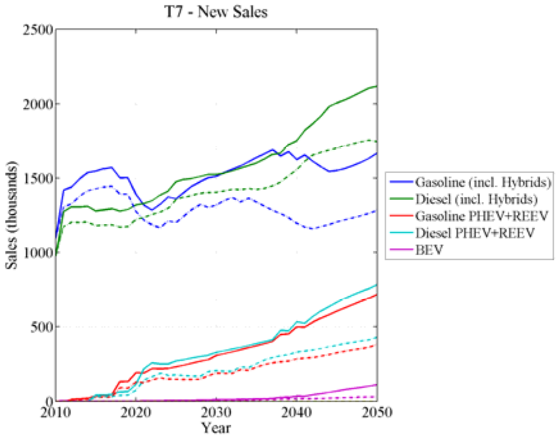
Figure 40 (a), (b) : In use and production and scrappage emissions T6.

3.7 T7 High Rate of Growth in Global Economy

T7 is similar to T5 (High UK GDP) but, as a result of global growth, has high commodity prices, a high cost of carbon and a much more advanced showroom offer. There are no changes in electricity pricing and supply (apart from there being a high domestic base load) or in consumer behaviour compared to the base.

3.7.1 Share of sales and parc in T7

There is a shift towards plug-in hybrids (PHEVs & REEVs) and BEVs compared to T5 despite the higher oil prices. This is thought to be due to the advanced showroom offer. By 2050 the share of PiVs is 26.1% (including 1.3% BEVs). Absolute sales are higher than in the base (reflecting the high growth assumptions).



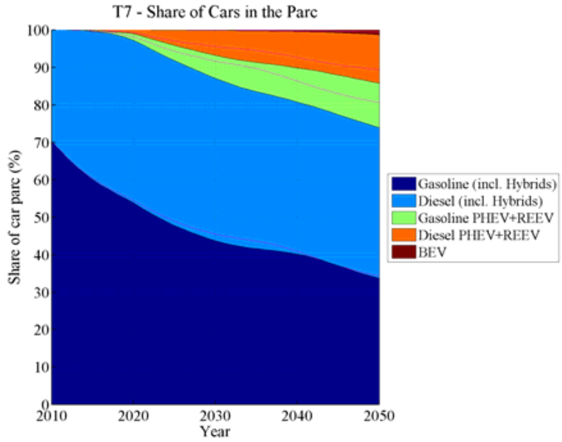


Figure 41 (a), (b) : T7 Total new sales and share of cars in the parc

3.7.2 Charge point deployment and profit in T7

Almost twice as many charge points are deployed compared to T5 or the base - 226 thousand charge points are in place in 2050. The notional and net profits follow a similar pattern to those in T5 with slightly higher profits. The results suggest that, beyond 2020, there is a marked uptake in PiVs which appears to be explained by the advanced showroom offer.

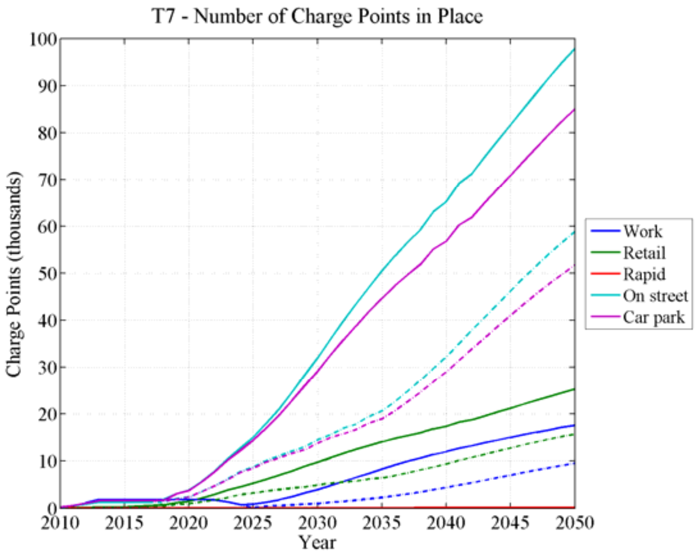
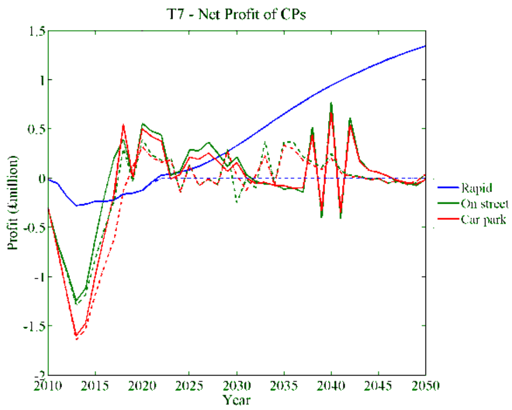


Figure 42 : Number of charge points in place T7



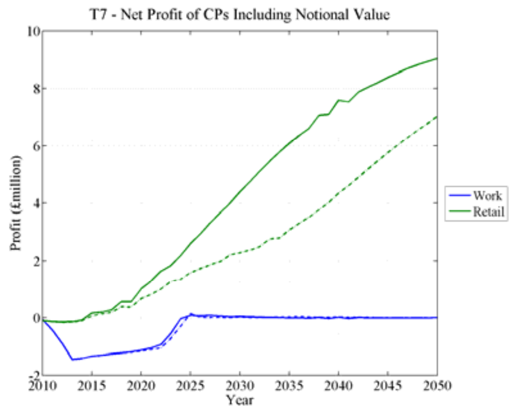


Figure 43a,b : Net profit and notional profit for charge points T7

3.7.3 Exchequer spend and revenue in T7

The Exchequer spend in T7 is similar to, albeit slightly lower than, T5 despite slightly more spent on subsidies for purchasers of PiVs. The total value of revenue to the Exchequer is some £67 bn greater than the base case, and around £6.4 bn greater than T5. The revenue trajectories are similar to T5 with slightly higher VAT receipts, lower VED, lower fuel duty, higher revenue preserver fees and slightly lower company car tax receipts. The higher VAT is due to the higher fuel prices, while lower VED and fuel duty are due to advances in the showroom offer. The net effect is that the Exchequer is better off in a world where there is a global growth with higher commodity prices.

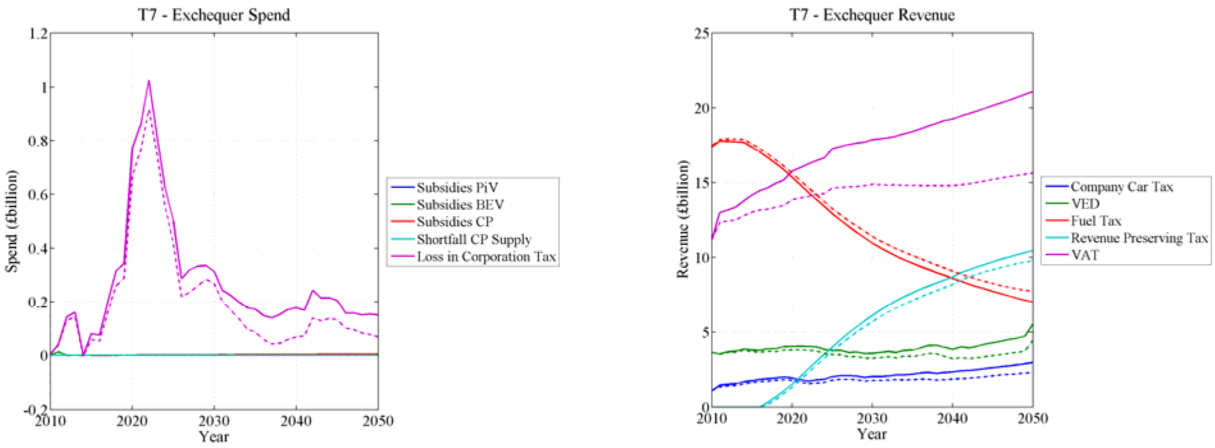


Figure 44a,b : Exchequer spend and revenues T7

3.7.4 Emissions in T7

Whilst the 2050 emissions are higher than the base case due to growth in the parc and VKT, they are, at 50.4 Mt - 13.3% lower than the comparable case T5. This is due to T7's higher share of PiVs and its more efficient fleet. Of the 50.4 Mt emitted in 2050, 25 Mt are due to production and scrappage which is a 20% less than in T5. In fact the reduction in emissions from production and scrappage contributes 6.3 Mt of the 7.7 Mt savings when comparing T7 with T5 (which has the same parc and VKT). This suggests that the main contribution of an advanced fleet to reduced emissions is from increases in average life times and reduced emissions associated with production and scrappage – advances which are not limited to PiVs.

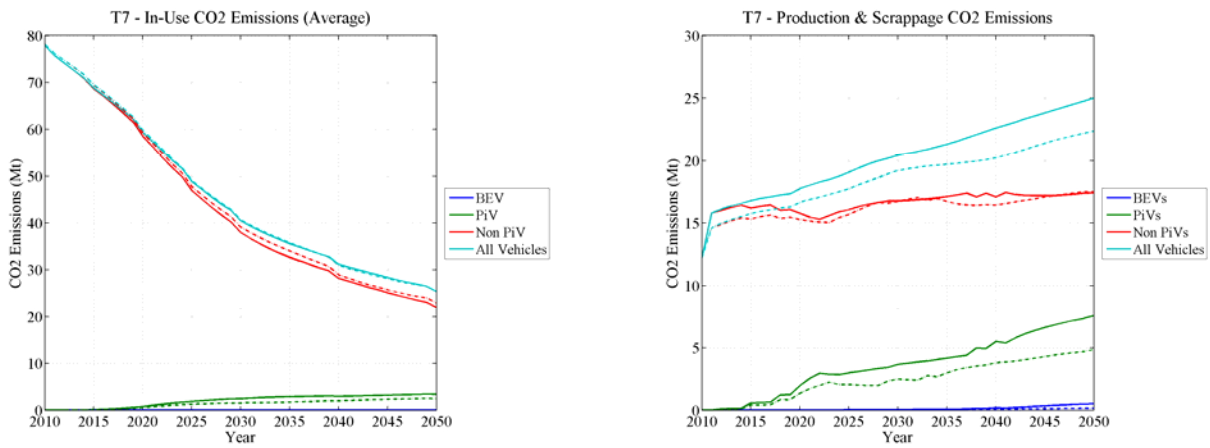


Figure 45 (a), (b) : In use and production and scrappage emissions T7.

3.8 T8 Medium Rate of Global Growth But With a Green Emphasis

T8 assumes a medium global growth but, due to the high price of carbon and other aspects of a "green" priority, it assumes low UK growth and high commodity prices. In other respects, it is similar to T1 with an advanced fleet but with higher prices in the showroom and increases in efficiency for non-PiVs. It assumes green behaviour by consumers as in T1and the government policy is similar to that in T1 with the government picking up any shortfalls. Electricity prices are set from a low base load with super ambition in carbon reduction target due to the green emphasis with pricing for PiVs by employers set as in T1 (e.g. free electricity is offered at retail and work charge points).

3.8.1 Share of sales and parc in T8

The sales and shares results are similar to those in T1 but set in a low growth scenario. The final share of PiVs is 82% (including 17.2% BEVs) which compares well to T1 or T3. The recovery in diesel and gasoline vehicles (including their non-plug-in hybrid variants) when PiV subsidies are removed beyond 2022 is more pronounced than in T1. This is due to the fact that in T8 there are also improvements in the efficiency of non-PiVs.

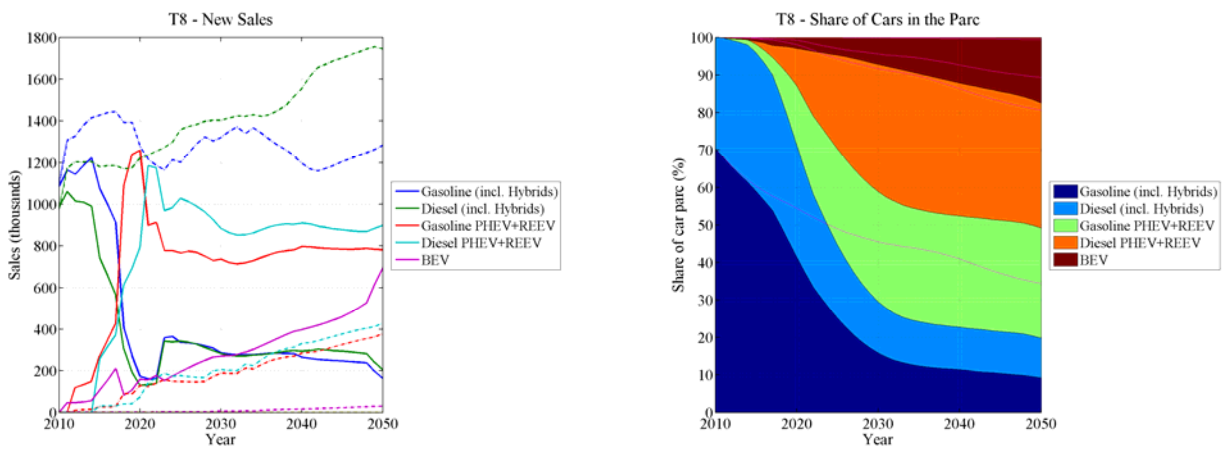


Figure 46 (a), (b) : T8 Total new sales and share of cars in the parc

3.8.2 Charge point deployment and profit in T8

The deployment of charge points follows a similar trajectory to that in T1 and T3 but with a lower final number for each type of charge point due to the lower parc size and lower final share of PiVs. By 2050 there are around 1.6 million retail charge points and around 870 thousand other public charge points. The notional profit for retail is around £1500 per charge point by 2050 which stimulates a high rate of installation. The net profits for car park and on-street charge points increase when the charge point deployment levels off beyond 2030. Beyond 2030 the total feed of electricity drawn begins to fall (see addendum document) which triggers a reduction in the rate of charge point installation. This suggests that the charge point deployment formula could be improved if linked to profits as well as electricity drawn.

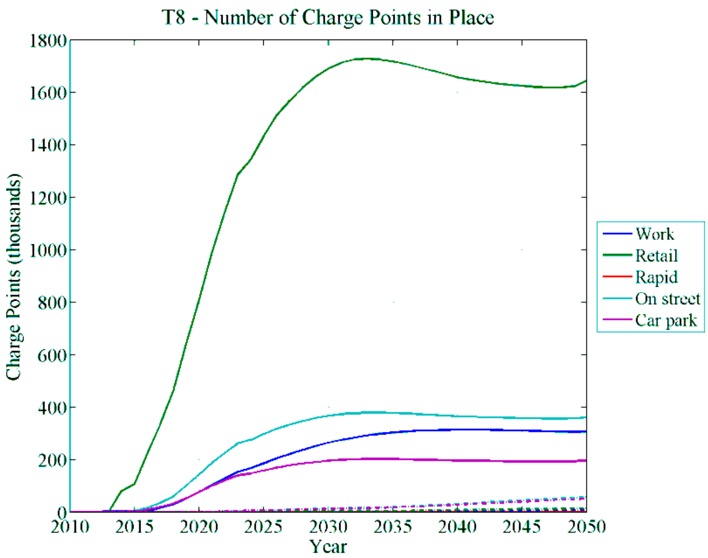


Figure 47 : Number of charge points in place T8

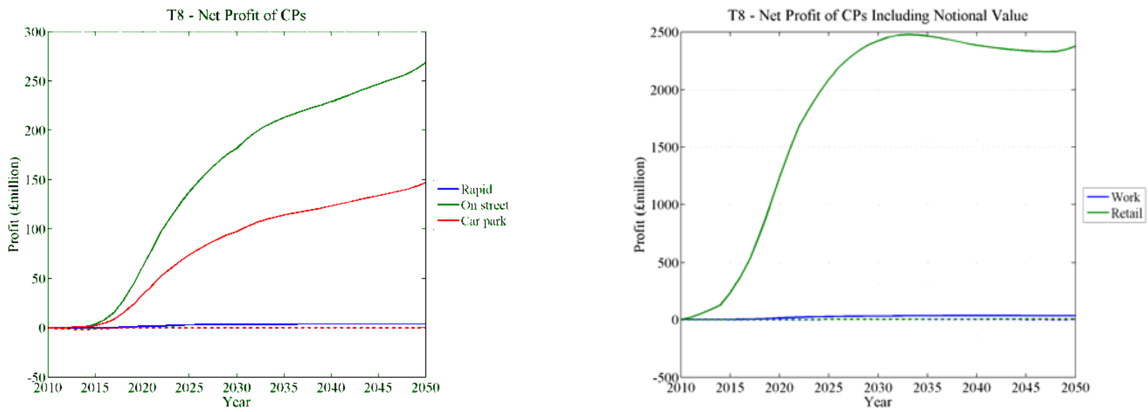


Figure 48a,b : Net profit and notional profit for charge points T8

3.8.3 Exchequer spend and revenue in T8

The Exchequer spend is similar to that in T1 but rather lower (overall value £50 bn compared to £75 bn in T1) due to the low growth setting. The value of subsidies to PiVs is £47 bn compared to £69 bn in T1.

In terms of revenues, T8 has a similar pattern to T1 but with lower VAT receipts due to lower growth, higher VED receipts due to lower PiV share and higher total revenue due to the presence of the revenue preserver (which was not included in T1). The value of revenues to the Exchequer are some £31bn higher than the base, however the net spend in T8 is £14 bn more than in the base due to the large spend on subsidies to PiVs.

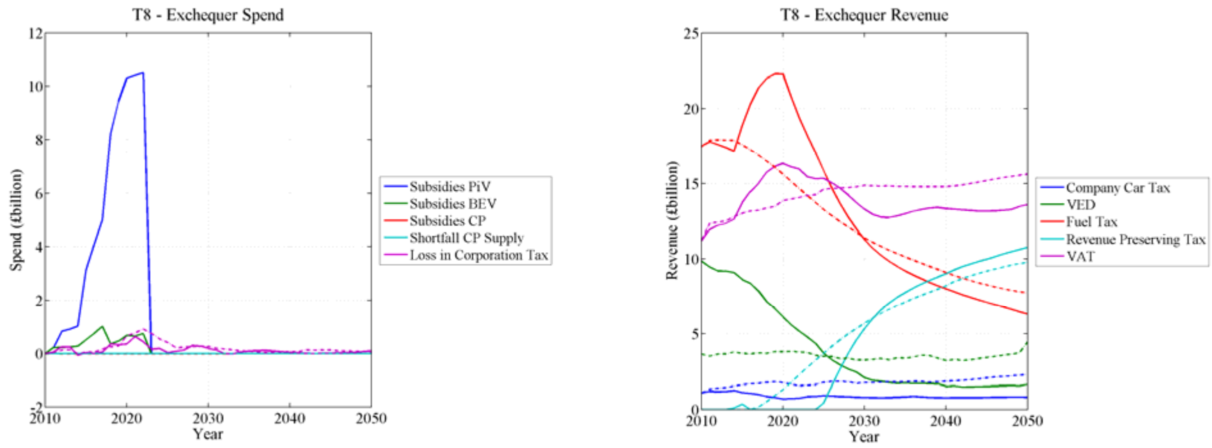


Figure 49a,b : Exchequer spend and revenues T8

3.8.4 Emissions in T8

The emissions trajectories are again similar to those in T1 - but for a different reason; the low emissions in T1 were attributable to a high share of PiVs while those in T8 are largely due to the lower parc and VKT. The total emissions in 2050 are reduced to 24.2 Mt of which 12 Mt are due to production and scrappage. This suggests that, even in a low growth scenario with increased life times for vehicles and low emissions assumed for production and scrappage, the production and scrappage emissions would still make it difficult to meet the 80% reduction targets for total transport related emissions. However the in use emissions target of 16.34 Mt is more than met in this case with only 12.2 Mt emitted in 2050.

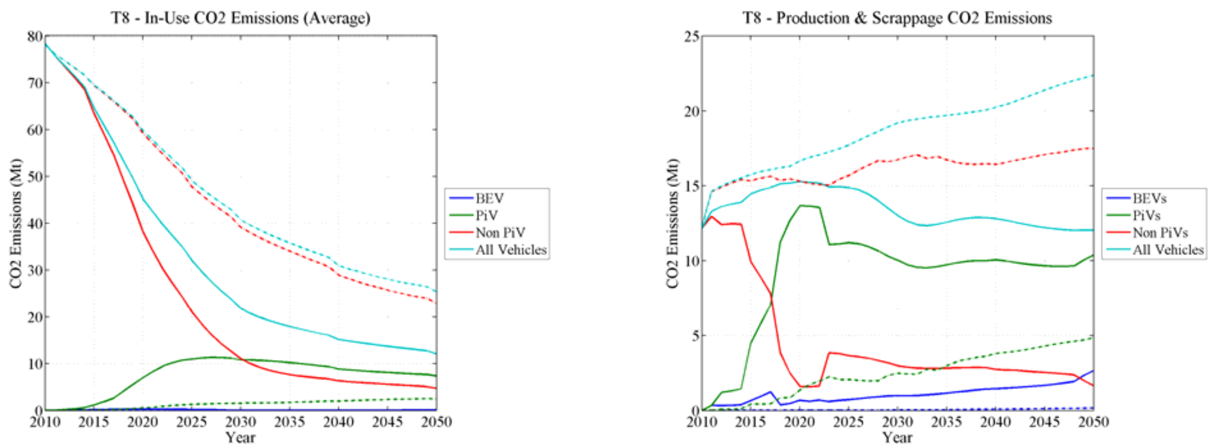


Figure 50 (a), (b) : In use and production and scrappage emissions T8.

3.9 T9 Medium Global Growth But With a High Oil Price

The results for T9 are very similar to those for the base (Figure 51 shows the results for emissions). To avoid repetition, we do not show any other graphs here (all figures and data are available in the addendum document). As will be described in Section 3.13 (where runs are compared), the trajectories for T9 result in only a slight increase in PiV shares compared to base and the slight reduction in emissions is due to slightly lower VKT in response to higher fuel prices. Note that the Production and Scrappage emissions are almost identical to the base case.

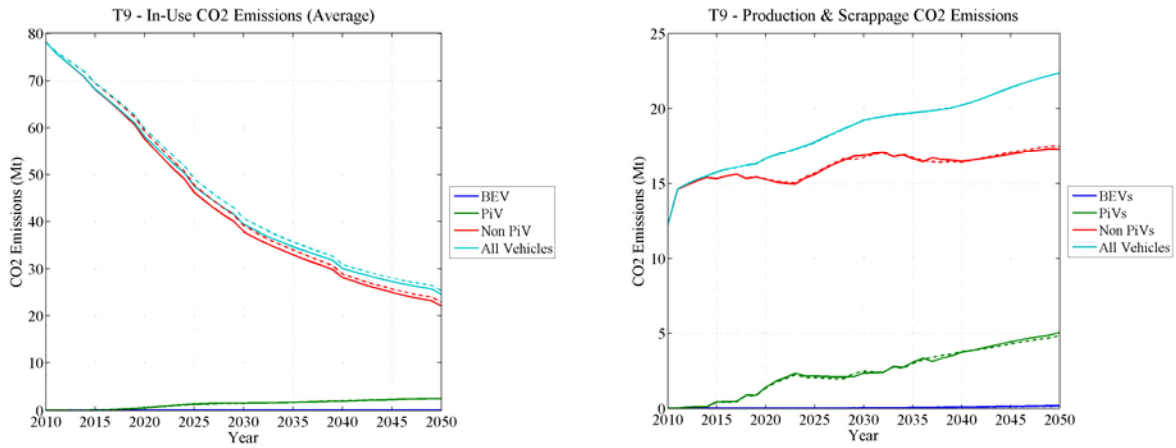


Figure 51 (a), (b) : In use and production and scrappage emissions T9.

3.10 T10 Medium Global Growth But With a Spike in Oil Prices

In T10 the only change from the base case is the spike in oil price between 2020-2030 peaking at 2025. Unsurprisingly, the results are very similar to those in the base and, again, to avoid repetition, we present only one graph here. Figure 52 shows results for emissions and indicates that overall emissions only reduce during the period 2021-2029. This is mainly thought to be due to reduced VKT rather than a significant change in purchase behaviour. By 2050 the effect of the spike is no longer apparent in terms of overall impact on emissions. Note that the Production and Scrappage emissions are almost identical to the base case.

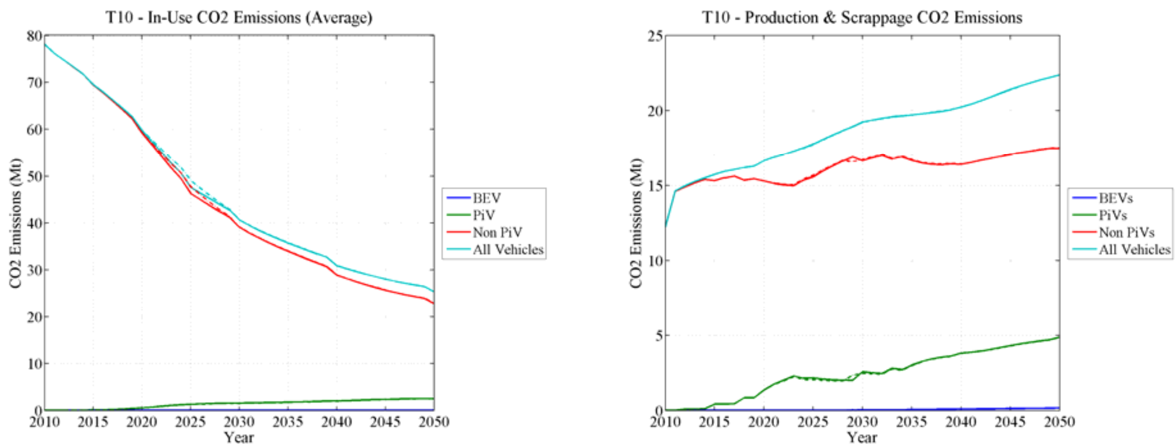


Figure 52: In use and production and scrappage emissions T10.

3.11 T11 Low Global Growth

T11 assumes low commodity prices and low growth in parc and VKT. It has a relatively poor showroom offer (similar to that in T4) and applies the same policies as in the base and T4. It differs from T4 in that the behavioural assumptions and electricity price assumptions are as the base rather than set to minimise PiV sales. Given this, we use T4 and the base as our comparators.

3.11.1 Share of sales and parc in T11

By 2050 the PiV share is 6.8% with only 0.1% BEV. This compares with a 19% share in the base case share but is significantly greater than the share achieved in T4. The share is lower than in the base because of the combination of lower commodity prices and the poorer showroom offer. The increase compared to T4 is due to the removal of the unfavourable behavioural assumptions and to the lower commodity prices. This would suggest that behaviour and showroom offer have both had a significant impact on the share of PiVs in T11.

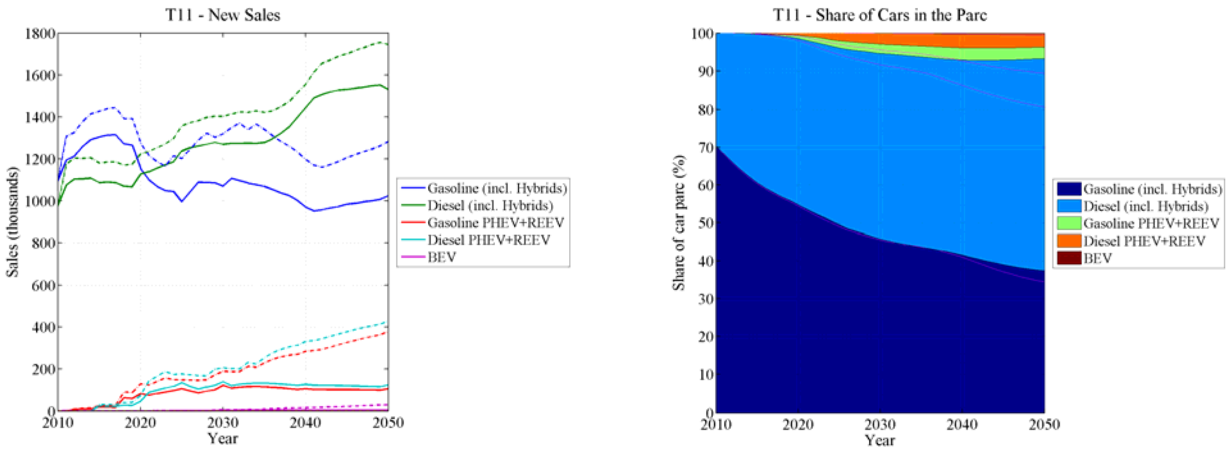


Figure 53 (a), (b) : T11 Total new sales and share of cars in the parc

3.11.2 Charge point deployment and profit in T11

In terms of charge point deployment, T11 appears to be closer to the failing market seen in T4 than to the viable market which exists in the base. There are only a few thousand charge points left in 2050. Use of the cut back mechanism in the charge point deployment formula is evident from the spikes in charge point numbers which correspond to variations in profits. Essentially the market is stuttering and eventually failing in this scenario.

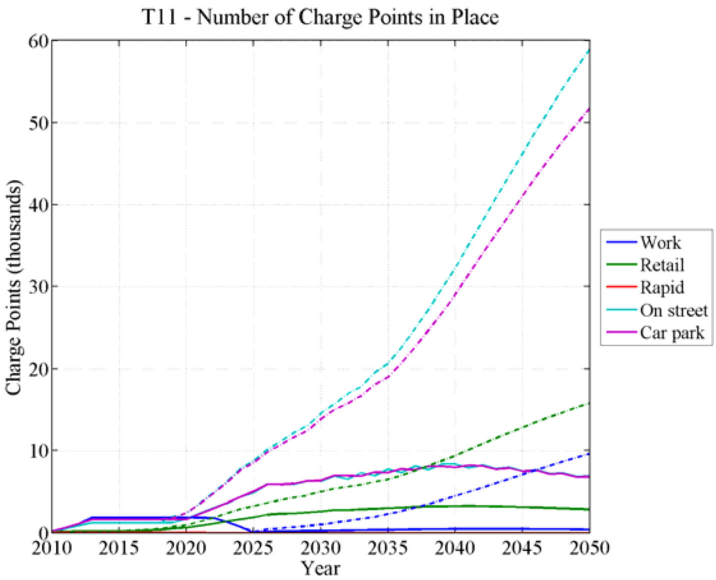


Figure 54 : Number of charge points in place T11

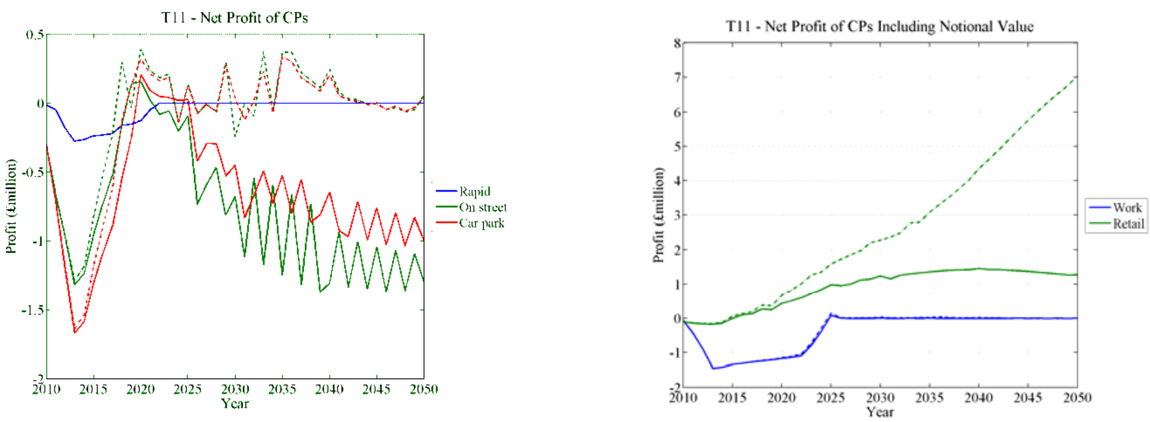


Figure 55a,b : Net profit and notional profit for charge points T11

3.11.3 Exchequer spend and revenue in T11

The general patterns of spend and revenue are similar to the base – although the overall revenue is £50 bn lower in T11. This is mainly due to much lower receipts from VAT, VED and company car tax associated with the assumed low growth in the car parc and VKT. Interestingly, however, the fuel duty revenues in later years are higher in T11 than in the base despite the lower parc and VKT. This is due to the much lower share of PiVs in the parc.

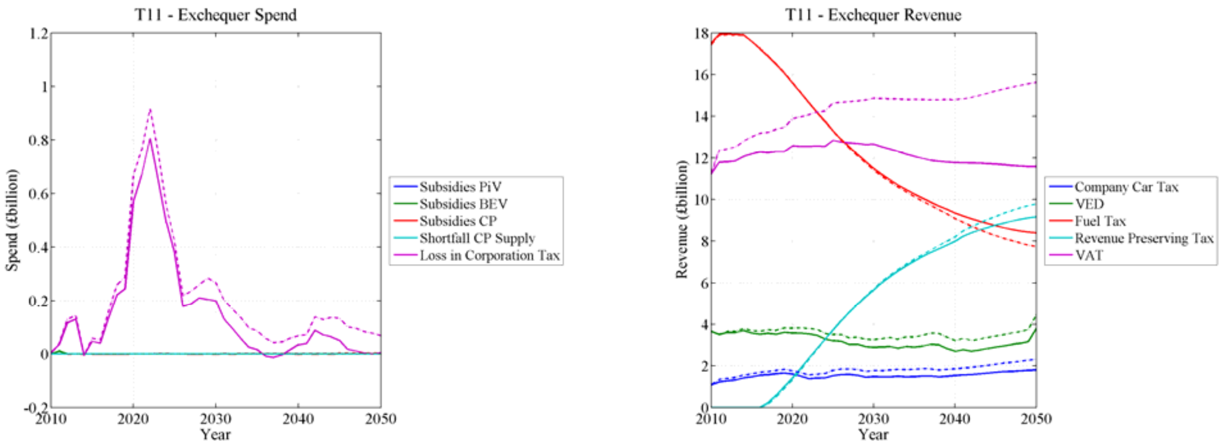


Figure 56a,b : Exchequer spend and revenues T11

3.11.4 Emissions in T11

Over all the emissions in T11 are lower than in the base but only by around 7% (3.3 Mt) in 2050, despite the parc being 25% smaller and the VKT being 10% lower. This is because, with a poor showroom on offer, the emissions due to use and to production and scrappage are higher than in the base case per km travelled and per vehicle in production. From the total of 44.5 Mt emitted in 2050, 19.4 Mt are due to production and scrappage (3 Mt lower than in the base case). This is a reduction of only 13.4% while the parc size has been reduced by 25%. The emissions from use are only reduced by 0.3 Mt compared to base, this is only a 1.2% reduction while VKT have been reduced by 10%. This implies a significantly higher average emission per km for the fleet. This is backed up by the detailed data which shows that the average emissions per km for new cars in 2050 is around 9% higher than in the base.

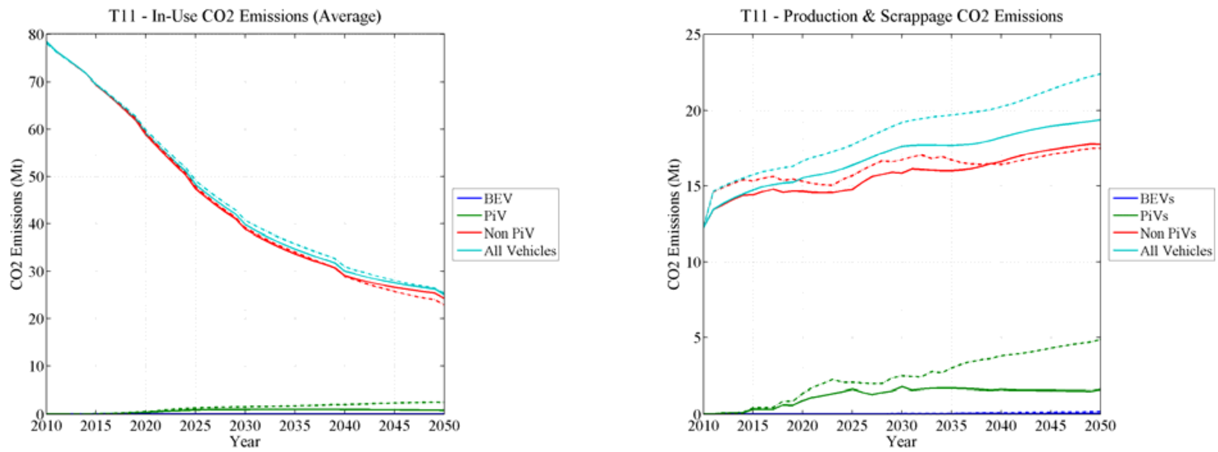


Figure 57 (a), (b) : In use and production and scrappage emissions T11.

3.12 T12 Minimum Carbon Emissions

T12 has everything set to minimise emissions. It is similar to T8 as it has high prices, low growth, behaviour and policies set to minimise emissions, and an advanced showroom offer. T12 differs from T8 in having low (rather than high) prices of vehicles and batteries, a high (rather than low) electricity consumption per 100km[9], preference for large (rather than small) vehicles, and a low (rather than medium) sensitivity to purchase price.

3.12.1 Share of sales and parc in T12

Sales are similar to those in T8 though there is not such a significant recovery in diesel and gasoline sales when subsidies are removed in 2023 as there was in T8. This is because the prices are now lower and the low battery prices favour PiVs more in T12 than in T8. The final share of PiVs by 2050 has increased to 93% (including 24.4% BEVs). This is significantly greater than in T8 and so we may conclude that the lower prices and the other changes described above are a significant factor in determining the share of PiVs.

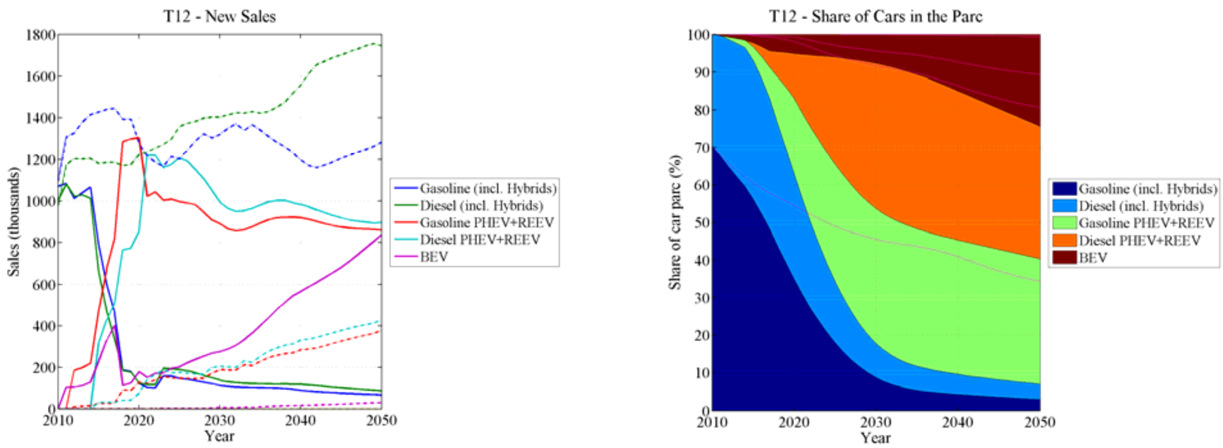


Figure 58 (a), (b) : T12 Total new sales and share of cars in the parc

3.12.2 Charge point deployment and profit in T12

T12 results in a greater number of charge points than T8 with around 2.5 million retail points by 2050 (still lower than T1). Net profits are similar to T8 though notional profits are higher. The profit for retail is around £3.5 bn by 2050 which equates to £1400 per charge point.

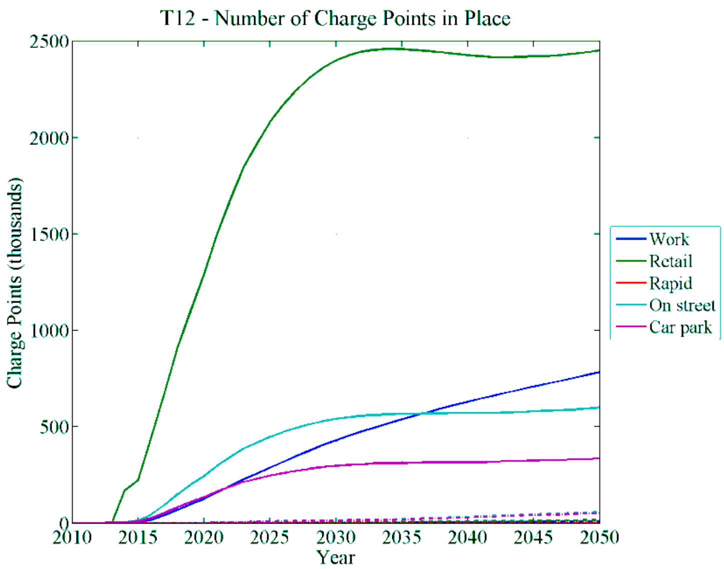


Figure 59 : Number of charge points in place T12

[9] As will be recalled this value was set thus because it generates more charge points and so reduces emissions

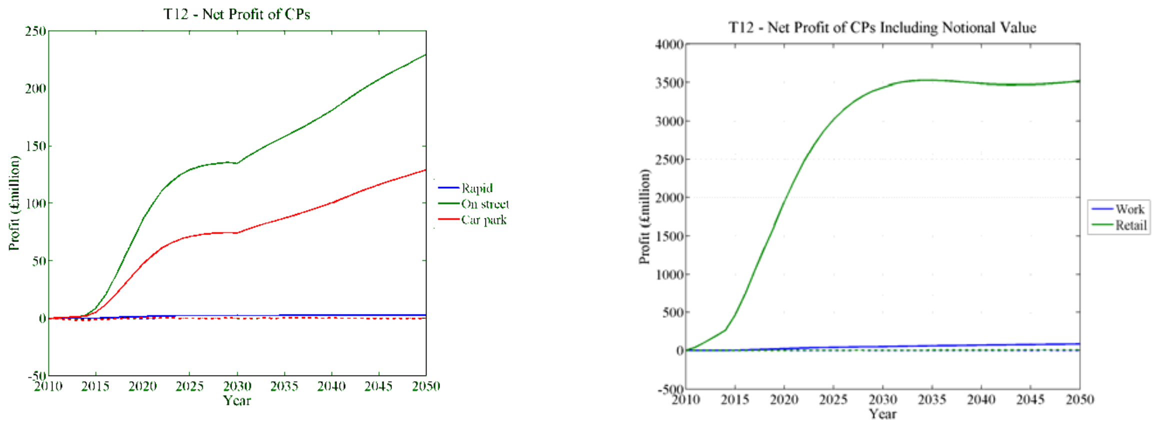


Figure 60a,b : Net profit and notional profit for charge points T12

3.12.3 Exchequer spend and revenue in T12

The Exchequer spend is higher than in T8 with the value of total spend being some £62.4bn which is £12bn higher than in T8 but significantly higher than the base (£57bn). The revenue trajectories are similar to T8 in the earlier years but VED and VAT receipts drop off in the later years due to lower prices and a greater share of PiVs which means losses in VED. The total value of the revenue is £30bn lower than T8 but very similar to the base. However because of the large spend here the net spend is £57bn higher than in the base and £43bn higher than in T8.

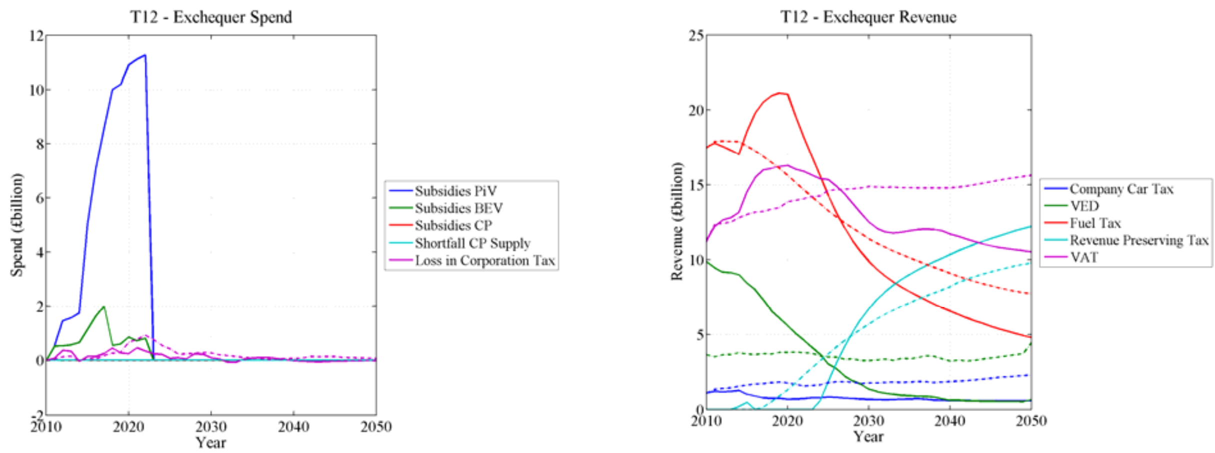


Figure 61a,b : Exchequer spend and revenues T12

3.12.4 Emissions in T12

As expected, T12 results in the lowest overall emissions with only 23.2 Mt in total emitted in 2050. Production and scrappage contributes 13.5 Mt which is still an increase compared to the 2010 production and scrappage emissions of 12.3 Mt. The emissions in 2050 due to use are only 9.7 Mt which would more than meet the 80% reduction target (16.34 Mt) for emissions from use.

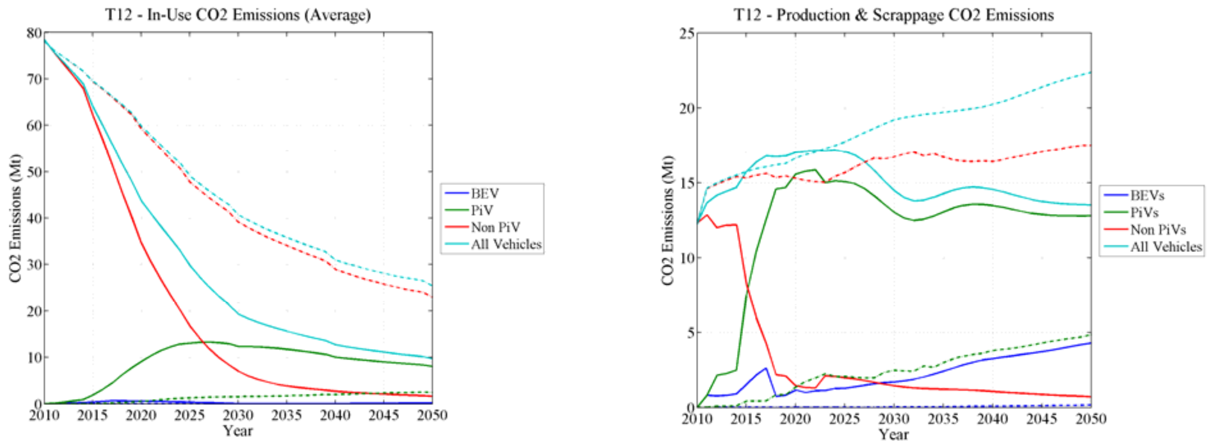


Figure 62 (a), (b) : In use and production and scrappage emissions T12.

3.13 Comparison Across Themes

3.13.1 Summary statistics

Table 8a-8d contains summary indicators for the years 2020, 2030, 2040 and 2050 for the base and themed scenarios. The following analysis concentrates on the final year values in table 8d. This table 8d confirms that the highest and lowest values of PiV shares, emissions and spend arise where we expected them. For example T12 has the lowest emissions, T2 the lowest share of PiV sales, T5 the highest emissions, T1 the highest subsidy etc. An apparent exception is the PiV share which is highest in T12 rather than in T1; however when we account for the size of the parc the absolute sales of PiVs is actually greatest in T1 as expected.

Since the parc and VKT assumptions inherent in the assumptions about the rate of growth in the UK GDP have a significant impact on total emissions our comparison across the themes groups them according to these assumptions. In terms of changes over time tables 8a-8c show similar patterns to the values in 2050 and demonstrate how quickly themes T1, T3, T8 and T12 impact on uptake compared to the much slower evolution in the other themes.

3.13.2 Medium GDP growth scenarios (T0, T9 and T10)

The PiV's percentage share of the 2050 parc in these three scenarios are 19.4, 19.7 and 19.4 respectively. As described above the oil spike and high oil scenarios have little impact compared to the base T0. The oil price spike scenario (T10) has very little impact by 2050 with only a 0.1 Mt reduction in emissions. The high oil price scenario (T9) reduces emissions from use and total emission are reduced by 0.8 Mt in 2050. The other impact of a high oil price is on revenues to the Exchequer (table 7) which are increased by some £20 bn – reducing the net spend significantly.

3.13.3 High GDP growth scenarios (T1, T3, T5 and T7)

The PiV's percentage share of the 2050 parc in these three scenarios are 90.2, 88.6, 18.7 and 26.1 respectively. We will begin by considering the theme with the lowest PiV share. Unsurprisingly, the high UK GDP scenario (T5) results in the highest emissions associated with vehicle use and the highest emissions associated with production and scrappage. The share of PiVs is slightly lower than the base case because, as explained above, the initial charge points can only support a similar number of PiVs. T5 has an increased revenue to the Exchequer and is second in terms of net spend (due to the higher receipts for VAT, VED and fuel duty).

Moving from T5 to T7, we have increased commodity prices and an advanced fleet. This brings an increase in PiV shares from 18.7% to 26.1%. Whilst there are some use-related emission savings due to a more efficient fleet and higher share of PiVs, the greatest savings come in those associated with production and scrappage where there is a reduction of 6.3 Mt in 2050. Thus we can conclude that the advanced fleet actually contributes most to the savings in emissions related to production and scrappage. T7 also results in the highest Exchequer revenues due to the higher prices which feed through to higher VAT, fuel duty, tax etc. and, because the spend is relatively low, the net spend is lower than in any other theme. Thus in terms of the revenue streams to the Exchequer a high global growth scenario is the best outcome.

Table 8a : Summary indicators for the base case and the 12 themed scenarios (2020)

Theme	PiV as % of 2020 Car Parc	BEV as % of 2020 Car Parc	Parc 2020 (m)	VKT 2020 bn Veh-km	Total whole life emissions in 2020 (Mt)	Production and scrappage emissions in 2020 (Mt)	WTW emissions in 2020 (Mt)	Total subsidy to all PiV purchases by 2020 (£million)	Total Exchequer Spend by 2020 (£bn)	Total Exchequ er Revenue by 2020 (£bn)	Total Exchequer Net Spend by 2020 (£bn)
T0 Base	2.0%	0.0%	32	416	76.4	16.7	59.8	7.7	11.4	1.4	330.8
T1 Max PiV	37.9%	6.8%	34	428	66.1	20.0	46.1	1937.6	51075.9	53.7	412.3
T2 Min PiV	0.3%	0.0%	30	402	72.2	15.4	56.8	1.3	0.0	0.8	307.6
T3 Max PiV policy T0	21.7%	2.7%	34	428	72.9	18.8	54.1	846.8	302.1	3.9	337.2
T4 Min PiV policy T0	0.3%	0.0%	30	402	72.2	15.5	56.7	5.0	0.9	0.8	317.4
T5 High UK GDP	2.1%	0.0%	34	428	79.6	18.7	60.9	8.2	12.5	1.6	339.8
T6 Low UK GDP	1.8%	0.0%	30	402	73.4	14.9	58.6	7.1	10.4	1.2	322.3
T7 High Global growth	2.8%	0.0%	34	428	77.1	17.8	59.3	11.0	13.4	1.7	341.6
T8 Medium GG - Green	28.8%	3.0%	30	402	60.4	15.3	45.1	1109.0	33140.3	34.5	395.5
T9 Medium GG- High Oil	2.1%	0.0%	32	416	74.8	16.7	58.1	8.0	11.7	1.4	333.3
T10 Medium GG- Oil Spike	2.0%	0.0%	32	416	76.4	16.7	59.8	7.7	11.4	1.4	330.8
T11 Low Global growth	1.4%	0.0%	30	402	74.7	15.5	59.2	5.9	9.8	1.2	321.8
T12 Minimise Emissions	37.2%	5.1%	30	402	60.7	17.0	43.7	1795.6	44316.6	46.1	393.1

Table 8b - Summary indicators for the base case and the 12 themed scenarios (2030)

Theme	PiV as % of 2030 Car Parc	BEV as % of 2030 Car Parc	Parc 2030 (m)	VKT 2030 bn Veh-km	Total whole life emissions in 2030 (Mt)	Production and scrappage emissions in 2030 (Mt)	WTW emissions in 2030 (Mt)	Total subsidy to all PiV purchases by 2030 (£million)	Total Exchequer Spend by 2030 (£bn)	Total Exchequer Revenue by 2030 (£bn)	Total Exchequer Net Spend by 2030 (£bn)
T0 Base	8.3%	0.1%	36	429	59.9	19.2	40.7	39.6	11.4	4.3	547.4
T1 Max PiV	81.5%	13.2%	41	453	43.0	19.4	23.7	4409.4	69201.3	74.1	638.0
T2 Min PiV	1.1%	0.0%	31	402	55.5	17.5	38.0	1.3	0.0	3.5	501.5
T3 Max PiV policy T0	72.7%	10.8%	41	453	46.6	19.7	26.9	3329.3	302.1	5.5	549.7
T4 Min PiV policy T0	1.9%	0.0%	31	402	55.3	17.6	37.6	6.0	0.9	3.5	517.9
T5 High UK GDP	8.6%	0.1%	41	453	65.6	23.3	42.3	42.8	12.5	5.1	571.1
T6 Low UK GDP	7.9%	0.1%	31	402	54.8	15.8	39.0	34.9	10.4	3.6	525.9
T7 High Global growth	12.9%	0.2%	41	453	60.9	20.4	40.5	81.0	13.4	5.0	576.0
T8 Medium GG - Green	70.4%	7.2%	31	402	34.8	13.0	21.8	2643.0	47230.8	50.1	614.6
T9 Medium GG- High Oil	8.5%	0.1%	36	429	58.7	19.2	39.5	40.9	11.7	4.3	556.1
T10 Medium GG- Oil Spike	8.4%	0.1%	36	429	59.9	19.2	40.7	39.5	11.4	4.3	550.3
T11 Low Global growth	5.4%	0.1%	31	402	57.4	17.6	39.8	20.6	9.8	3.7	524.8
T12 Minimise Emissions	82.2%	7.7%	31	402	33.8	14.5	19.3	3917.3	59380.7	62.4	603.5

Table 8c - Summary indicators for the base case and the 12 themed scenarios (2040)

Theme	PiV as % of 2040 Car Parc	BEV as % of 2040 Car Parc	Parc 2040 (m)	VKT 2040 bn Veh-km	Total whole life emissions in 2040 (Mt)	Production and scrappage emissions in 2040 (Mt)	WTW emissions in 2040 (Mt)	Total subsidy to all PiV purchases by 2040 (£million)	Total Exchequer Spend by 2040 (£bn)	Total Exchequer Revenue by 2040 (£bn)	Total Exchequer Net Spend by 2040 (£bn)
T0 Base	13.6%	0.3%	40	441	51.2	20.2	31.0	108.8	11.4	4.7	703.2
T1 Max PiV	88.7%	21.4%	50	473	38.1	22.2	15.9	7825.0	69201.3	75.0	756.0
T2 Min PiV	1.3%	0.0%	32	403	47.4	18.4	29.0	1.3	0.0	3.7	637.8
T3 Max PiV policy T0	86.1%	19.9%	50	473	38.8	21.9	16.9	6103.1	302.1	5.8	695.5
T4 Min PiV policy T0	2.3%	0.0%	32	403	46.8	18.5	28.3	7.0	0.9	3.7	657.7
T5 High UK GDP	14.0%	0.3%	50	473	58.9	26.3	32.6	119.4	12.5	5.9	744.5
T6 Low UK GDP	13.2%	0.2%	32	403	44.4	15.5	28.9	95.9	10.4	3.8	667.1
T7 High Global growth	19.3%	0.4%	50	473	53.8	22.6	31.2	214.5	13.4	5.8	750.6
T8 Medium GG - Green	77.2%	12.1%	32	403	28.0	12.8	15.2	4617.6	47230.8	50.3	750.6
T9 Medium GG- High Oil	13.4%	0.3%	40	441	50.4	20.2	30.1	110.0	11.7	4.7	717.9
T10 Medium GG- Oil Spike	13.8%	0.3%	40	441	51.2	20.2	31.0	111.8	11.4	4.7	706.0
T11 Low Global growth	7.1%	0.1%	32	403	48.2	18.2	30.0	39.4	9.8	3.8	666.0
T12 Minimise Emissions	90.4%	14.9%	32	403	27.3	14.6	12.7	7011.7	59380.7	62.5	730.5

Table 8d - Summary indicators for the base case and the 12 themed scenarios (2050)

Theme	PiV as % of 2050 Car Parc	BEV as % of 2050 Car Parc	Parc 2050 (m)	VKT 2050 bn Veh-km	Total whole life emissions in 2050 (Mt)	Production and scrappage emissions in 2050 (Mt)	WTW emissions in 2050 (Mt)	Total subsidy to all PiV purchases by 2050 (£million)	Total Exchequer Spend by 2050 (£bn)	Total Exchequer Revenue by 2050 (£bn)	Total Exchequer Net Spend by 2050 (£bn)
T0 Base	19.4%	0.6%	45	453	47.8	22.4	25.4	11.4	5.0	816.6	-811.6
T1 Max PiV	90.2%	28.8%	61	484	36.5	23.9	12.6	69201.3	75.4	836.4	-761.0
T2 Min PiV	1.2%	0.0%	34	405	43.8	19.7	24.1	0.0	3.8	734.9	-731.1
T3 Max PiV policy T0	88.6%	27.8%	61	484	37.0	23.9	13.1	302.1	6.1	802.4	-796.3
T4 Min PiV policy T0	1.7%	0.0%	34	405	43.5	19.7	23.8	0.9	3.8	756.8	-753.0
T5 High UK GDP	18.7%	0.7%	61	484	58.1	31.3	26.8	12.5	6.5	876.6	-870.1
T6 Low UK GDP	19.9%	0.5%	34	405	39.1	15.9	23.2	10.4	3.9	766.2	-762.3
T7 High Global growth	26.1%	1.3%	61	484	50.4	25.0	25.4	13.4	6.3	883.0	-876.7
T8 Medium GG - Green	80.2%	17.5%	34	405	24.2	12.0	12.2	47230.8	50.4	847.5	-797.1
T9 Medium GG- High Oil	19.7%	0.6%	45	453	47.0	22.4	24.6	11.7	5.0	836.2	-831.2
T10 Medium GG- Oil Spike	19.4%	0.6%	45	453	47.7	22.4	25.3	11.4	5.0	819.5	-814.4
T11 Low Global growth	6.8%	0.1%	34	405	44.5	19.4	25.1	9.8	3.9	766.2	-762.3
T12 Minimise Emissions	93.0%	24.4%	34	405	23.2	12.3	10.9	59380.7	62.4	816.8	-754.3

Moving from T7 to T3, we now have lower gas, coal and carbon prices; introduce a similarly advanced fleet though with differentials in favour of PiVs; and change the consumer behaviour and assumptions for setting electricity prices to favour of PiV sales (e.g. free electricity at work and retail charge points, and low sensitivities to range, PiV idea and purchase prices). It should be noted that the policy variable settings in T3 are the same as in T7. These changes result in a significant increase in PiV shares from 26.1% to 88.6%. This time the significant reduction in emissions is brought about by the reduction in usage-related emissions (which are almost 50% less than in T7). The usage-related emissions are now 13.1 Mt in 2050 which is below the 80% reduction target of 16.3 Mt. However, the production and scrappage emissions are still 23.9 Mt which is significantly higher than the 14 Mt in 1990. The value of PiV subsidies increases significantly to £300 million despite subsidies only being offered in 2011. The revenue to the Exchequer is also less than T7 due to lower VAT and VED receipts as people move to PiVs. This results in a net spend which is some £15.3 bn higher than in the base case. From these results and comparing T7 with T3 we can infer that the favourable behavioural assumptions have a significant impact on the outcome for both PiV share and emissions.

Finally, moving from T3 to T1, all policy variables are set to favour PiV sales. This results in an increase in PiV share from 88.6% to 90.2% with a further reduction in emissions of only 0.5 Mt in 2050. The largest impact is on the revenue streams where PiV subsidy increases in value to a massive £69.2 bn. This outweighs the increased revenues from increases in VED and fuel duty which bring in an additional £34 bn compared to T3 resulting in a higher net spend of -£761 bn. Whilst this is still a surplus to the Exchequer it is an increase of £50 bn. From the comparison of T3 and T1 we may infer that the policy impact is limited compared to the other scenario factors around the high growth in PiV sales scenario and that it impacts more on revenues than on emissions.

3.13.4 Low growth scenarios (T2, T4, T6, T8, T11 and T12)

For the low growth scenarios we begin with the lowest PiV share which, as expected, comes as a result of running T2 which has all scenario and policy variables set unfavourably for PiV sales. As described above this results in a failing market for PiVs and charge points. Despite this the emissions are 4 Mt lower than in the base case - mainly due to a 2.7 Mt saving in emissions from production and scrappage. Although the policies in T2 spend nothing on PiV subsidies, they have less revenue than the base case due to the lower fleet size. This contributes to the Exchequer being around £80 bn worse off than in the base case over the whole period.

Moving from T2 to T4, all scenario variables are the same whilst the policy variables revert to the base values. This results in a small increase in PiV share and only a 0.3 Mt reduction in emissions associated with vehicle use. The effect on revenues is to increase revenues by around £22 bn compared to T2. Once again we can infer that the policy impact is limited in impact on PiV share and emissions but significant in terms of revenues.

Moving from T4 to T11, we change the prices of gas, coal and carbon to low, revert to the base behavioural assumptions (from unfavourable) and assume a lower efficiency within the fleet for non-PiVs. These changes increase shares to 6.8% and despite this there is a slight increase in emissions due to use (as we have a lower efficiency for non-PiVs). This also increases revenues by around £10 bn. From these comparisons we infer that behaviour assumptions are important in determining the PiV share and have a greater impact than do the policy assumptions (T2-T4 impact being small).

Moving from T11 to T6, we revert to base assumptions in a low growth scenario which means reverting to the base showroom offer which is an improvement on the offer within T11. This trebles the share of PiVs relative to T11 and reduces emissions related to production and scrappage by around 18% while also reducing those due to use by 8%. This implies moving from a poor showroom to the base showroom offer has a significant impact on purchase behaviour and both types of emissions. The effect on Exchequer spend and revenues is only marginal.

Moving from T6 to T8, we replace a low global growth assumption to a medium global growth assumption. The low UK growth in T8 is assumed to be associated with the green emphasis; we have high commodity prices, an advanced efficient showroom but with high prices, behaviour and electricity supply in favour of PiVs and policies set to maximise PiV shares as in T1. This results in a significant shift towards PiVs with share increasing from 19.9% to 80.2%. Production and scrappage emissions are at their lowest in 2050 at 12 Mt while usage-related emissions are also down to only 12.2 Mt in 2050 which more than meets the 80% target for usage-related emissions but represents only a slight reduction on the 1990 level of emissions associated with production and scrappage. The policy effects are to increase PiV subsidies to around £47 bn with increased revenues of around £81 bn compared to T6. The increased revenues are due to higher VED and fuel duty receipts in the early years plus greater VAT receipts; however the net spend in T8 is £14 bn more than in T0 due to the large spend on subsidies to PiVs.

Finally, moving from T8 to T12, only a few variables are modified to minimise emissions. These include showroom prices for the fleet which are now low, price sensitivity of consumers is set to low rather than medium, and electricity consumption per 100km is set high rather than low to induce the deployment of charge points which then impacts on PiV sales. These changes result in an increase in PiV share from 80.2% to 93% which reduced total whole life emissions by 1 Mt in 2050. This reduction results from a reduction in emissions associated with vehicle use being offset by a slight increase in emissions related to production and scrappage. The usage-related emissions are only 10.9 Mt which more than meets the 80% reduction target while those associated with production and scrappage are 12.3 Mt which is only a 12.2% reduction on the 1990 values despite the improved fleet and low growth assumptions. The impact of lower prices and other changes between T8 and T12 is significant in terms of PiV share but limited in terms of emissions which suggests some diminishing returns when the non-PiV fleet is also as efficient as could be in terms of emissions. In terms of revenues, the subsidies are increased by £12 bn while revenues are decreased by around £30 bn which is due to the lower prices and associated loss in VAT and lower receipts for VED compared to T8.

3.13.5 Summary

The market share achieved by BEVs is generally very small because they are much less attractive to consumers than other PiVs. However, in themes T1, T3, T8 and T12 there is a very a significant uptake of BEVs by 2050. As T3 does not contain any policy levers other than those in the base we may conclude that this large share is not a result of policy actions. Rather, it is a result of a combination of factors including; low sensitivity to capital costs, high oil prices, free electricity at work and retail charge points - and an associated high utilisation of such charge points. This combination of variables increases the attractiveness of BEVs relative to all other vehicles.

Next, the emissions associated with production and scrappage range from 12 Mt to 31.3 Mt in 2050 which does not compare well with the 14 Mt in 1990. The high values result from high growth and the only way to reduce these emissions is to improve the emissions rates associated with production and scrappage across the whole fleet offer.

Emissions associated with vehicle use vary from 12.0 Mt to 26.8 Mt and only those from T1, T3, T8 and T12 meet the 80% reduction target which is equivalent to 16.3 Mt in 2050 (80% reduction from 81.7 Mt in 1990). To achieve this requires all scenario variables including fleet and behavioural assumptions to be in favour of PiV sales. The fact that T3 which includes the base policies with high growth assumptions meets the reduction target, demonstrates the fact that the policy initiatives have a very limited impact on emissions compared to the scenario variables.

In terms of net spend, while the PiV subsidies are significant as under T1, they do not seem to be necessary to stimulate the market for PiVs - similar shares can be achieved with no subsidies (T1 *vs.* T3). The net spend is however highly dependent on the growth assumptions as demonstrated by the low and high growth scenarios T5 and T6 which increase/decrease the net spend by £50-60 bn over the period to 2050. The fact that this growth is driven by other global factors and domestic policies should be borne in mind when developing strategies to reduce the emissions from transport. From a narrow Exchequer perspective, the high revenues associated with high GDP growth are clearly to be welcomed - but this comes at the price of with high emissions!

In terms of policy actions it appears from the above comparisons that while the policies considered here have little impact, more emphasis should be put on improving the showroom on offer and upon changing attitudes of consumers (it should however be noted that these two aspects are not included in the general feedback within the CRM) - there is no feedback from sales of PiVs to the attributes of the showroom on offer, nor from uptake to consumer attitudes.

4 The Optimisation Work

4.1 Introduction

4.1.1 The goal

The purpose of the optimisation work was to identify the "best package" of policies. "Best package" was here defined as the set of values for the 29 available policy levers (fully defined in WS3/ARUP/10) which, while meeting a target reduction in CO2 by 2050, did so at minimum cost to the Exchequer.

It was initially assumed that the target CO2 emissions would be 20% of the 1990 level (95.7 Mt), i.e. 19.14 Mt. However, examination of results from the ECBM indicated that, in the absence of any representation of hydrogen-powered vehicles[10] and given agreed constraints on the policy levers[11], a reduction to 20% of the 1990 level was unlikely to be achievable – the best result at that stage was around 44 Mt– about 46% of the 1990 level.

Following further discussion with MEDAG, it was agreed that, the 20% level being unattainable, we would instead adopt a more realistic target. It was agreed that this should be set about five percentage points above the best result we could identify in an initial systematic search of policy space (the reason for adopting a target which was less onerous than the best result we had achieved was that this would give some scope for modelling - had we adopted as the target, it might have been impossible to achieve it with any other combination of policy variables).

The lowest 2050 emissions we were able to identify was 41.566 Mt (this was from run 1K640) – 43% of the 1990 level[12]. Five percentage points above 43% is 48%; 48% of the 1990 suggests a target of 45.94 Mt. We rounded this to 46Mt and conducted the optimisation work using a target of 46.0Mt[13].

The other key component of the definition of the "best" policy is the definition of "cost to the Exchequer". This was defined as having two main components:

(i) The excess of expenditure over revenue over the 41 years from 2010 to 2050, and

(ii) The value of carbon emissions over the 41 years from 2010 to 2050.

The relevant expenditures were taken to be:

a) Any subsidy, or tax breaks, to purchasers of PiVs

b) Any subsidy, or tax breaks, to installers of non-domestic charge points

c) Any net loss in Corporation Tax due to favourable treatment of companies' capital expenditure on PiVs, or charge points.

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[10] MEDAG decided to exclude this class of vehicles because the CRM did not have a realistic means of constraining their uptake.

[11] E.g. that fuel tax could not be increased by more than 50% and that VED could not be increased by more than 100%.

[12] Omission of emissions associated with production and scrappage from all calculations would have shown the 2050 results in a more favourable light because production and scrappage emissions form a much larger proportion of total emissions in 2050 than they did in 1990. The 1990 emissions excluding production and scrappage were 81.7 Mt. The target 80% reduction on this would thus have been 16.34 Mt. The usage-only emissions in the optimal run (1L068) is 23.5Mt which represents a 71.2% reduction on the 1990 level (i.e. still not meeting the 80% reduction target). The usage-related emissions in run 1K640 represent a 77% reduction on the 1990 levels for that those emissions.

[13] Note that, given that emissions associated with production and scrappage contribute 22.4 Mt in 2050, and that emissions associated with use were 81.7 Mt in 1990, the 46 Mt target translates to a 71% reduction on 1990 levels for emissions associated with vehicle use.

The relevant revenues were taken to be:

a) Income from fuel duty
b) Income from VED (and first year tax)
c) Income from VAT on electricity used to power PiVs

CO_2 emissions were valued at the mid-range traded values quoted by DECC[14].

Monetary values for years beyond 2010 were discounted at 3.5% per year.

4.1.2 The methodology

The method used to locate the best policy package (as defined above) is a statistical process based on an optimisation methodology used since the early 1990s. The 1990s method sought to mimic a response surface close to an actual optimum, using quadratic functions where possible, and solving for predicted optima by calculus and consideration of permissible policies. The policies chosen in this way had then to be checked using a run of the original model. Initially, we developed our methods using a model of a hypothetical city. Full details can be found in Bristow et al (1994)[15], an edited version in Bonsall et al (1994) [16] and a brief description in May et al (1995)[17].

On the basis of our experience we drew up Figure 63. Although the flowchart looks very precise it must be emphasised that considerable discretion is necessary in its usage.

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

[15] Bristow, A.L., Fowkes, A.S., Bonsall, P.W. and May, A.D. (1994). *The optimisation of integrated urban transport strategies. Tests using PLUTO*, WP 424, Institute for Transport Studies, University of Leeds.

[16] Bonsall, P.W., Bristow, A.L., Fowkes, A.S. and May, A.D. (1994). *A tool for the optimisation of transport strategy.* Proc. European Transport Forum, Paper G22. PTRC, London.

[17] May, A.D., Bonsall, P.W., Bristow, A.L. and Fowkes, A.S. (1995). A streamlined approach for the preparation of package approach bids, *Traffic Engineering and Control*, 36(2), pp 68-72.

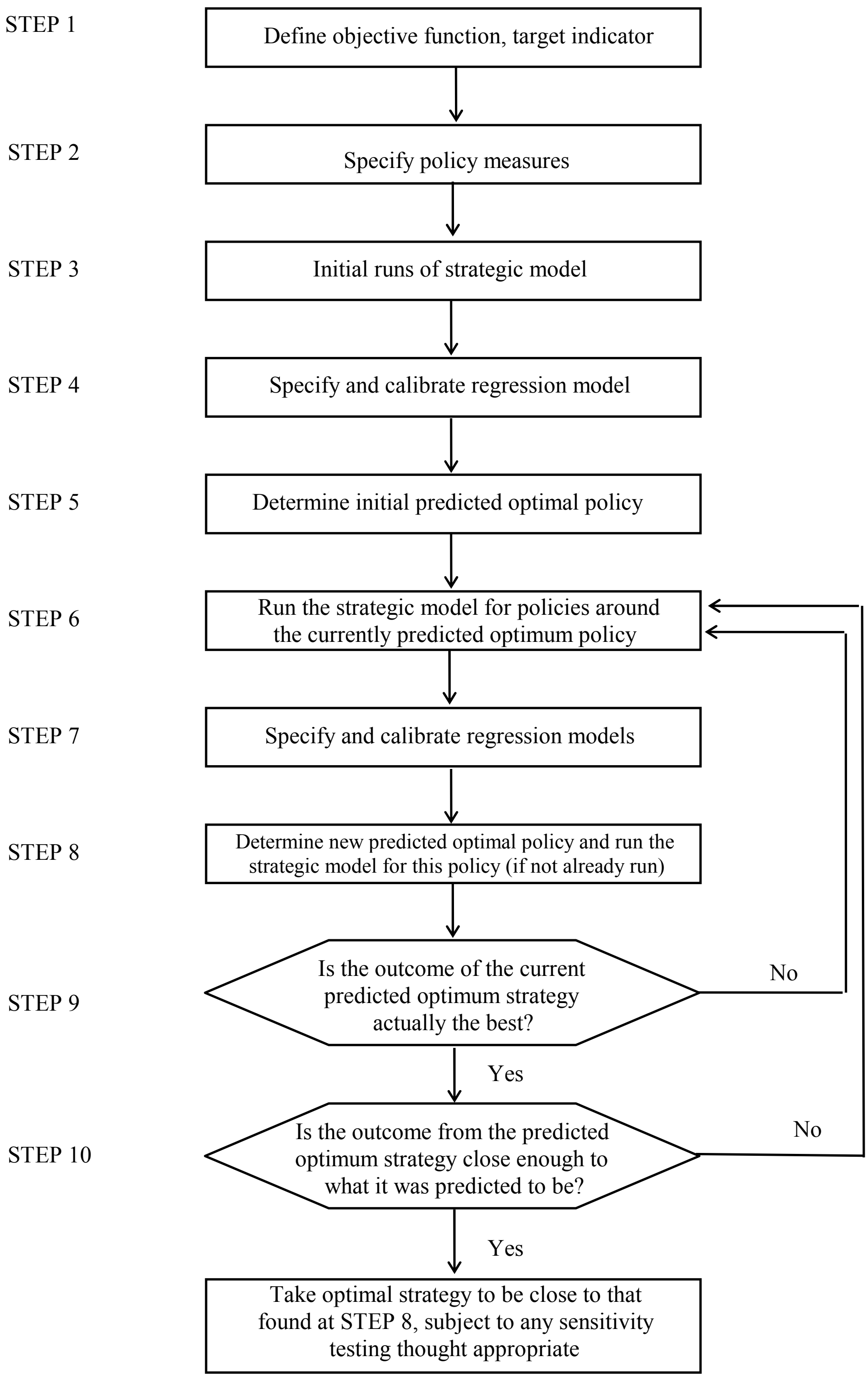

Figure 63 : The Optimisation Process

Referring to the figure, let Y be the target variable (STEP 1), and suppose that we wish to minimise it. Simple regression will fit an equation like

$$Y = a + bX + cX^2$$

$$dY/dX = b + 2cX \quad = \quad 0 \text{ for a turning point}$$

$$d^2Y/dX^2 \quad = 2c \quad > 0 \text{ for a minimum}$$

In order to have a minimum we must have c positive, in which case the optimum level of X is –b/2c. We then need to check if this is a permissible value; for example if b is also positive the optimal X will be negative, which may not be permissible. There will usually be pre-determined permissible ranges for each variable. If we find a maximum (rather than the minimum we want) in that range we will need to consider which of the two bounds to that range give the best outcome. For zero/one variables, we similarly choose zero if its coefficient is positive and one if it is negative.

Since we are using a quadratic approximation to, presumably, much more complex relationships, we must not expect it to fit well over all possible policies. The approximation only needs to be good in the vicinity of the optimum. Elsewhere we will wish to tolerate much larger errors.

The iterative process can be protracted. Referring again to Figure 63, if we have calibrated a regression model at STEP 7, we should estimate the predicted optimal policy (STEP 8) and consider its adequacy (STEP 9 and STEP 10), returning to STEP 6 if not.

4.1.3 Operationalisation of the objective function

Our Objective Function (Y) was defined as follows:

$$Y(X) = S(X) + vE(X) + qD[T - E^{2050}(X)]^2$$

where :

Y is the objective function (in this case to be minimised, since it is a 'bad')

X represents the vector of policy variables

S is government net spending

E is emissions of CO_2 in Megatonnes

v is the official value of a Megatonne of CO_2 saved

E^{2050} is the emissions of CO_2 in 2050

T is the target level (in Mt) for CO_2 in 2050

D is a dummy variable that takes the value 1 when E^{2050}>T and zero otherwise

q is a sensitivity parameter.

Y, S, E and E^{2050} are functions of the *X* variables. We seek to find *X* that minimises *Y*. We do this by running a weighted least squares regression including quadratic terms. In that way, we obtain the '*b*' and '*c*' values mentioned in Section 4.1.2. All monetary amounts are discounted (at 3.5% pa). The job of the final term is to ensure that any exceedence of the 2050 target are heavily penalised (without being totally removed from the information pool). Once we had sufficient runs, we set *q*=0 and used the penalty only in the regression weighting.

The reported regression model used data (i.e. runs of the CRM model) with q=0 (i.e. with no penalty in the Y function) but with weights including the effect of the penalty with q=100000. The choice of q values in the calculation of the weights was determined by trial and error. Earlier runs used non-zero q values in the Y function directly, but the abrupt change in slope occasioned by the penalty as each variable (given the levels of all other variables) caused Y to exceed T and interfered with the estimation of the 'b' and 'c' values, producing distinctly inferior regression models.

The process involves estimation of "unbounded" optimal settings and then deriving "bounded" values (i.e. values which represent allowed combinations of policy levers) for all the Xs. For variables which only have a linear term, the unbounded values are 0.0 if the coefficient is positive, 1.0 if it is negative, and indeterminate if the linear term is not present. For variables with both a linear and squared term, following the method described above, the unbounded value is $-b/2c$ if c is positive (giving a minimum, as desired) or "Max" if c is negative. In that case we determine the contribution to Y at the two bounds for X, and choose the X value that performs best.

4.2 The Optimal Policy Package

Our search for the optimal policy package for the base scenario utilised 1329[18] runs of the Consumer response model (CRM) – including the runs which had been specified for the sensitivity testing work. Around 300 runs were used to estimate an initial regression model. The iteration procedure then took over, with a series of run batches being speedily and efficiently provided by Element Energy.

Table 9 presents our final position, showing the 5 runs with the best values of the objective function. The first column gives brief identifiers and description for each of the 29 policy levers tested. The main body of the table reports the lever values used in the runs. The first row in each column provides the ID code for the run. Results are shown for the "base" policy run (T0) and then for the eight best ranked runs, with the best (1L068) leftmost

The final three rows of the table show:

i. the 2050 emissions (which is always less than 46 Mt, as required[19])

ii. the objective function (these are all negative because spending is always swamped by revenue. We are minimising net spend so we want the most negative value)

iii. The ranked value of the objective function as estimated by our final regression model (pleasingly, the best 4 runs ranked on actual values are also ranked 1 to 4 on the regression model).

The recommended levels for the policy variables are in the column headed "1L068" and we will now comment on these values.

(A1, A2, A3 A4) We have found it best to offer no subsidy for purchase of PiVs beyond 2011 (the earliest year in which we were permitted to abandon it) and, until that date, to offer no more than the minimum (i.e. the existing level) – the cost of this subsidy would have been greater than the value of consequential saving in emissions and was not required to meet the 2050 emissions target.

(A5, A6, A7, A8) We found no net gain from offering a subsidy only to BEVs in place of that for all PiVs – again, the cost of this subsidy would have been greater than the value of consequential saving in emissions and was not required to meet the 2050 emissions target.

(B1, B2) We found it appropriate to leave eligibility for the company car tax incentive on tailpipe (rather than a well-to-wheel) emissions and but to make the limit more stringent. The superior performance of the more stringent limit suggests that companies respond by purchasing vehicles which fall within the more stringent limits.

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[18] Other runs were specified, and provided, for other scenarios but, in line with instructions from MEDAG, optimisation was not conducted for any scenarios other than the base.

[19] Note that, following correction to an error in the CRM after completion of our optimisation work, our preferred run (1L068) had its E^{2050} recomputed to 46.03, but that is still 46.0 to one decimal place.

Table 9: Values of policy levers in the optimal run and in other specified runs

Policy levers	1L068	1L076	1L164	1L172	1L000	T0
A. Subsidy on purchase of PiVs						
A1. Max budget for subsidy (£m)	na	na	na	na	na	43
A2. End yr for PiV subsidy	11	11	11	11	11	11
A3. Max subsidy per PiV %	0	0	0	0	0	25
A4. Max subsidy per PiV (£k)	0	0	0	0	0	5
A5. End yr for BEV-only subsidy	0	0	0	0	0	0
A6. Max subsidy per BEV (%)	0	0	0	0	0	0
A7. Max subsidy per BEV (£k)	0	0	0	0	0	0
B. Company car tax treatment						
B1. Tighter limit on tax benefit for companies' LEV purchases?	Y	Y	Y	Y	Y	
B2. Tax treatment of PiVs as company cars based on WTW (rather than tailpipe) emissions?						
C. VAT						
C1. Set domestic electricity rate at 20%?	Y	Y	Y	Y	Y	
D. VED						
D1. Multiplier relative to base VED rates	2	2	2	2	2	1.0
D2. VED based on WTW (rather than tailpipe) emissions?	Y	Y	Y	Y	Y	
E. Fuel tax						
E1. Multiplier on current rates	1.5	1.5	1.5	1.5	1.5	1.0
E2. Relating all fuel taxes to their emissions relative to petrol?						
E3. Recovering any reductions in fuel tax by a fee per vehicle?						Y
E4. Recovering any reduction from fuel tax by a usage charge?	Y	Y	Y	Y	Y	
F. Congestion charges						
F1. Extend charging to all major cities?					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
G2. Charge points are R.As ?						
G3. Network intelligence is an R.A.?	Y	Y	Y	Y	Y	Y
H. Charge point incentives						
H1. Initial deployment multiplier	2	2	2	2	2	1.0
H2. Level of capital grants 2013-2015	0	0	0	0	0	0
H3. Is tax write-off available?						Y
H4. Maximum electricity price premium factor	1	1	1	1	1	1
H5. Excess provision coefficient	1.3	1.3	1.5	1.5	1.15	1
H6. Does government cover shortfall beyond 2013?	Y	Y	Y	Y	Y	
J. Average fleet emissions regulations						
J1. Emission level limit in 2050	30	30	42	42	30	42
J2. Measurement ton WTW (rather than tailpipe) emissions?	Y	Y			Y	
Co2 emissions in 2050 (Mt)	45.94	45.96	45.91	45.94	45.91	47.75
Value of objective function (bns of £)	-844.5	-844.4	-843.5	-843.4	-843.0	-693.1
Rank according to regression model	1	2	3	4	12	

(C1) Unsurprisingly, we find it best to raise the rate of VAT on domestic electricity to 20% - this brings in additional revenue from electricity used to feed PiVs.

(D1, D2) Unsurprisingly, we find it best to raise VED rates as high as is permitted (i.e. to double them) – thus generating significant revenue and, with the rates based on well-to-wheel emissions, helping to persuade people to purchase lower emitting vehicles.

(E1) Unsurprisingly, we find it best to raise fuel duty as high as is permitted (i.e. to raise it by 50%) – thus generating significant revenue and helping to dissuade people from purchasing or using petrol and diesel vehicles – particularly those models with low mpg.

(E2) Basing fuel duties on average emissions per litre (pro rata with petrol) was found to have no significant effect on the objective function.

(E3, E4) The introduction of a revenue preserving tax (designed to replace any fuel duty receipts lost due to migration from conventional fuels) was found to be most effective when charged as a per-km charge (rather than as a per-vehicle charge). Note that, the regression model coefficients indicate that costs to the Exchequer would be minimised with fee per vehicle, but this was found to result in the 2050 CO_2 target being exceeded – thus the additional cost to the Exchequer was warranted.

(F1, F2) We did not find it appropriate to extend congestion charging beyond London but we did remove the exemption for non-PiV LEVs. Our explanation of these decisions has three components:

The Exchequer does not receive the congestion charge revenue (as per statement on “additivity of Road charging revenues” more than a decade ago) so have no "major" reason to extend CC to other cities

Extension beyond London reduces emissions but we are already below target and the further saving in emissions is worth less than loss in VED revenue - whether or not the “restrict exemptions” lever is activated.

(G1, G2, G3) Unsurprisingly, we concluded that Network Reinforcement and Network Intelligence should be treated as regulated assets (had they not been, the business model for installation of charge points would have collapsed – or the Exchequer would have had to provide a significant subsidy to the installers). Although the cost to the Exchequer might have been reduced and/or the supply of charge points increased, by designating charge points as regulated assets, it was thought unrealistic to do so.

(H1) We found it advantageous to double the initial deployment of charge points – despite the costs that this generates for the Exchequer. This result reflects the fact that, according to the CRM, the deployment of an adequate number of public charge points is crucial to the uptake of PiVs.

(H2, H3) Since we meet the financial shortfall directly (see H6, later), we do not give grants or tax write-offs.

(H4) We find it appropriate to set the factor controlling the maximum price of electricity at its highest level (1.0)[21] – any lower level would have reduced the profitability of charge points, thus damaging the business case and resulting in reduced deployment.

(H5, H6) We found it appropriate to have government willing to meet any shortfall in revenues from non-domestic charge points installed (subject to the number installed in any year not being more than 30% greater than the minimum number required to maintain a minimum level of service). This result, with its significant financial cost to the Exchequer, is a further testimony to the fact that, according to the CRM, maintenance of a generous supply of non-domestic charge points is crucial to the uptake of PiVs and thereby achieving the 2050 emissions target. (The regression model indicated that cost to the Exchequer would be minimised if the government did not underwrite any financial shortfall – or if it did, with new installations being based on achieving 0.78 of the minimum level of service – but adoption of these values would have resulted in the 2050 CO_2 emissions target being missed. Similarly, it was clear that 2050 emissions could be further reduced if the minimum level of service factor was higher than 1.3, but the cost to the Exchequer would be higher).

(J1, J2) We set the 2050 fleet emission limit at 30g/km well-to-wheel. The superior performance of the well-to-wheel scale is presumably due to the fact that it provides a better-targeted incentive to manufacturers to promote purchase of low-emitting vehicles. Interestingly, the regression model indicated that a 43.61 g/km limit would reduce net cost to the Exchequer (it would do so because, in the absence of a stringent limit, VED receipts would be increased). However, such a lax limit would lead to an overshoot of the 2050 CO_2 emissions target. We should also note that, in several runs (1L164 for example), an actual outturn almost as good as our optimum can be had by setting H5=1.5 (further away from our regression model) and J1= 42 (closer to our regression model) but, as discussed above, our purpose in departing from our regression model is to meet the 2050 target, and that is surely better done by setting a stringent 2050 limit rather than providing 50% more Charge Points than required – over a period of 41 years.

Finally, it is worth drawing attention to some features of the runs which performed well but not as well as the "optimal" run. Table 10 shows the settings and outcome for the six policy packages which came closest to the optimal run.

The second best (1L076) differs from the optimal package only in that it does not end exemptions to congestion charges in 2015 (this reduces Exchequer income below that in the optimal run).

The third best (1L164) differs from the optimal package only in that it increases the level of provision of charge points from 1.3 to 1.5 (increasing Exchequer expenditure above the level in the optimal run but encouraging PiV uptake), and moving from a fleet emissions target based on well-to-wheel emissions to one based on tailpipe emissions (reducing the PiV uptake somewhat).

The fourth best (IL172) differs from the third best only in that it does not end exemptions to congestion charges in 2015 (thus reducing Exchequer income compared to the third best run).

The fifth best (IL000) differs from the optimal package only in that it extends congestion charging to other major cities and in that it reduces the "over" provision of charge points from 1.3 to 1.15 (the former causes the Exchequer to lose revenue but reduces emissions the latter makes up for some of the lost revenue but takes the emissions back up).

Note that the base policy (T0) is inferior to all these runs in respect of 2050 emissions and the objective function.

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[21] It can be argued that this is not really a policy lever – rather it reflects the public's willingness to pay a higher premium. Government could perhaps have a marginal effect on this willingness via publicity campaigns.

4.3 Results for the Optimal Policy Package

The following sections report the results of the optimal run using the same graphs and structure as for the themed scenarios in Section 3.

4.3.1 Summary indicators

Table 10 shows the summary indicators for the optimal run compared to the base policy run (T0). As can be seen, the share of PiVs is increased to 25.6% which is we have found to be the lowest share which can meet the agreed target of 46 Mt emitted in 2050. This 1.8 Mt reduction was achieved at least cost to the Exchequer and actually results in a significantly increased surplus revenue. Table 11 shows that net spend is reduced through removal of subsidies and reduced corporation tax, but most significant is the increased revenues to the Exchequer. This increase of £146 bn is achieved by setting the fuel duty, VED and VAT to their upper bounds in the optimisation process.

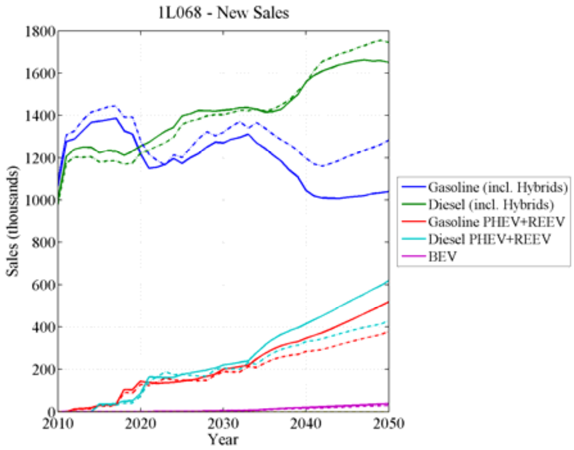
It should be noted that the net spend or surplus of £960 bn is higher than any surplus found among the themed scenarios. This reflects the fact that the agreed objective function means that the value to the Exchequer of a non-PiV driving around with high fuel duty and high VED is higher than the value placed on the emissions associated with such a vehicle. This resulted in us having to apply a penalty term or constraint on the emissions in 2050 via the target, which in turn resulted in the optimal strategy as described above which effectively finds the "least cost" way of meeting the emissions target in 2050. The "least cost" approach includes several measures which bring in more money to the Exchequer.

Table 10 : Summary indicators for the optimal policy package

Theme	2050 values							Values for the entire period (2210-2050) discounted at 3.5% p.a.			
	PiV as % of Car Parc	BEV as % of Car Parc	Total Car Parc (m)	VKT (bn)	WTW emissions (Mt)	Production and scrappage emissions (Mt)	Total whole life emissions (Mt)	Total subsidy to all PiV purchases (£m	Total Exchequer Spend (£bn)	Total Exchequer Revenue (£bi)	Total Exchequer Net Spend (£bn)
Base Policy (T0)	19.4	0.6	45	453	25.4	22.4	47.8	11.4	5.0	817	-812
Optimal Policy Package	25.6	0.7	45	453	23.5	22.4	45.9	0.0	1.8	962	-961

4.3.2 Share of sales and parc

The pattern of sales and share is similar to that in the base policy run (T0) but the final share of PiVs in 2050 is much higher (25.6% compared to 19.4% in T0) including a marginally higher share of BEVs (0.7% c.f. 0.6%). The increase in the PHEV and REEV share is particularly marked in the later years (beyond 2025 and is largely at the expense of sales of gasoline vehicles (including the non-plug-in hybrid variants) for which the 2050 share is circa 33% compared to circa 39% in T0. Sales of diesel vehicles (including the non-plug-in hybrid variants) seem relatively unaffected – this is because the tighter emissions regulations favour the more efficient diesel market.



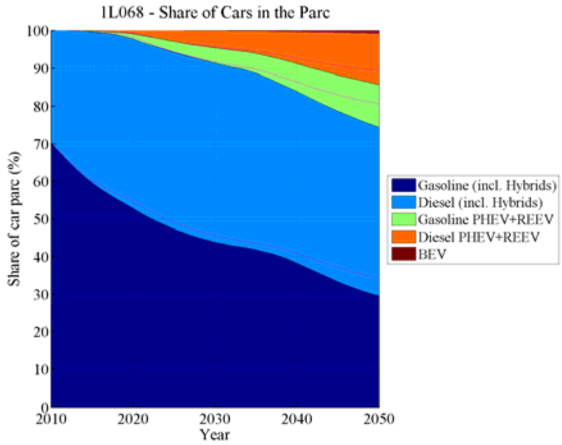


Figure 64 (a), (b) : Optimal run - Total new sales and share of cars in the parc

4.3.3 Charge point deployment and profit

A key feature of the optimal policy run is that the deployment of charge points is much greater than in the base policy run (T0). This begins in 2010, when the initial deployment of charge points is double that in T0, and continues in subsequent years. The higher on-going deployment is due to two factors; firstly, the increased PiV share brings an increase in electricity drawn which leads to a greater deployment of charge points, and secondly the deployment formula results in a deployment which is 1.3 times the manifest demand (c.f. 1.0 in T0). For these reasons, the total stock of public charge points in 2050 is 350 thousand (c.f. 136 thousand). The increase is particularly marked for on-street and in car-park charge points for which the 2050 stock is 2.5-2.6 times as in T0.

The net profit curves are different from T0 in that they show highly negative profits for car park and on-street charge points and negative notional profit for workplace charge points. Negative profits would normally result in no charge points being installed but is possible in this scenario because the government is picking up any shortfall in revenue. The notional profit for retail charge points is reduced – though still positive.

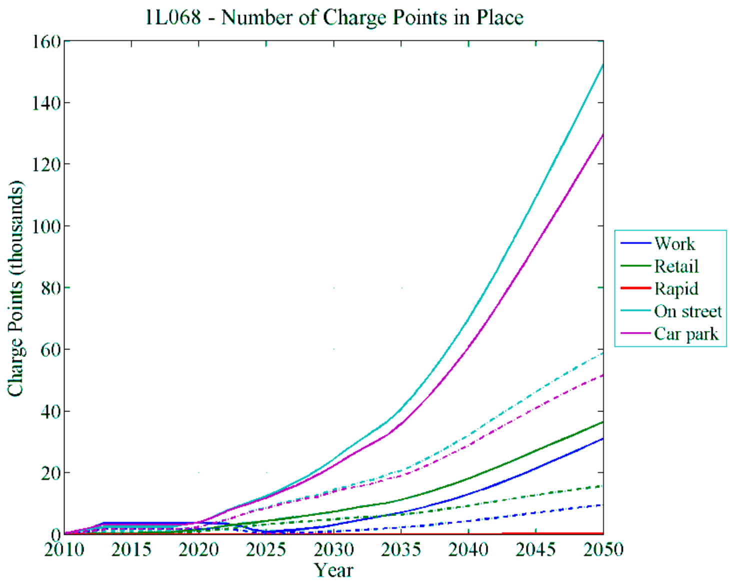


Figure 65 : Number of charge points in place : optimal run

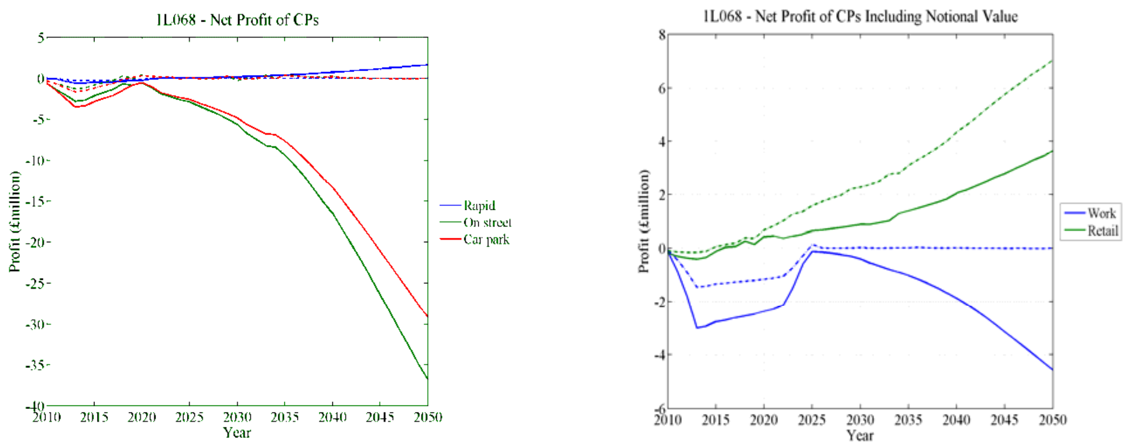


Figure 66 a,b : Net profit and notional profit for charge points : optimal run

4.3.4 Exchequer spend and revenue

In terms of spend, the first thing to note is that the absence of purchaser subsidies in the optimal policy run saves money compared to the base policy run (T0). Secondly the spike in corporation tax which was apparent in T0 replaced by a more variable profile across the whole time period. The third key change in spending is in respect of the subsidy to charge point installers associated with the requirement on the government to meet any shortfall in charge point costs. This subsidy rise steadily over the period to around £70m p.a. by 2050.

The overall expenditure is £3.2 bn (64%) lower than in T0 despite the requirement to meet any shortfall on charge point deployment. As only £11m is saved in PiV subsidy requirements the savings appear to come from changes in corporation tax where the write off allowance and purchase tax for company cars is now based on well to wheel rather than tailpipe emissions. With the well to wheel tax basis, more vehicles including PiVs are required to pay more tax as the zero rate is no longer available and more vehicles will fall into the highest tax band. The resulting profile is peaked where new model types with lower well to wheel emissions become available.

The overall revenues to the Exchequer are some £146 bn (17.8%) higher than in T0. This increase is due firstly to the increased fuel duty receipts in the early years (fuel duty is increased by 50%), though in later years this is offset by a lower revenue preserver fee. Secondly, VAT receipts are slightly higher due to the increase in rates applied to electricity used for recharging vehicles (and to the increased number of PiVs). Thirdly, and most significantly, the VED receipts per vehicle are more than double those in T0 (the 2010 average receipt per vehicle is £352 c.f. £125 in T0). This increase, due to the doubling in VED rates and moving from tailpipe to WTW ratings, declines over the years but is still apparent in 2050 when the average VED receipt per vehicle is £151 compared to £98 in T0. The rates are less than double those in T0 in 2050 because of the larger shift to PiVs which attract lower VED.

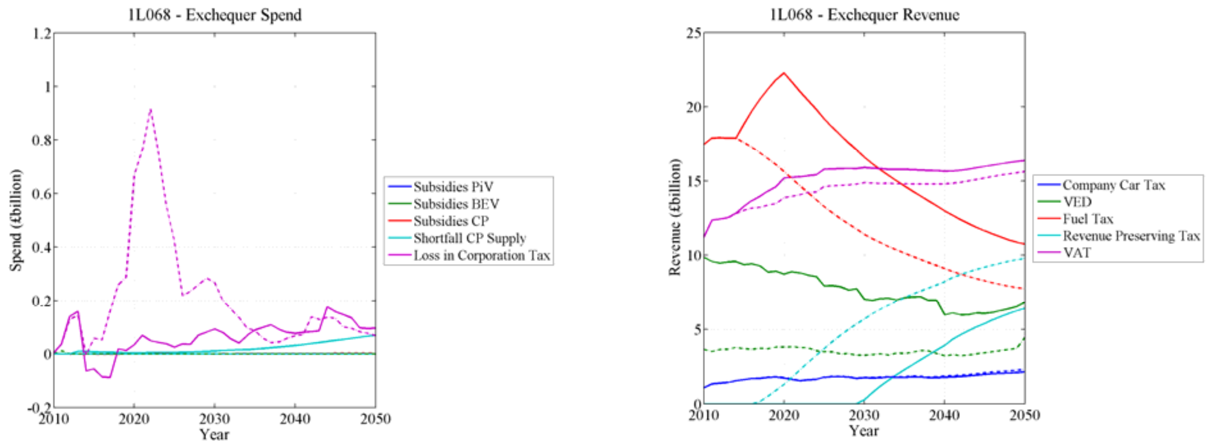


Figure 67 a,b : Exchequer spend and revenues : Optimal run

4.3.5 Emissions

The optimal policy run was designed to meet the target of 46 Mt in 2050. The target is achieved thanks to a reduction in emissions from non-PiVs despite a slight increase in emissions from PiVs. The main contributor to the overall reduction is the increased share of PiVs and other LEVs in the final fleet. The effect of the tighter emissions regulations are apparent in the fact that the new car average emissions in 2050 are 46.7 g/km in the optimal run compared to 50.0 g/km in the base policy run (T0).

All the savings are due to a reduction in emissions associated with vehicle use. Emissions associated with vehicle production and scrappage are, at 22.4 Mt, almost the same as for T0 – unsurprisingly because the parc size and sales are the same as for the base. Ignoring emissions associated with production and scrappage, the optimal run achieves emissions of 23.6 Mt – which does not meet the 16.34Mt target for usage-only emissions but is closer to it than the 46Mt is to the 19.14 Mt target for all emissions.

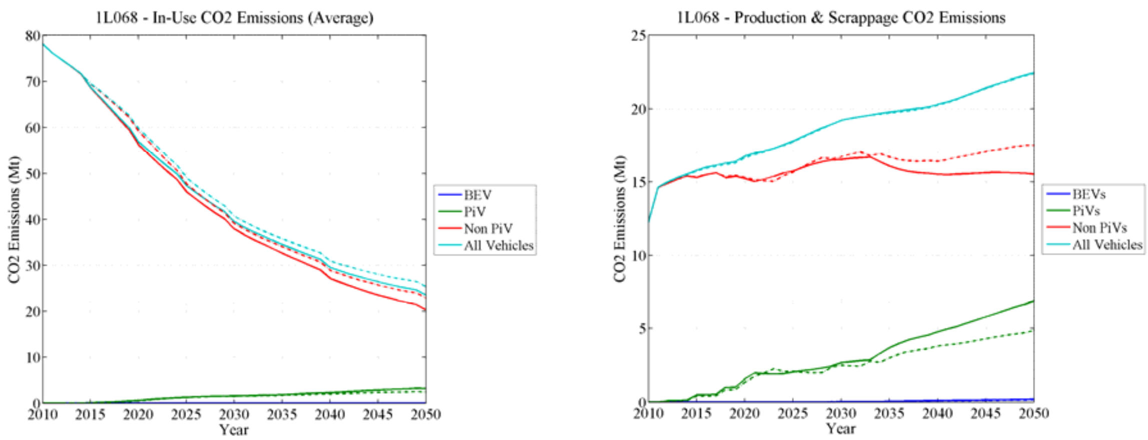


Figure 68 (a), (b) : In use and production and scrappage emissions T12.

5 The Sensitivity Analyses

5.1 Introduction

The overall project has developed a number of models and datasets to address a range of issues of importance to the ETI. For example there are models and datasets to predict:

- The likely attributes of vehicles of different types over the modelling period;
- The cost of charge points of different types in different locations; and
- Consumer purchase decisions given different vehicle attributes.

SP3 has combined the models and datasets developed in the overall project to investigate the performance of the overall system. The overall system is rather complex, so sensitivity analyses have been carried out in order to:

- Better understand the behaviour of the overall system and the interaction between the individual models;
- Identify those variables with the biggest effect on the overall system; and
- Identify areas where the model is limited or further work is considered to be required in order to reduce uncertainty.

The sensitivity analyses test the effect of different values of each input variable while holding the value of all other variables at their base levels. Some variables are considered to vary together, either because the variable being changed has dependent variables or because it requires a change in another variable to make sense, and the sensitivity tests reflect this.

One hundred and three sensitivity analyses were carried out. These analyses are summarised in the Appendix B and are fully defined in the Scenarios Development Final Report (WS3/ARUP/10).

5.2 Overview of Results of Sensitivity Runs

This section provides an overview of the most important variables and examines them in more detail. Summary results of the sensitivity analyses are given in Table 11 and in Figures 69 to 72. Full results are available in the addendum document - their inclusion in the current document would have made it too unwieldy.

To provide an overview of the changes in each sensitivity analysis relative to the base case the values of four outputs of the model in 2050 are considered:

- PiV (and BEV) % of UK car parc in 2050;
- Total number of charge points installed in 2050;
- Whole life emissions in 2050 calculated on an average basis; and
- Exchequer spend between 2010 and 2050.

For each sensitivity analysis the percentage change in these indicators relative to the base case is calculated as below.

$$\%Change = \frac{(SensitivityAnalysisValue - BaseCaseValue)}{BaseCaseValue}$$

The maximum and minimum percentage changes are plotted in bar charts in Figures 69 to 72. The sensitivity analyses are grouped by variable: where a variable takes a high or low value these two sensitivity analyses are paired; where a variable takes many values, for example the implementation of fleet average emissions legislation, all the associated sensitivity analyses are grouped.

Examination of Table 11 and of Figures 69 to 72 indicates that the most significant changes in the output indicators are caused by following the variables:

- Consumer attitude to the idea of PiVs
- Elasticity of car use with running costs
- Lower proportion of charging takes place at home
- Fixed charge point deployment
- Charge point level of service
- Regulated asset status of charging infrastructure
- Free electricity at workplace and retail charge points
- Likely utilisation of charge points
- PiV purchase allowances
- Stringent criteria for PiV capital allowances
- Fleet average emissions legislation
- Upfront vehicle prices
- Residual value and average life expectancy
- Vehicle showroom maximally favourable to PiVs
- UK vehicle parc and vehicle kilometres travelled.

Section 5.3 will deal in somewhat more detail with the results for "families" of tests: Consumer behaviour, Charge point supply, Electricity Generation, Electricity Price, Government Policy, Vehicle showroom and UK GDP.

Table 11 Key indicators for each sensitivity analysis

(the percentage change relative to the base case given in brackets and the 10 most significant changes for each indicator are highlighted. See Appendix for test definitions)

		% of Car Parc in 2050		Total Charge Points Installed in 2050 ('000s)	In-use Emissions in 2050 (Mt)	Total Exchequer Spend 2010 to 2050 (£bn)
		BEV	PiV			
Consumer Behaviour Tests	CB1	1.5 (147.8)	18.4 (-4.9)	122.2 (-10.1)	1879 (1.5)	4.79 (-4.9)
	CB2	0.6 (3.3)	20.2 (4.2)	157.3 (15.6)	1901 (1.8)	5.16 (2.6)
	CB3	0.7 (10.3)	20.5 (6.2)	138.3 (1.7)	1886 (-0.9)	4.27 (-15.1)
	CB4	0.1 (-78.3)	11.0 (-43.4)	49.2 (-63.8)	1905 (4.8)	4.95 (-1.7)
	CB5	3.3 (461.7)	35.1 (81.3)	426.1 (213.4)	1847 (-8.9)	5.29 (5.1)
	CB6	1.8 (211.2)	21.5 (11.1)	171.7 (26.3)	1884 (-1.7)	5.04 (0.2)
	CB7	0.3 (-43.1)	18.8 (-2.7)	127.0 (-6.6)	1888 (0.4)	5.03 (-0.2)
	CB8	1.2 (98.4)	20.0 (3.4)	150.5 (10.6)	1886 (-0.5)	5.04 (0.2)
	CB9	0.6 (10.2)	20.3 (4.8)	132.7 (-2.4)	1894 (-1.4)	4.95 (-1.6)
	CB10	0.5 (-9.4)	18.7 (-3.5)	149.5 (9.9)	1874 (1.4)	5.17 (2.8)
	CB11	0.6 (6.4)	17.0 (-12.4)	77.5 (-43.0)	1890 (1.3)	5.01 (-0.4)
	CB12	0.6 (-1.3)	20.7 (7.1)	172.5 (26.8)	1887 (-0.6)	5.04 (0.2)
	CB13	0.6 (-2.8)	18.7 (-3.6)	111.1 (-18.3)	1802 (-5.2)	5.03 (-0.1)
	CB14	0.7 (26.8)	34.2 (76.5)	840.6 (518.2)	1863 (-7.2)	5.24 (4.2)
	CB15	0.6 (0.8)	18.7 (-3.2)	93.6 (-31.2)	1889 (0.4)	5.02 (-0.2)
	CB16	0.6 (-2.1)	18.9 (-2.5)	117.0 (-14.0)	1888 (0.4)	5.03 (-0.1)
Charge Point Supply Tests	CP01	0.6 (9.9)	21.4 (10.6)	95.8 (-29.5)	1883 (-0.9)	5.05 (0.3)
	CP02	0.5 (-11.2)	17.9 (-7.7)	221.5 (62.9)	1893 (0.7)	5.02 (-0.2)
	CP03	0.8 (42.8)	49.1 (153.7)	2410.0 (1672.3)	1753 (-15.2)	46.55 (824.9)
	CP04	0.8 (33.2)	41.0 (111.9)	1205.0 (786.2)	1819 (-10.8)	24.88 (394.3)
	CP05	0.7 (13.2)	28.6 (47.6)	602.5 (343.1)	1861 (-4.3)	14.79 (193.8)
	CP06	0.6 (0.0)	19.4 (0.0)	136.2 (0.1)	1888 (0.0)	5.03 (0.0)
	CP07	0.6 (0.0)	19.4 (0.0)	136.1 (0.1)	1888 (0.0)	5.03 (0.0)
	CP08	0.6 (4.3)	20.5 (6.1)	182.2 (34.0)	1886 (-0.7)	5.21 (3.5)
	CP09	0.6 (1.1)	19.6 (1.3)	142.3 (4.7)	1887 (-0.1)	5.04 (0.0)
	CP10	0.6 (-4.5)	18.3 (-5.5)	111.0 (-18.4)	1889 (0.6)	5.03 (-0.2)
	CP11	0.6 (0.1)	19.4 (0.1)	136.6 (0.4)	1888 (0.0)	5.08 (0.9)
	CP12	0.7 (11.9)	25.2 (30.0)	450.9 (231.6)	1882 (-2.9)	6.15 (22.1)
	CP13	0.6 (1.7)	21.2 (9.6)	241.0 (77.2)	1881 (-0.8)	8.77 (74.2)
	CP14	0.5 (-10.7)	16.0 (-17.4)	0.0 (-100.0)	1889 (1.5)	5.00 (-0.7)
Electricity Generation	EG1	0.6 (7.9)	19.7 (2.0)	139.0 (2.2)	1841 (-3.3)	5.05 (0.3)
	EG2	0.6 (-5.4)	18.5 (-4.4)	99.8 (-26.6)	1906 (1.6)	5.02 (-0.2)
	EG3	0.6 (-1.0)	19.3 (-0.4)	135.3 (-0.5)	1890 (0.5)	5.03 (0.0)
	SA01	0.6 (0.0)	19.3 (0.0)	136.0 (0.0)	1888 (0.0)	5.03 (0.0)
	SA02	0.6 (0.0)	19.4 (0.0)	136.0 (0.0)	1888 (0.0)	5.03 (0.0)
	SA03	0.6 (0.0)	19.4 (0.1)	229.3 (68.6)	2652 (88.3)	5.03 (0.0)
	SA04	0.6 (-1.0)	19.3 (-0.4)	135.4 (-0.5)	1890 (0.5)	5.03 (0.0)
	SA05	0.6 (-5.5)	18.4 (-4.7)	181.6 (33.6)	2664 (89.4)	5.02 (-0.2)

Table 11 (continued)

		% of Car Parc in 2050		Total Charge Points Installed in 2050 ('000s)	In-use Emissions in 2050 (Mt)	Total Exchequer Spend 2010 to 2050 (£bn)
		BEV	PiV			
Electricity Price Tests	EP1	0.6 (-2.2)	18.4 (-4.9)	94.6 (-30.4)	1888 (0.5)	5.03 (0.0)
	EP2	0.6 (0.0)	19.4 (0.0)	136.3 (0.2)	1888 (0.0)	5.02 (-0.2)
	EP3	0.6 (-0.7)	19.3 (-0.5)	134.9 (-0.8)	1887 (0.1)	5.05 (0.3)
	EP4	0.6 (-0.5)	19.3 (-0.1)	135.5 (-0.3)	1888 (0.0)	5.02 (-0.3)
	EP5	0.6 (0.1)	19.4 (0.1)	136.6 (0.4)	1888 (0.0)	5.02 (-0.3)
	EP6	0.5 (-10.6)	16.0 (-17.2)	5.1 (-96.2)	1892 (1.9)	5.00 (-0.7)
	EP7	0.6 (0.0)	19.3 (0.0)	136.0 (0.0)	1888 (0.0)	5.04 (0.0)
	EP8	0.6 (-0.5)	19.3 (-0.2)	135.8 (-0.1)	1888 (0.0)	5.02 (-0.3)
	EP9	0.6 (0.0)	19.4 (0.0)	136.0 (0.0)	1888 (0.0)	5.03 (0.0)
	EP10	0.6 (-3.5)	18.0 (-6.8)	84.1 (-38.2)	1889 (0.7)	5.02 (-0.3)
	EP11	0.7 (26.1)	44.5 (130.0)	1360.4 (900.4)	1832 (-12.4)	5.40 (7.4)
	EP12	0.6 (0.0)	19.3 (0.0)	136.0 (0.0)	1888 (0.0)	5.03 (0.0)
	EP13	0.6 (0.0)	19.3 (0.0)	135.9 (0.0)	1888 (0.0)	5.03 (0.0)
	EP14	0.5 (-9.9)	16.2 (-16.1)	21.8 (-83.9)	1891 (1.7)	5.00 (-0.6)
	EP15	0.6 (8.4)	24.2 (24.8)	398.9 (193.4)	1883 (-2.3)	5.09 (1.1)
	EP16	0.6 (0.9)	19.4 (0.5)	137.4 (1.0)	1887 (-0.1)	5.04 (0.0)
	EP17	0.6 (-1.2)	19.2 (-0.6)	134.7 (-1.0)	1888 (0.1)	5.03 (0.0)
Government Policy Tests	P1	0.6 (0.0)	19.3 (0.0)	136.0 (0.0)	1888 (0.0)	5.02 (-0.2)
	P2	0.6 (0.1)	19.4 (0.1)	136.5 (0.4)	1886 (0.0)	6.35 (26.2)
	P3	0.6 (0.7)	19.5 (0.9)	139.8 (2.8)	1882 (-0.1)	8.84 (75.6)
	P4	0.6 (1.3)	19.9 (2.7)	149.8 (10.1)	1876 (-0.2)	14.90 (196.0)
	P5	0.6 (0.1)	19.4 (0.2)	136.9 (0.6)	1886 (0.0)	6.43 (27.8)
	P6	0.6 (1.1)	19.8 (2.4)	141.2 (3.9)	1886 (-0.5)	0.86 (-82.9)
	P7	0.6 (-2.5)	18.8 (-2.8)	128.8 (-5.3)	1889 (0.4)	5.02 (-0.2)
	P8	0.6 (-3.1)	18.8 (-2.9)	120.9 (-11.1)	1889 (0.4)	5.03 (-0.1)
	P9	0.6 (8.1)	19.4 (0.5)	139.4 (2.5)	1813 (-2.1)	5.03 (-0.1)
	P10	0.6 (-0.4)	19.7 (1.6)	138.2 (1.7)	1882 (-0.6)	5.07 (0.7)
	P11	0.6 (0.3)	19.4 (0.4)	137.5 (1.1)	1887 (-0.1)	5.03 (0.0)
	P12	0.5 (-9.2)	17.7 (-8.5)	84.8 (-37.7)	1924 (2.0)	5.01 (-0.5)
	P13	0.6 (6.7)	19.6 (1.2)	137.1 (0.8)	1811 (-2.5)	5.05 (0.3)
	P14	0.6 (0.0)	19.3 (0.0)	136.0 (0.0)	1888 (0.0)	5.03 (0.0)
	P15	0.6 (0.0)	19.3 (0.0)	136.0 (0.0)	1888 (0.0)	5.03 (0.0)
	P16	0.6 (-1.1)	19.2 (-1.0)	129.2 (-5.0)	1862 (-2.3)	5.03 (0.0)
	P17	0.6 (-2.7)	19.1 (-1.4)	222.4 (63.5)	2650 (88.3)	5.03 (-0.1)
	P18	0.6 (7.4)	21.5 (11.0)	160.3 (17.9)	1881 (-1.0)	5.08 (0.9)
	P19	0.7 (15.7)	22.3 (15.5)	197.8 (45.5)	1866 (-2.2)	5.09 (1.1)
	P20	0.4 (-40.5)	14.2 (-26.6)	75.0 (-44.9)	1907 (4.8)	4.99 (-0.8)
	P21	0.6 (1.5)	19.5 (0.7)	136.1 (0.1)	1888 (-0.4)	5.03 (-0.2)

Table 11 (continued)

		% of Car Parc in 2050		Total Charge Points Installed in 2050 ('000s)	In-use Emissions in 2050 (Mt)	Total Exchequer Spend 2010 to 2050 (£bn)
		BEV	PiV			
Vehicle Showroom Tests	S1	0.5 (-14.9)	14.5 (-25.2)	89.6 (-34.1)	1895 (2.8)	5.09 (1.1)
	S2	0.6 (2.5)	23.8 (22.7)	184.1 (35.4)	1881 (-2.1)	4.92 (-2.2)
	S3	0.5 (-18.4)	19.1 (-1.5)	130.6 (-4.0)	1889 (0.2)	5.05 (0.3)
	S4	0.7 (21.9)	19.6 (1.2)	142.4 (4.7)	1886 (-0.1)	5.02 (-0.4)
	S5	0.6 (-4.2)	18.5 (-4.5)	127.8 (-6.0)	1889 (0.5)	5.03 (-0.1)
	S6	0.6 (2.5)	20.1 (4.1)	144.6 (6.4)	1886 (-0.3)	5.04 (0.1)
	S7	0.6 (2.0)	20.0 (3.2)	151.0 (11.1)	1882 (-0.4)	5.01 (-0.4)
	S8	0.5 (-12.2)	15.6 (-19.1)	94.7 (-30.4)	1896 (2.1)	5.15 (2.3)
	S9	0.6 (2.0)	19.5 (0.9)	138.3 (1.7)	1885 (-0.6)	5.04 (0.1)
	S10	0.6 (-2.8)	19.0 (-1.6)	129.8 (-4.6)	1890 (0.7)	5.03 (-0.1)
	S11	0.6 (1.1)	19.8 (2.2)	159.3 (17.2)	1887 (-0.2)	5.04 (0.1)
	S12	0.6 (-1.7)	18.9 (-2.6)	112.8 (-17.0)	1888 (0.3)	5.03 (-0.1)
	S13	0.8 (42.0)	20.0 (3.5)	168.6 (24.0)	1887 (-0.3)	5.04 (0.1)
	S14	0.4 (-30.2)	18.2 (-5.7)	100.1 (-26.4)	1889 (0.7)	5.02 (-0.2)
	S15	0.6 (8.1)	21.6 (11.4)	162.1 (19.2)	1884 (-1.3)	5.05 (0.3)
	S16	0.5 (-7.3)	17.3 (-10.4)	113.7 (-16.4)	1891 (1.1)	5.02 (-0.3)
	S17	0.6 (0.0)	19.3 (0.0)	136.0 (0.0)	1888 (0.0)	5.03 (0.0)
	S18	0.6 (0.0)	19.3 (0.0)	136.0 (0.0)	1888 (0.0)	5.03 (0.0)
	S19	1.2 (110.6)	31.5 (62.8)	428.5 (215.1)	1858 (-6.8)	4.87 (-3.2)
	S20	0.2 (-66.4)	8.3 (-57.2)	22.8 (-83.2)	1912 (7.0)	5.11 (1.6)
UK GDP Tests	UK1	0.6 (-5.3)	18.2 (-5.8)	114.9 (-15.5)	1942 (5.8)	6.51 (29.4)
	UK2	0.6 (6.2)	20.8 (7.3)	157.2 (15.6)	1823 (-9.0)	3.90 (-22.5)
	UK3	0.7 (15.6)	19.9 (2.9)	150.0 (10.3)	1885 (0.0)	5.04 (0.1)
	UK4	0.5 (-17.6)	18.6 (-3.7)	120.5 (-11.4)	1890 (0.0)	5.02 (-0.2)
	UK5	0.4 (-33.9)	18.1 (-6.5)	109.0 (-19.8)	1890 (-0.2)	5.02 (-0.2)

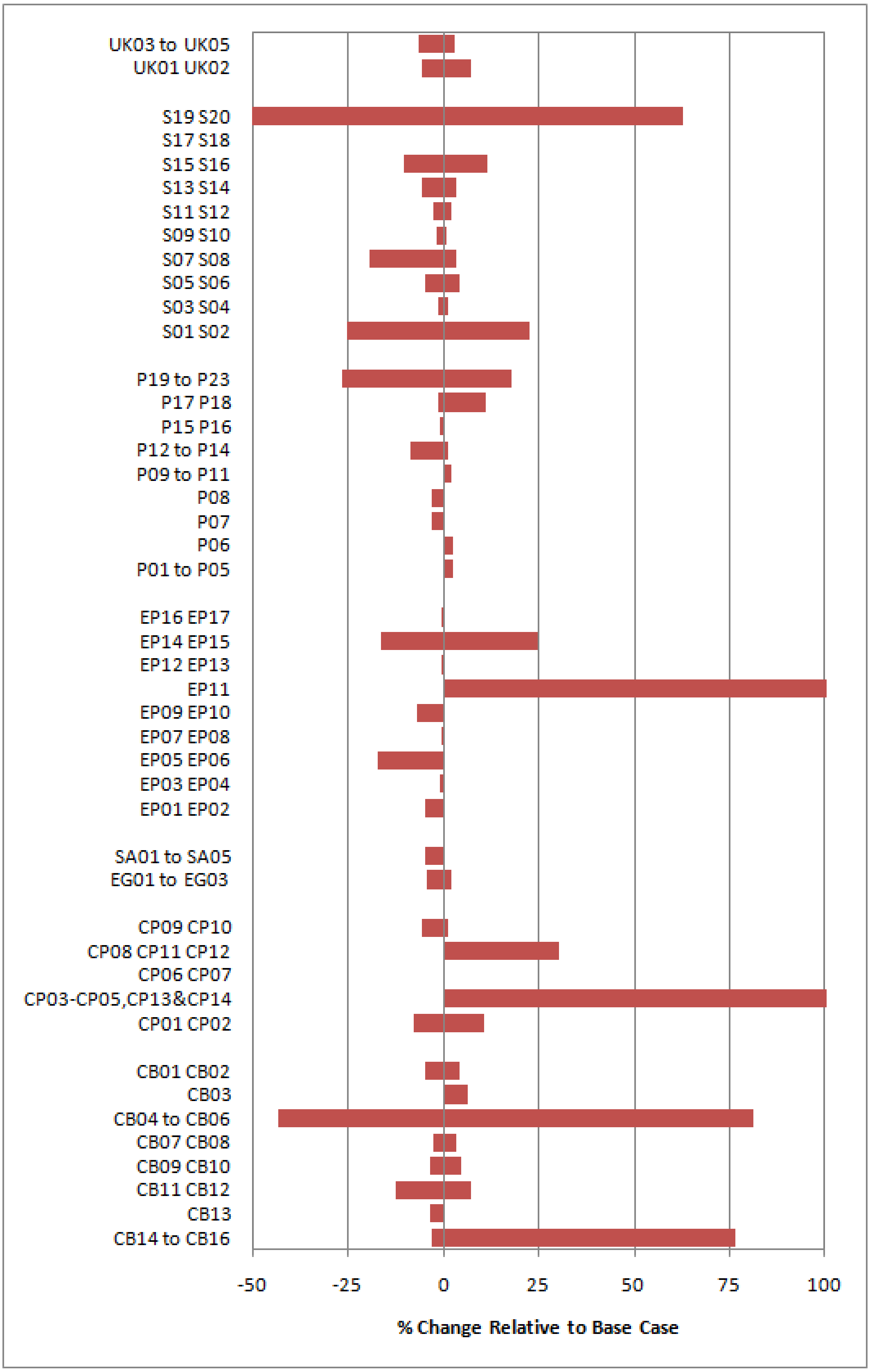


Figure 69 Range of variation of PiV as % of UK car parc in 2050 for different variables (y-axis truncated at +100%) See Appendix B for test definitions

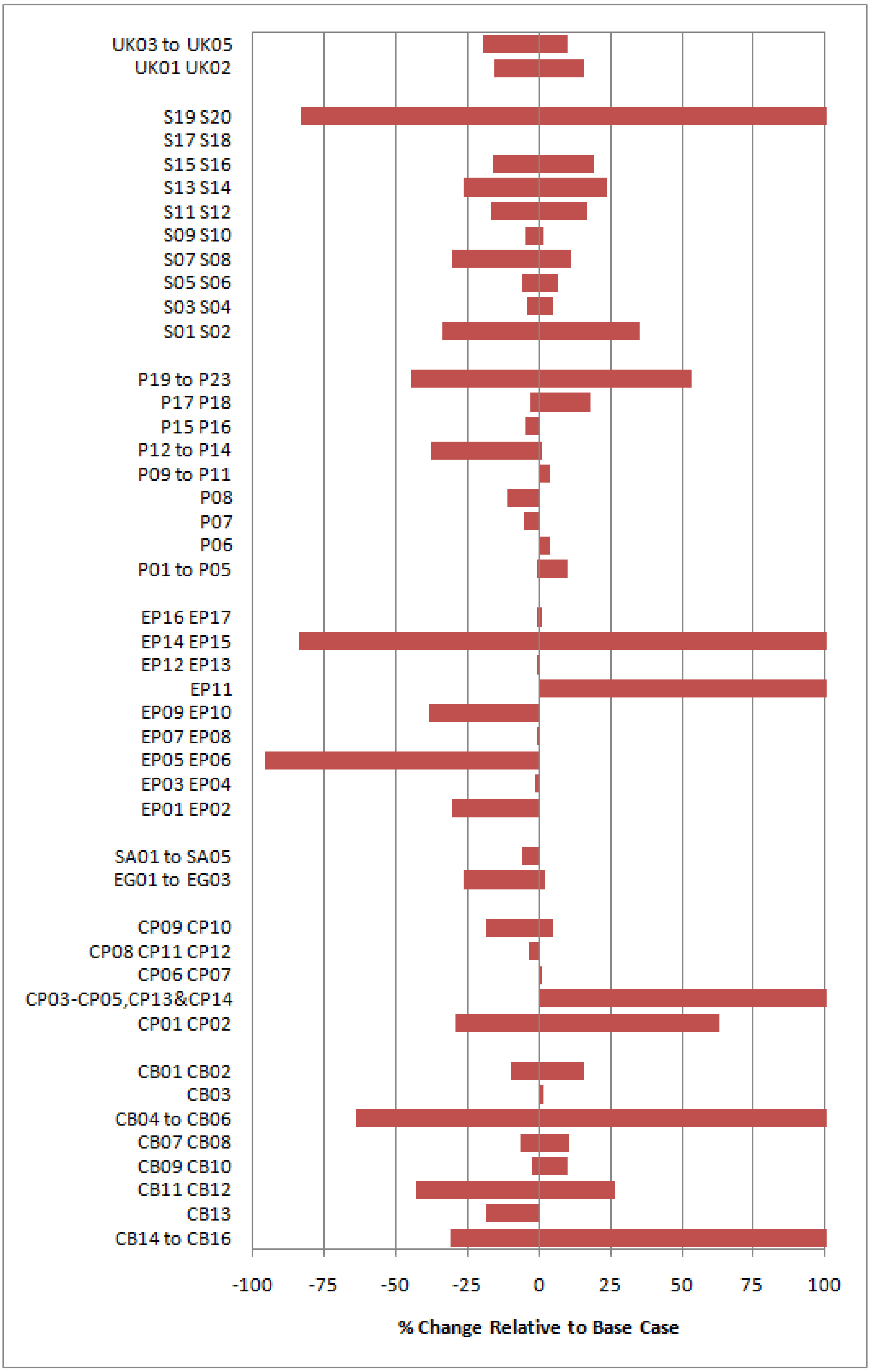


Figure 70 Range of variation of total charge points installed in 2050 for different variables (y-axis truncated at +100%, note CP03 to CP05 varies between +591% and +2662% so does not show on the graph) See Appendix B for test definitions

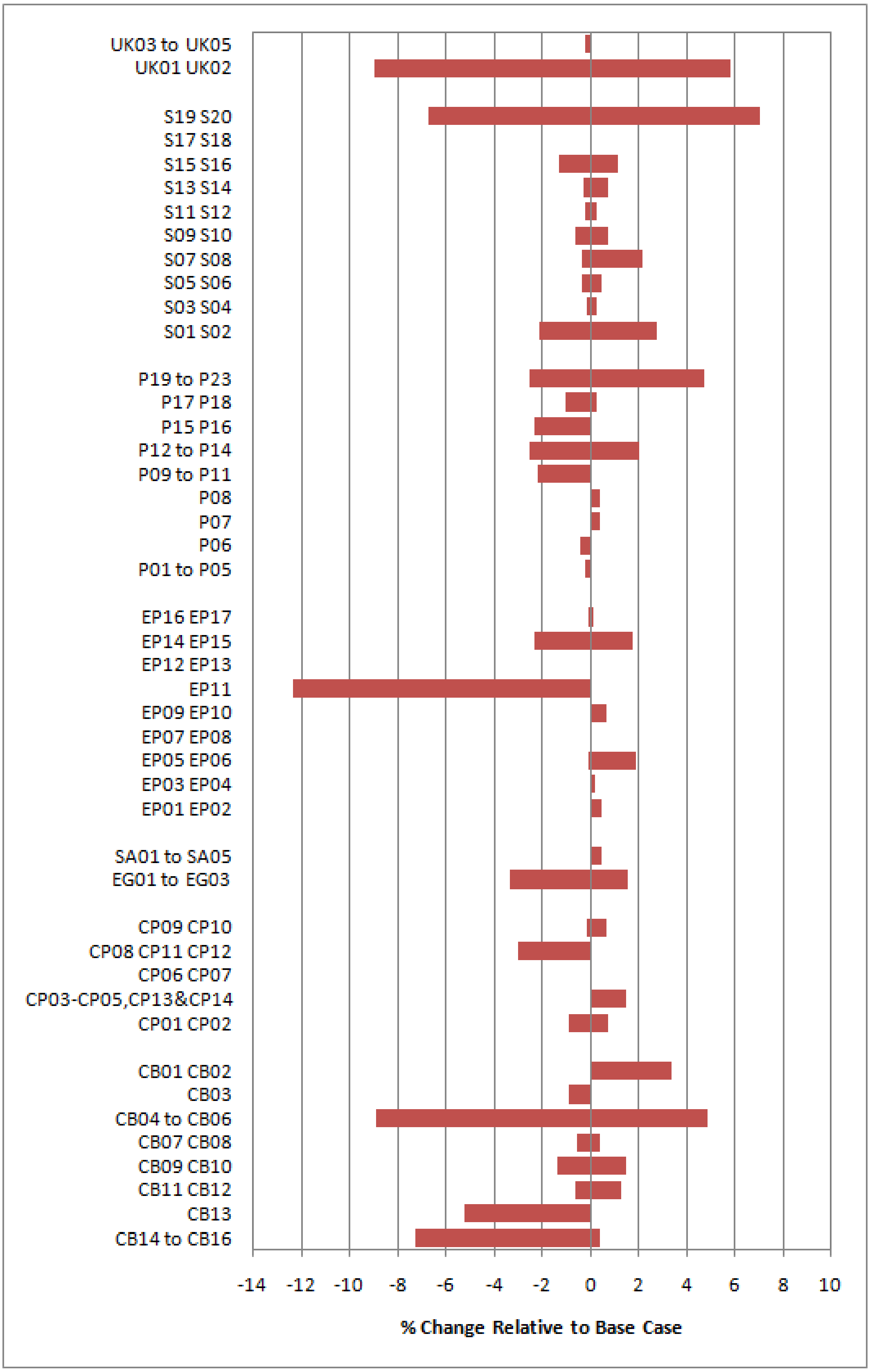


Figure 71 Range of variation of whole life emissions in 2050 for different variables
See Appendix B for test definitions

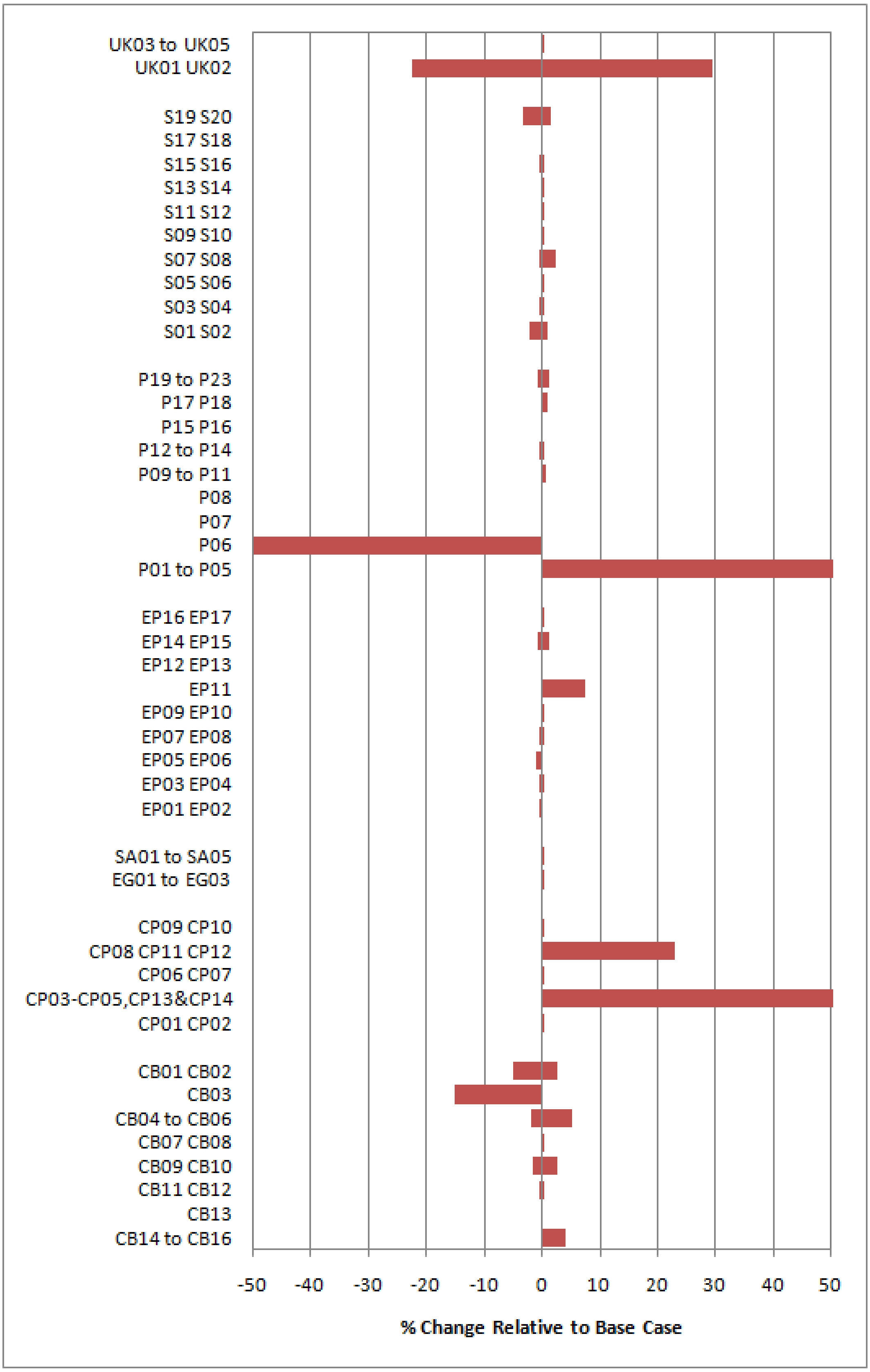


Figure 72 Range of variation of exchequer spend 2010 to 2050 for different variables (y-axis truncated at ±50%) See Appendix B for test definitions

5.3 Consumer Behaviour Tests

As is clear from Section 1 of Table 11, consumer behaviour has a strong effect on the outputs of the overall system, perhaps the greatest effect of all the categories of variables considered in the sensitivity analyses.

The most significant consumer behaviour issues are attitudes to the idea of PiVs and recharge behaviour.

Consumer attitudes to the idea of PiVs have been derived from consumer surveys. Whilst this is the best available data, there remains considerable uncertainty over how consumer attitudes will change with time, as PiVs become more commonplace.

Due to the scarcity of data on recharge behaviour this was based on expert opinion. Whilst there is widespread agreement that domestic recharging will dominate the market, the availability of non-domestic charge points was found to be important to consumer willingness to purchase a PiV in the consumer survey. Small changes in recharge behaviour can have significant effects on the deployment of non-domestic charge points and subsequently on consumer willingness to buy PiVs.

5.3.1 Consumer attitude to the idea of PiVs

Sensitivity analyses CB4, CB5 and CB6 test the effect of disutility of PiVs relative to conventional vehicles, i.e. a general bias against PiVs unaccounted for by the objective attributes of the vehicles.

Table 12 Effect of consumer attitudes to the idea of PiVs (% change relative to base case shown in brackets)

	Description	% of Car Parc in 2050		Total Charge Points Installed in 2050 ('000s)	In-use Emissions in 2050 (Mt)	Total Exchequer Spend 2010 to 2050 (£bn)
		BEV	PiV			
CB4	50% higher PiV disutility	0.1 (-78.3)	11.0 (-43.4)	49.2 (-63.8)	26.6 (4.8)	4.95 (-1.7)
CB5	50% lower PiV disutility	3.3 (461.7)	35.1 (81.3)	426.1 (213.4)	23.1 (-8.9)	5.29 (5.1)
CB6	PiV disutility starts at base case and decreases linearly to zero as PiV sales reach conventional vehicle sales	1.8 (211.2)	21.5 (11.1)	171.7 (26.3)	25.0 (-1.7)	5.04 (0.2)

Changing the disutility of PiVs directly affects sales (increased disutility results in fewer sales), with a greater effect on BEV sales than on PiV sales.

The change in PiV numbers has a knock-on effect on the number of charge points installed through two mechanisms.

The first mechanism is simply that an increased number of PiVs results in a proportional increase in demand for electricity (see Figure 73). However, the % change in charge point numbers is greater than the % change in PiV numbers. The amplification effect is due to the second mechanism.

The second mechanism relates to the annual reallocation of drivers to categories in the recharge behaviour look-up tables. If drivers are reallocated from categories that carry out a low proportion to categories that carry out a higher proportion of recharging at non-domestic charge points, then the average use of non-domestic electricity will increase and consequently demand for non-domestic charging will increase faster than PiV numbers. This is what happens in CB5 (see Figure 73).

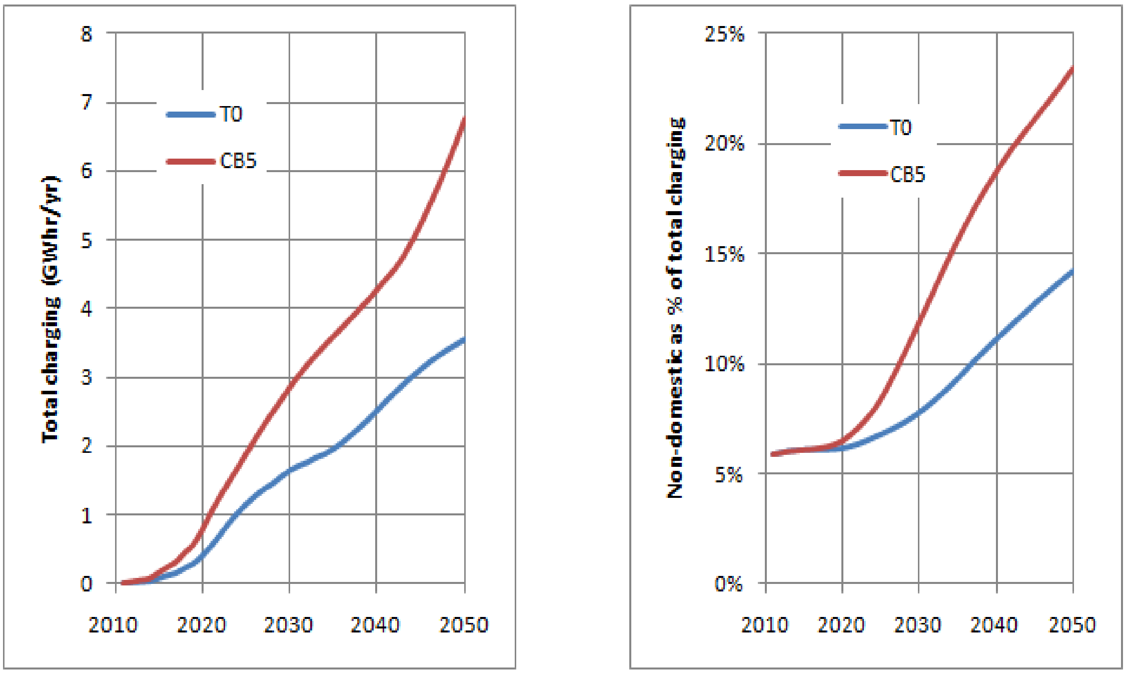


Figure 73 Comparison between total charging (left) and % non-domestic charging (right) for base case (T0) and CB5

The large changes in PiV numbers result in only moderate changes to in-use emissions, which may appear unexpected but is explained below.

As was noted in Section 2.4, the base case in-use emissions of PHEV/REEVs in 2050 are around half those of conventional vehicles and the in-use emissions of BEVs are negligible in comparison to conventional vehicles. In general the size of the UK parc is constant across different analyses, so if the proportion of PiVs increases the average emissions of the UK parc will decrease, which will lead to a reduction in total in-use emissions.

The overall reduction of in-use emissions is generally quite low, even with large swings in PiV numbers. This is because PiV take-up is dominated by PHEV/REEVs, which provide only 50% emissions reduction, and PiVs make up only around a fifth of the parc in the base case. For example, in CB5, PiV numbers increase by 80%, but this only increases the PiV share of the UK parc by 15%. Halving the emissions of this 15% of the parc gives an estimate for the reduction in overall emissions of around only 7.5% (the exact calculation from CB5 gives 8.9% reduction).

Total exchequer spend changes in proportion to the change in PiV take-up, reflecting changes to spending on PiV subsidies, charge point subsidies and effects on tax revenue due to PiVs.

In the case where disutility is linearly decreased to zero when PiV sales equal conventional vehicle sales the changes are moderate, reflecting the fact that PiV sales remain much lower than conventional vehicle sales, so the change in disutility is correspondingly small.

Sensitivity analyses CB4 to CB6 show that consumer attitudes to the idea of PiVs are very important to the model outputs. The disutility coefficient implemented in the base case has been determined from consumer survey data and remains constant throughout the modelling period. There remains considerable uncertainty over how consumer attitudes will affect PiV sales and in particular how they will change over time as PiVs become more widespread (CB6 tests only one possible variation).

Given the significant effect of consumer attitudes to the idea of PiVs, it would be of considerable benefit to improve confidence in this parameter in the testing phase of the project.

5.3.2 Elasticity of car use with running costs

CB13 tests the importance of the elasticity of car use with running costs. In the base case an elasticity of -0.26 is used. In CB13 the elasticity effect is ignored.

Table 13 Effect of elasticity of car use with running costs (% change relative to base case shown in brackets)

	Description	% of Car Parc in 2050		Total Charge Points Installed in 2050 ('000s)	In-use Emissions in 2050 (Mt)	Total Exchequer Spend 2010 to 2050 (£bn)
		BEV	PiV			
CB13	Elasticity of car use with running costs ignored	0.6 (-2.8)	18.7 (-3.6)	111.1 (-18.3)	24.1 (-5.2)	5.03 (-0.1)

When the elasticity of car use with running costs is ignored the whole life emissions decrease without a corresponding increase in PiVs. The decrease in emissions must therefore result from a reduction in vehicle kilometres travelled. This means that in the base case running costs must be decreasing, resulting in more car use, due to the elasticity effect.

The large improvements in fuel efficiency provided by both conventional vehicles and PiVs by 2050 could be partially offset by increases in car use due to the lower associated running costs.

Variation of overall vehicle kilometres travelled is an important driver of whole life emissions, because it affects the emissions of both PiVs and conventional vehicles. CB13 gives the sixth largest reduction in total emissions of all the sensitivity analyses.

The elasticity of car use with running costs is well established for conventional vehicles, so this effect is probably well predicted, even though the sensitivity case is not realistic. Similar effects would be expected if running costs were increased, and indeed doubling fuel tax (sensitivity analysis P13) results in a reduction in emissions well in excess of the increase in PiV take-up.

Published values of the elasticity of car use with running costs may not hold for PiVs where the running costs are a lower proportion of the overall cost and similarly may change for conventional vehicles if the large reduction in fuel consumption by 2050 changes the balance of running costs to fixed costs. The effect of very low running costs on car use could be investigated in the next phase of the project.

5.3.3 Lower proportion of charging takes place at home

CB14 tests the effect of assuming that consumers recharge more in public locations than in the base case. No sensitivity was carried out for consumers recharging less in public locations. The recharge behaviour for the base case and for CB14 are shown in Table 14 and Table 15.

Table 14 Base case recharge behaviour for privately owned cars

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

Notes:

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

Table 15 CB14 recharge behaviour for privately owned cars

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

Notes as for Table 14.

Table 16 Effect of a higher proportion of public recharging (% change relative to base case shown in brackets)

	Description	% of Car Parc in 2050		Total Charge Points Installed in 2050 ('000s)	In-use Emissions in 2050 (Mt)	Total Exchequer Spend 2010 to 2050 (£bn)
		BEV	PiV			
CB14	Higher proportion of public recharging	0.7 (26.8)	34.2 (76.5)	840.6 (518.2)	23.6 (-7.2)	5.24 (4.2)

Increasing the proportion of public recharging increases the proportion of electricity drawn from public charge points from 14% in the base case, in 2050, to 51% in CB14 (see Figure 74).

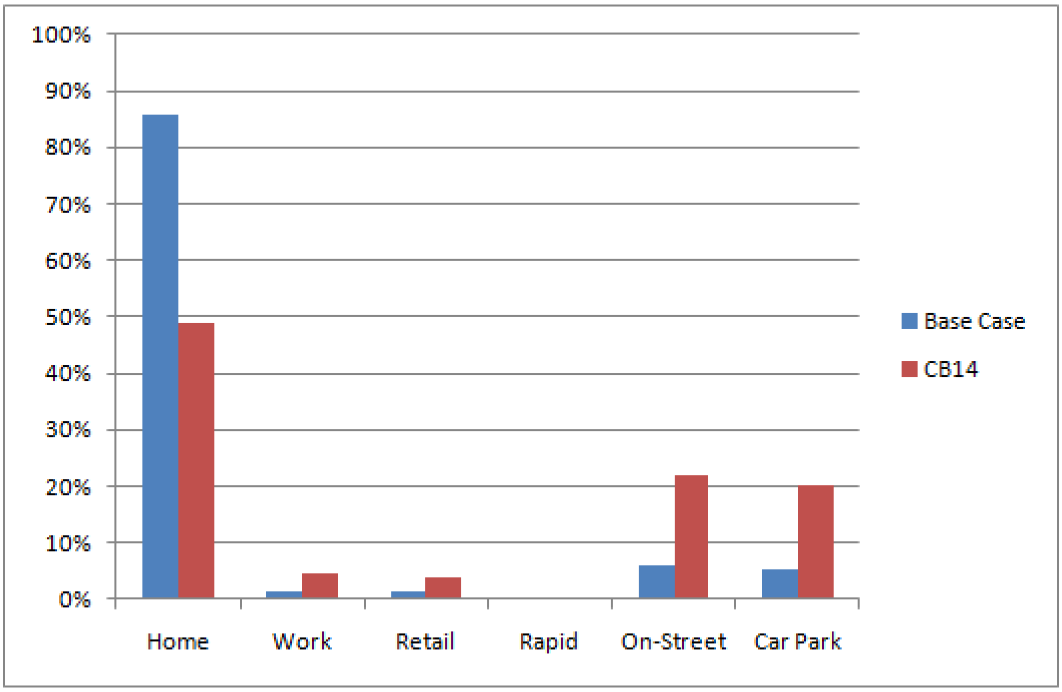


Figure 74 Distribution of recharging of PiVs on weekday in 2050 for base case and CB14

Greater use of non-domestic charge points results in more charge points being installed to meet the additional demand. This in turn results in a significant increase in PiV sales, through the perceived value of access to infrastructure in the consumer response model (see Section 1.2.1).

The large increase in PiVs in the parc reduces vehicle average emissions, because PiVs are more efficient than conventional vehicles (see Section 5.3.1), resulting in a 7.2% reduction in emissions compared to the base case.

CB14 shows that the model is sensitive to the assumed recharge behaviour. However, recharge behaviour is highly uncertain and in the absence of trial data, has been based on expert opinion. Given how significant the effect of recharge behaviour can be, it is a critical area for study in the next phase of the project.

5.4 Charge Point Supply Tests

With reference to Section 2 of Table 11, the charge point supply sensitivity analyses highlight two important sensitivities of the model.

Firstly, the link between charge point deployment and PiV take-up is very strong, implemented through the perceived value of access to infrastructure coefficient in the consumer response model. In the base case the number of consumers with access to all three types of charging infrastructure (domestic, workplace, public) is small, so many consumers have a low value of access.

Secondly, the deployment of charge points is sensitive to recharging behaviour and the algorithm that assesses whether consumers have access to non-domestic charge points.

5.4.1 Varying assumed access to domestic charge points

Sensitivity tests CP1 and CP2 test the effect of assuming lower and higher levels of access to domestic charge points respectively. The base assumes that 80% of people with access to off-street parking at home could have access to a domestic charge point. CP1 assumes 100% and CP2 assumes 60%. Increased access to domestic charge points in CP1 results in an increased PiV share despite a much reduced deployment of public charge points. (vice versa in CP2). These results emphasise that PiV uptake is highly dependent on the availability of domestic charging and that public charge points are only required as a supplement.

Table 17 Effect of varying assumed access to domestic charge points (% change relative to base case shown in brackets)

	Description	% of Car Parc in 2050		Total Charge Points Installed in 2050 ('000s)	In-use Emissions in 2050 (Mt)	Total Exchequer Spend 2010 to 2050 (£bn)
		BEV	PiV			
CP1	100% of those with off-street parking have access to domestic CP	0.6 (9.9)	21.4 (10.6)	95.8 (-29.5)	1883 (-0.9)	5.05 (0.3)
CP2	60% of those with off-stree parking have access to domestic CP	0.5 (-11.2)	17.9 (-7.7)	221.5 (62.9)	1893 (0.7)	5.02 (-0.2)

5.4.2 Fixed charge point deployment

Sensitivity analyses CP3, CP4, CP5, CP13 and CP14 test the effect of assuming different levels of fixed deployment of charge points in contrast to the approach of balancing supply and demand used in the base case (see Section 1.2.3). When deployment is fixed it is assumed that the government must meet any shortfall in funding for the charge points.

Table 18 Effect of fixed charge point deployment (% change relative to base case shown in brackets)

	Description	% of Car Parc in 2050		Total Charge Points Installed in 2050 ('000s)	In-use Emissions in 2050 (Mt)	Total Exchequer Spend 2010 to 2050 (£bn)
		BEV	PiV			
CP3	410k in 2010, increasing by 50k/yr	0.8 (42.8)	49.1 (153.7)	2410.0 (1672.3)	21.5 (-15.2)	46.55 (824.9)
CP4	205k in 2010, increasing by 25k/yr	0.8 (33.2)	41.0 (111.9)	1205.0 (786.2)	22.6 (-10.8)	24.88 (394.3)
CP5	102.5k in 2010, increasing by 12.5k/yr	0.7 (13.2)	28.6 (47.6)	602.5 (343.1)	24.3 (-4.3)	14.79 (193.8)
CP13	41k in 2010, increasing by 5k/yr	0.6 (1.7)	21.2 (9.6)	241.0 (77.2)	25.2 (-0.8)	8.77 (74.2)
CP14	Zero fixed deployment	0.5 (-10.7)	16.0 (-17.4)	0.0 (-100.0)	25.8 (1.5)	5.00 (-0.7)

Apart from CP14 the fixed deployment cases increase total charge points installed, sometimes hugely.

Where fixed deployment results in higher numbers of charge points installed, PiV sales are increased, as a result of the perceived value of access to infrastructure (see Section 1.2.1). In fact, CP3 gives the greatest increase in PiV numbers of all the sensitivity analyses.

With the increased proportion of PiVs in the UK parc, total in-use emissions are reduced due to the greater fuel efficiency of PiVs compared to the conventional vehicles they replace (see Section 5.3.1).

Total exchequer spend is greatly increased for fixed charge point deployment because charge point supply outstrips demand, so charge points make a loss (Figure 75) and the government makes up for this shortfall (Figure 76).

In CP14, where no non-domestic charge points are installed, PiV numbers reduce, but only by 17.4%. This again emphasises that access to non-domestic charge points is less important than access to domestic charging.

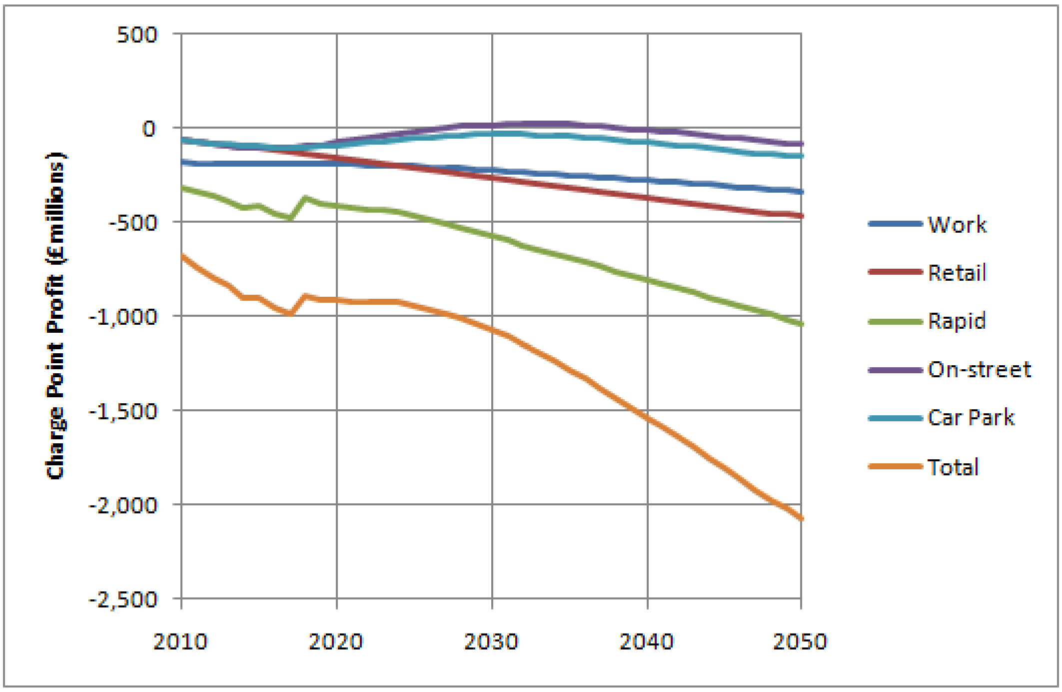


Figure 75 Charge point profit by type for CP3

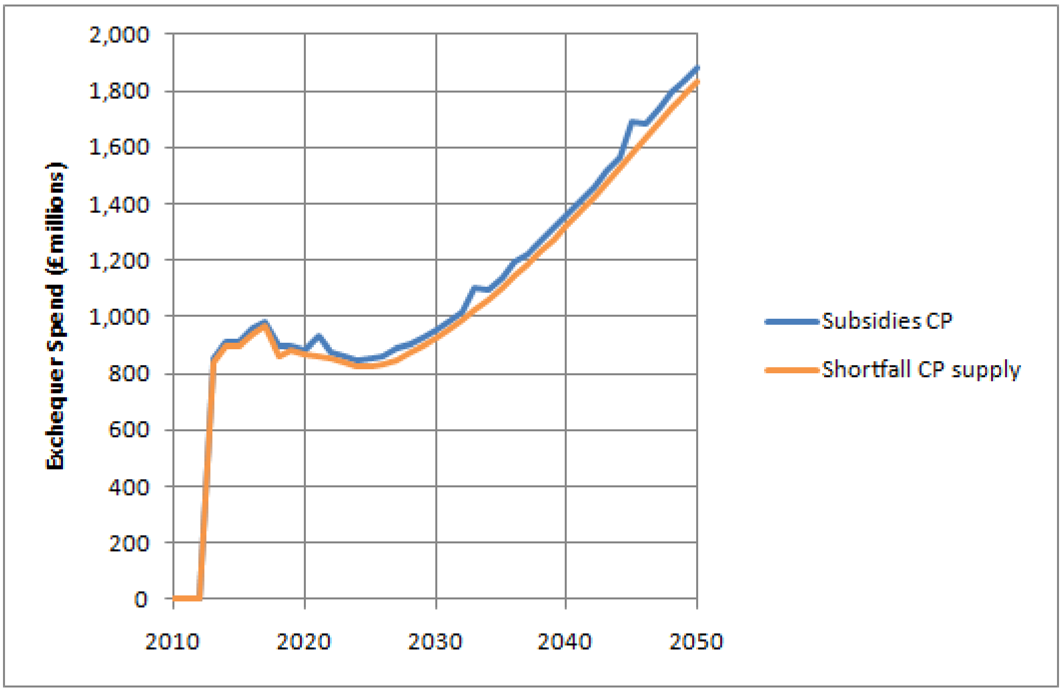


Figure 76 Exchequer spend associated with charge points for CP3

The fixed charge point deployment analyses illustrate the importance of the perceived value of access to infrastructure discussed in Section 1.1.2. For very high levels of charge point deployment the positive effect on PiV take-up appears to reduce (Figure 77).

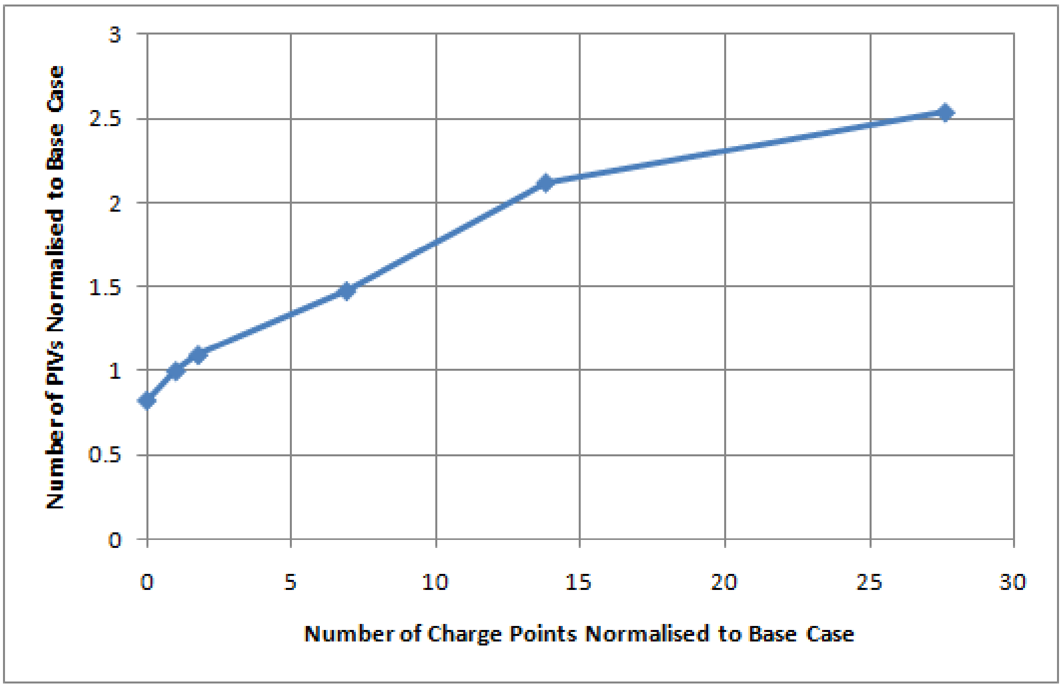


Figure 77 Variation of PiV numbers with number of charge points installed

5.4.3 Charge point level of service

CP8 and CP12 test the effect of the level of service coefficient. The level of service coefficient is a multiplier in the calculation for the number of charge points that will be installed in any year in response to demand. It allows the case where the government wishes to encourage a higher level of charge point deployment to be modelled and as such, in cases where the level of service coefficient is greater than 1.0, the government is assumed to meet any shortfall in charge point funding.

Table 19 Effect of level of service coefficient (% change relative to base case shown in brackets)

	Level of Service Coefficient	% of Car Parc in 2050		Total Charge Points Installed in 2050 ('000s)	In-use Emissions in 2050 (Mt)	Total Exchequer Spend 2010 to 2050 (£bn)
		BEV	PiV			
CP8	1.1	0.6 (4.3)	20.5 (6.1)	182.2 (34.0)	25.2 (-0.7)	5.21 (3.5)
CP12	1.5	0.7 (11.9)	25.2 (30.0)	450.9 (231.6)	24.6 (-2.9)	6.15 (22.1)

An increased level of service coefficient means a larger number of charge points are installed in any particular year. This has two important knock-on effects.

Firstly, the increased number of charge points means fewer consumers are judged not to have access to non-domestic charge points. Consumers without access to non-domestic charge points charge exclusively at home, reducing demand for public recharging.

Secondly, the increased number of charge points increases the perceived value of access to infrastructure, increasing PiV sales (see Section 1.2.1). As a result the average fuel efficiency of the UK parc is improved, so whole life emissions reduce (see Section 5.3.1).

As a result of the greater number of PiVs and the greater demand for public recharging combined with government making up for the shortfall in charge point profits, charge point numbers continue to increase. These effects result in significantly more charge points in 2050 in CP8 and CP12 and also moderate increases in the proportion of PiVs in the UK parc. Because the government meets any shortfall in charge point profits, the exchequer spend is greater than in the base case.

CP8 and CP12 highlight the critical effect of the perceived value of access to infrastructure and the assumptions and algorithms that determine recharge behaviour.

5.5 Electricity Price Tests

With reference to Section 4 of Table 11, the price of electricity from non-domestic charge points is a significant factor in charge point use, charge point deployment and PiV take-up. Increasing the price, for example by passing the full infrastructure costs directly to charge point users, significantly reduces take-up and charge point deployment. Conversely free electricity is predicted to be a significant incentive to the PiV market.

The magnitude of the effects of parameters that affect electricity price are large. This is because the modelled system is very sensitive to the following factors:

- Recharge behaviour has a critical effect on demand for non-domestic charging, which has strong knock-on effects on charge point deployment and PiV take-up. Both the definition of the recharge behaviour matrix and the allocation of consumers to different categories within that matrix are important in this respect.
- The effect of the perceived value of access to infrastructure is strong (see Section 1.1.2), so encouraging charge point deployment drive PiV take-up.
- The likely utilisation of charge points, which directly determines how many charge points are required each year.
- The notional value of charging to retailers and employers has an important effect on charge point deployment, by making charge points profitable, even in cases where the PEP is low.

5.5.1 Regulated asset status of charging infrastructure

Table 20 Effect of charging infrastructure regulated asset status (% change relative to base case shown in brackets)

	Description	% of Car Parc in 2050		Total Charge Points Installed in 2050 ('000s)	In-use Emissions in 2050 (Mt)	Total Exchequer Spend 2010 to 2050 (£bn)
		BEV	PiV			
EP5	All costs regulated	0.6 (0.1)	19.4 (0.1)	136.6 (0.4)	25.4 (0.0)	5.02 (-0.3)
EP6	No costs regulated	0.5 (-10.6)	16.0 (-17.2)	5.1 (-96.2)	25.9 (1.9)	5.00 (-0.7)

EP5 and EP6 test the effect of assumptions about the regulated asset status of charging infrastructure. In the base case network intelligence and network reinforcement costs are assumed to be regulated, with costs spread across all electricity use, and charge point costs not regulated, so reflected in the cost of electricity from charge points. In EP5 all costs are regulated and in EP6 no costs are regulated.

In EP5 the cost of electricity from charge points is lower, because the charge point costs are regulated and therefore spread over all electricity use, rather than recovered from charge point electricity use only. However, this reduction in cost has a negligible effect on the indicators.

In EP6 the cost that must be recovered through the electricity price at charge points is higher, because it includes the network intelligence and network reinforcement costs. These costs are large and would imply a very high public electricity premium (PEP), but this is limited by the PEPMax parameter in the model, so instead charge points struggle to be profitable severely restricting deployment.

The high cost and low deployment of public recharging means the running costs of PiVs are higher and the perceived value of infrastructure is lower (see Section 1.1.2), so PiV sales and in turn demand for public recharging reduce, which further reduces charge point installation.

The reduction in PiV share of the UK car parc results in an increase in whole life CO_2 emissions due to the higher emissions of the conventional vehicles that replace them (see Section5.3.1). There is also a small reduction in exchequer spend due to the reduced number of PiVs qualifying for tax incentives.

Network intelligence costs (NIC) dominate the overall cost of charging infrastructure, with network reinforcement costs (NRC) making up most of the remaining overall cost (Figure 78). The cost of the charge points (CPC) is a very small proportion. Consequently the effect of deregulating NIC and NRC, which greatly increases the PEP, is far greater in magnitude than the effect of regulating the CPC, which decreases the PEP by a far smaller amount.

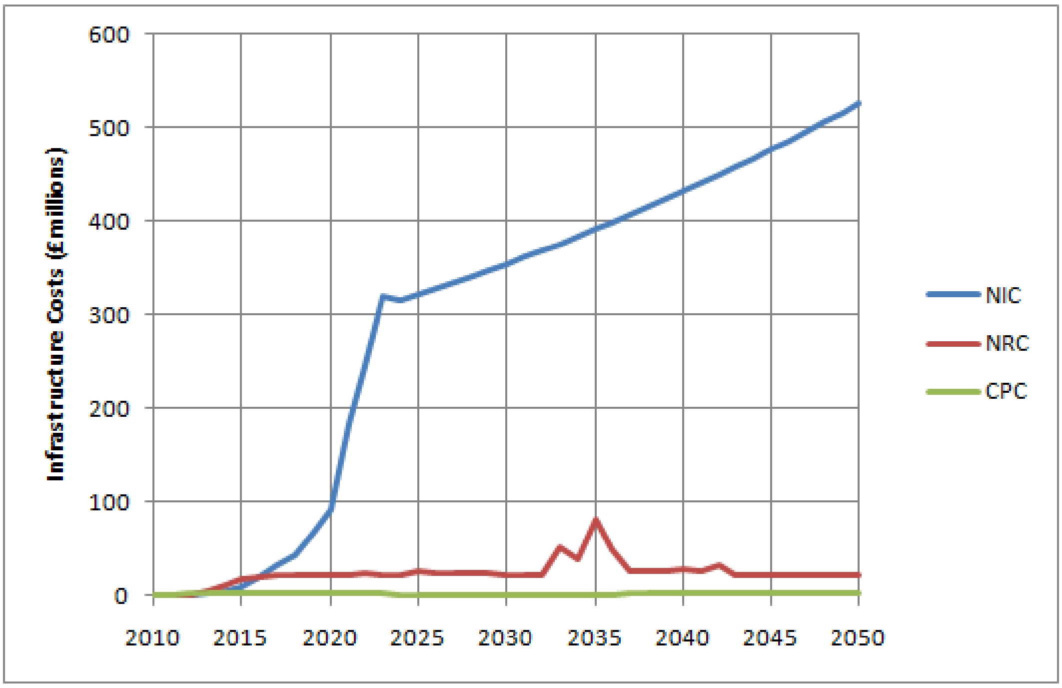


Figure 78 EP6 infrastructure costs

The cost of infrastructure can have a significant effect on its commercial viability. If the full costs of charging infrastructure must be recovered by the charge point owner, it will severely limit the opportunity for profit and therefore restrict deployment.

In EP6 retail, on-street and car park charge points consistently make a loss and yet after the period of initial deployment charge points are installed, albeit at low levels. This suggests the charge point deployment algorithm may not be functioning correctly at these very low levels of deployment.

5.5.2 Free electricity at workplace and retail charge points

EP11 tests the effect of free electricity being offered at retail and workplace charge points. The effect of this on charge point use is modelled by modifying the recharge behaviour of private drivers to favour these free charge points. The resulting amount of recharging per PiV carried out in different locations on a weekday for the base case and for EP11 is shown in Figure 79 .

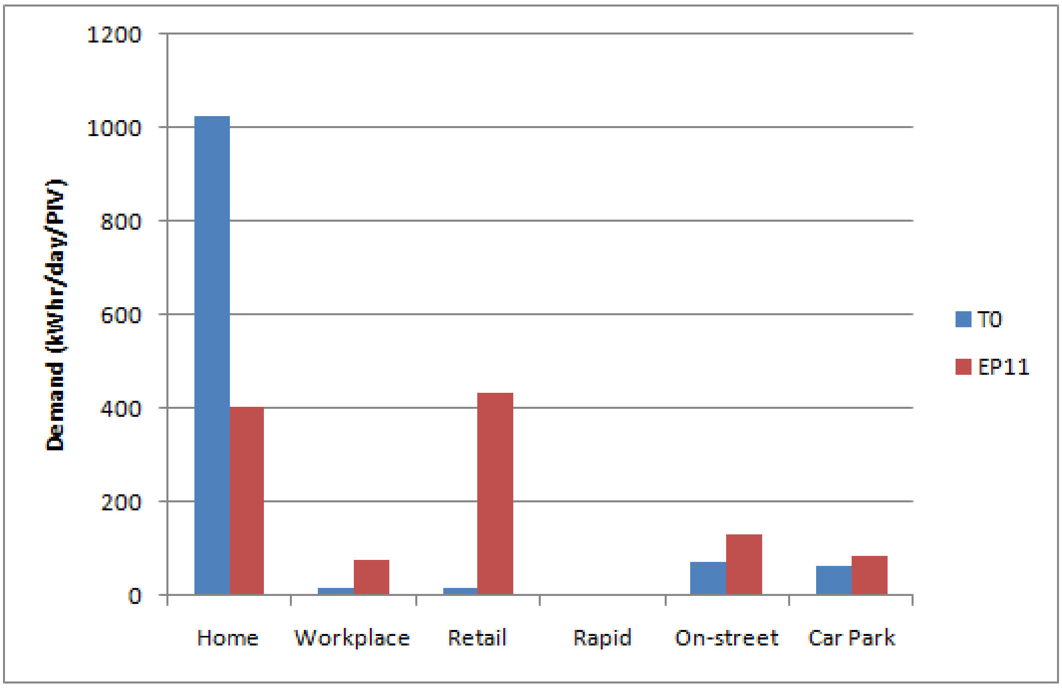


Figure 79 Comparison of recharging demand per PiV between T0 and EP11 in 2050

Table 21 Effect of free workplace and retail charging (% change relative to base case shown in brackets)

	Description	% of Car Parc in 2050		Total Charge Points Installed in 2050 ('000s)	In-use Emissions in 2050 (Mt)	Total Exchequer Spend 2010 to 2050 (£bn)
		BEV	PiV			
EP11	Free workplace and retail charging	0.7 (26.1)	44.5 (130.0)	1360.4 (900.4)	22.2 (-12.4)	5.40 (7.4)

EP11 results in a nine fold increase in charge points deployed and a 130% increase in the PiV share of the UK car parc compared to the base case. There are a number of reasons for this:

- A significant amount of consumer recharging is reallocated from domestic charge points to free workplace and retail charge points, which increases demand for non-domestic charge points for a given number of PiVs
- The notional value of recharging at workplace and retail charge points allows them to remain ‘profitable’ (see Figure 80), so significant numbers of charge points are deployed to meet the additional demand
- Free charging reduces the running costs of PiVs and the higher number of charge points increases the perceived value of access to infrastructure, so PiV sales are increased
- Increased PiV sales further increases demand for non-domestic charge points

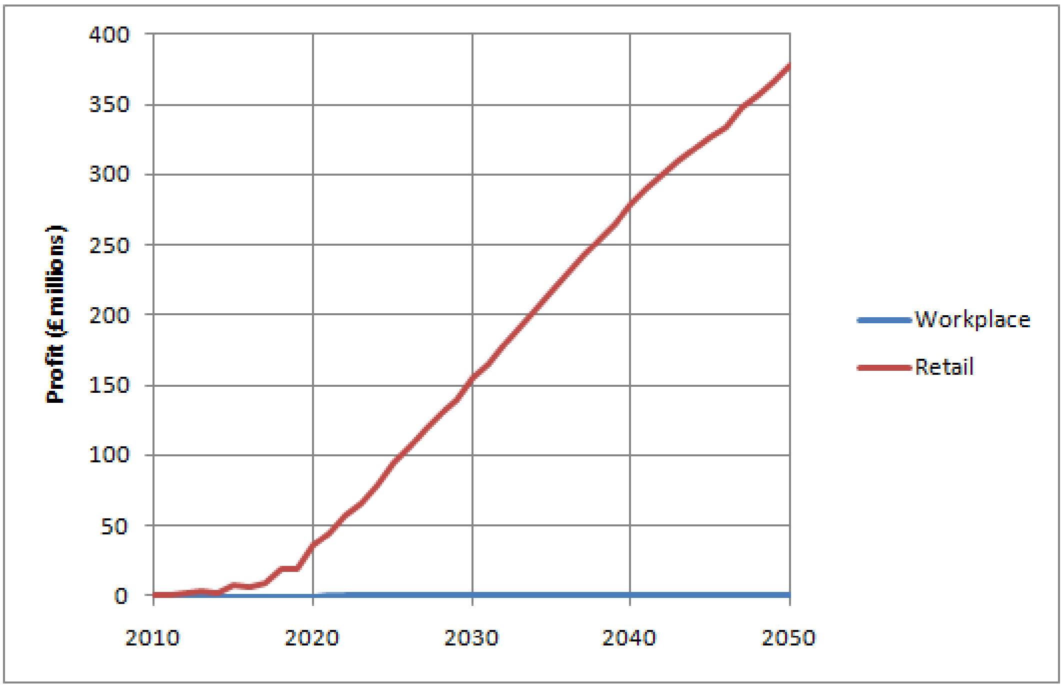


Figure 80 EP11 workplace and retail charge point profit, including notional value

EP11 demonstrates the strong effect of the perceived value of access to infrastructure and the assumed recharge behaviour on the behaviour of the overall system. It also highlights the importance of the assumed notional value of charging to retail and workplace locations.

The perceived value of access to infrastructure is based on survey data, but does not include any change with time. Both recharge behaviour and the notional value of charging are based on expert opinion, in the absence of better data, and are therefore subject to considerable uncertainty.

5.5.3 Likely utilisation of charge points

EP14 and EP15 test the effect of the likely utilisation of charge points. This parameter is used in the model as part of the calculation of the PEP and the number of charge points required.

Table 22 Effect of likely utilisation of charge points (% change relative to base case shown in brackets)

	Likely utilisation	% of Car Parc in 2050		Total Charge Points Installed in 2050 ('000s)	In-use Emissions in 2050 (Mt)	Total Exchequer Spend 2010 to 2050 (£bn)
		BEV	PiV			
EP14	25kWhr /day	0.5 (-9.9)	16.2 (-16.1)	21.8 (-83.9)	25.8 (1.7)	5.00 (-0.6)
Base Case	10kWhr /day	0.6 (0.0)	19.3 (0.0)	136.0 (0.0)	25.4 (0.0)	5.03 (0.0)
EP15	5kWhr /day	0.6 (8.4)	24.2 (24.8)	398.9 (193.4)	24.8 (-2.3)	5.09 (1.1)

Each year the total number of charge points required to meet demand is calculated as the forecast draw of electricity from non-domestic charge points divided by the annual likely utilisation. Therefore, the number of charge points required to meet demand is inversely proportional to the likely utilisation.

PiV sales are affected by changes in the number of charge points deployed through the perceived value of access mechanism (see Section 1.1.2), resulting in a reduction in PiV sales when the likely utilisation is high.

Charge point numbers, in-use emissions, and exchequer spend all vary with PiV numbers in the ways described in Section 5.3.1.

The likely utilisation of charge points is based on estimates of reasonable numbers of visits during a 24hr period and the amount of electricity that would be required by those users. It will be possible to gather much better data in the next phase of the project, to better inform the charge point deployment algorithm.

5.6 Government Policy Tests

With reference to Section 5 of Table 11, government policy levers offer little scope to dramatically stimulate the PiV market over the base case, with more stringent fleet average emissions legislation offering the greatest effect. However, government subsidy of charge points to drive greater levels of charge point deployment, described in Section 5.4.1, is predicted to have a substantial effect on PiV take-up.

The likely effectiveness of the fleet average emissions legislation should not be overlooked – it is included in one form in the base case and is probably essential to the level of PiV take-up predicted.

The mechanism by which the manufacturers apply penalties to vehicles of different types, in order to influence sales to hit the fleet average emissions target appears to fail when the emission target gets very low, or the penalties required to shift demand get very high.

5.6.1 PiV purchase allowances

P1, P2, P3, P4 and P5 test different limits on the PiV purchase allowances provided by government (see Table 23).

Table 23 Effect of PiV purchase allowances tests (% change relative to base case shown in brackets)

	PiV purchase allowances	% of Car Parc in 2050		Total Charge Points Installed in 2050 ('000s)	In-use Emissions in 2050 (Mt)	Total Exchequer Spend 2010 to 2050 (£bn)
		BEV	PiV			
Base Case	Max £5k/25%, budget cap £43m, to 03/12	0.6 (0.0)	19.3 (0.0)	136.0 (0.0)	25.4 (0.0)	5.03 (0.0)
P1	No PiV purchase allowances	0.6 (0.0)	19.3 (0.0)	136.0 (0.0)	25.4 (0.0)	5.02 (-0.2)
P2	As base, but uncapped , to 2015	0.6 (0.1)	19.4 (0.1)	136.5 (0.4)	25.4 (0.0)	6.35 (26.2)
P3	As base, but uncapped, to 2017	0.6 (0.7)	19.5 (0.9)	139.8 (2.8)	25.4 (-0.1)	8.84 (75.6)
P4	As base, but uncapped, to 2022	0.6 (1.3)	19.9 (2.7)	149.8 (10.1)	25.3 (-0.2)	14.90 (196.0)
P5	As base, but uncapped to 2015 for PHEV/REEV and to 2022 for BEVs	0.6 (0.1)	19.4 (0.2)	136.9 (0.6)	25.4 (0.0)	6.43 (27.8)

Adjusting the PiV purchase allowances has little effect on PiV proportion of UK car parc, total charge points installed, and in-use emissions, with the exception of P4 which results in a small increase in PiV take-up and a moderate increase in charge point deployment. P1, which represents the only less generous PiV purchase allowance case also has little effect on exchequer spend, giving only a very small saving. P2 to P5 result in significant increases in exchequer spend up to a 196% increase for the most generous case.

Figure 81 and Figure 82 show the annual sales figures from 2010 to 2050 for PHEV and REEVs, and BEVs. The reasons for the steps in the sales profile are likely to be a combination of steps in the development of PiV technology and steps in PiV incentives during this period.

Government subsidies have a significant effect in the short term, which is equivalent to reducing the price of PiVs. However, shortly after the subsidies are stopped PiV sales return to close to the base case levels. No market stimulation effect of PiVs subsidies is in evidence in these sensitivity analyses.

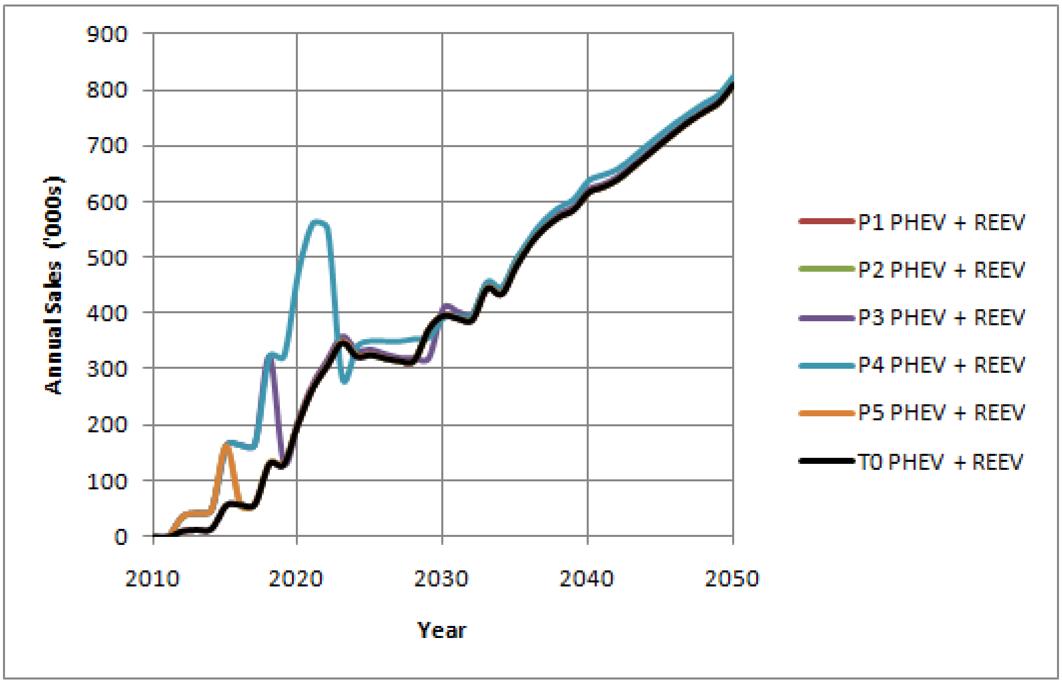


Figure 81 PHEV and REEV annual sales figures for base case and P1 to P5

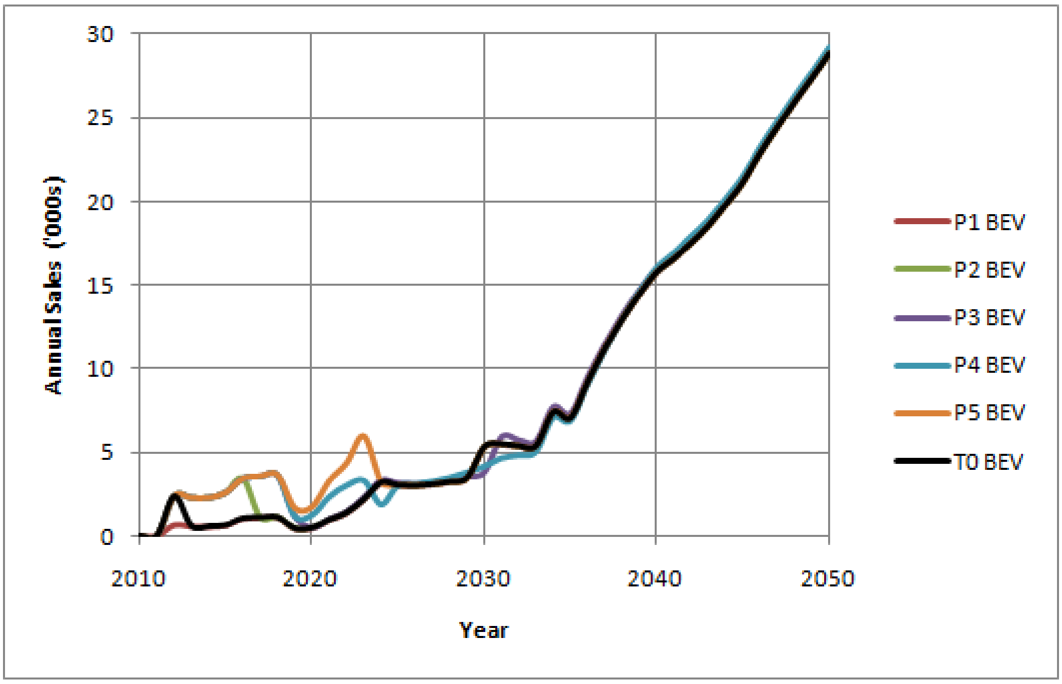


Figure 82 BEV annual sales figures for base case and P1 to P5

P1 to P5 highlight that the overall system model may not capture a market stimulation effect. One effect that could result in early sales stimulating the market is PiVs reaching efficient levels of production earlier and therefore prices reducing more quickly. This effect is not accounted for in the overall system model.

5.6.2 Stringent criteria for PiV capital allowances

P6 tests a more stringent criterion for low emission vehicles to qualify for the 100% first year capital allowance. In the base case the allowance is available on vehicles emitting less than 95g/km CO_2, which is tightened to 42g/km CO_2 in P6.

Table 24 Effect of more stringent criteria for PiV capital allowances (% change relative to base case shown in brackets)

	% of Car Parc in 2050		Total Charge Points Installed in 2050 ('000s)	In-use Emissions in 2050 (Mt)	Total Exchequer Spend 2010 to 2050 (£bn)
	BEV	PiV			
P6	0.6 (1.1)	19.8 (2.4)	141.2 (3.9)	25.3 (-0.5)	0.86 (-82.9)

The more stringent PiV capital allowance criterion encourages a small increase in PiV sales and consequently charge points installed, and a corresponding reduction in whole life emissions. There is a significant reduction in exchequer spend due to fewer vehicles qualifying for the capital allowance and therefore less lost corporation tax.

This test suggests a more stringent PiV capital allowances criterion would have the desired effect on all indicators, i.e. increase PiV sales and charge point deployment, reduce emissions and reduce exchequer spend.

5.6.3 Fleet average emissions legislation

P19, P20 and P21 test the effect of adjusting the basis of the fleet average emissions legislation.

Table 25 Effect of changing the basis of fleet average emissions legislation (% change relative to base case shown in brackets)

	Fleet Average Emissions Legislation	% of Car Parc in 2050		Total Charge Points Installed in 2050 ('000s)	In-use Emissions in 2050 (Mt)	Total Exchequer Spend 2010 to 2050 (£bn)
		BEV	PiV			
Base Case	130g TTW 2015, 95g TTW 2020, 42g TTW 2050	0.6 (0.0)	19.3 (0.0)	136.0 (0.0)	25.4 (0.0)	5.03 (0.0)
P19	130g TTW 2015, 95g TTW 2020, 25g TTW 2050	0.7 (15.7)	22.3 (15.5)	197.8 (45.5)	24.8 (-2.2)	5.09 (1.1)
P20	As T0, but WTW from 2020 to achieve same overall CO_2 cap as T0	0.4 (-40.5)	14.2 (-26.6)	75.0 (-44.9)	26.6 (4.8)	4.99 (-0.8)
P21	As T0, but WTW from 2020 to achieve same overall CO_2 cap as P19	0.6 (1.5)	19.5 (0.7)	136.1 (0.1)	25.3 (-0.4)	5.03 (-0.2)
P22	130g TTW 2015, 95g TTW 2020, 15g TTW 2050	0.7 (17.8)	22.8 (18.1)	208.8 (53.6)	24.8 (-2.5)	5.10 (1.3)
P23	As T0, but WTW	0.6	20.7	161.6	25.0	5.05

	from 2020 to achieve same overall CO_2 cap as 20g TTW in 2050	(7.8)	(7.2)	(18.9)	(-1.3)	(0.3)

P19 introduces more stringent fleet average tank-to-wheel targets, which more vehicles in the showroom fail to meet. To try to achieve the fleet average target manufacturers increase the price of non-compliant (conventional) vehicles and cross-subsidise compliant vehicles (PiVs), making PiVs more attractive in the consumer response model and increasing PiV take-up.

The larger number of PiVs increases demand for charging, which results in more charge points installed, and improves the overall fuel efficiency of the UK parc, which reduces in-use emissions (see Section 5.3.1).

Exchequer spend increases because the losses in corporation tax due to PiV capital allowances are greater with the larger number of PiVs.

Similar effects are seen in P22, but because the target is lower, the changes are greater in magnitude.

Figure 83 shows how the base case and P19 average emissions of new cars in UK compare to their respective targets. Figure 84 shows an example of the corresponding penalties applied by manufacturers to vehicles to influence sales to meet the emissions targets and the total penalties incurred (a negative penalty represents a cross-subsidy by the manufacturer).

Figure 84 shows that manufacturers begin applying penalties in 2020 and these successfully influence sales so that average emissions tracks below the target. The extent to which the target is exceeded may be unrealistic. However, in both the base case, in 2046, and in P19, in 2037, the emissions targets are exceeded and manufacturers begin incurring penalties. This is because the penalties, which are based on the fleet average emissions fines that a vehicle will incur, are not large enough to overcome other factors such as consumer attitudes towards the idea of PiVs.

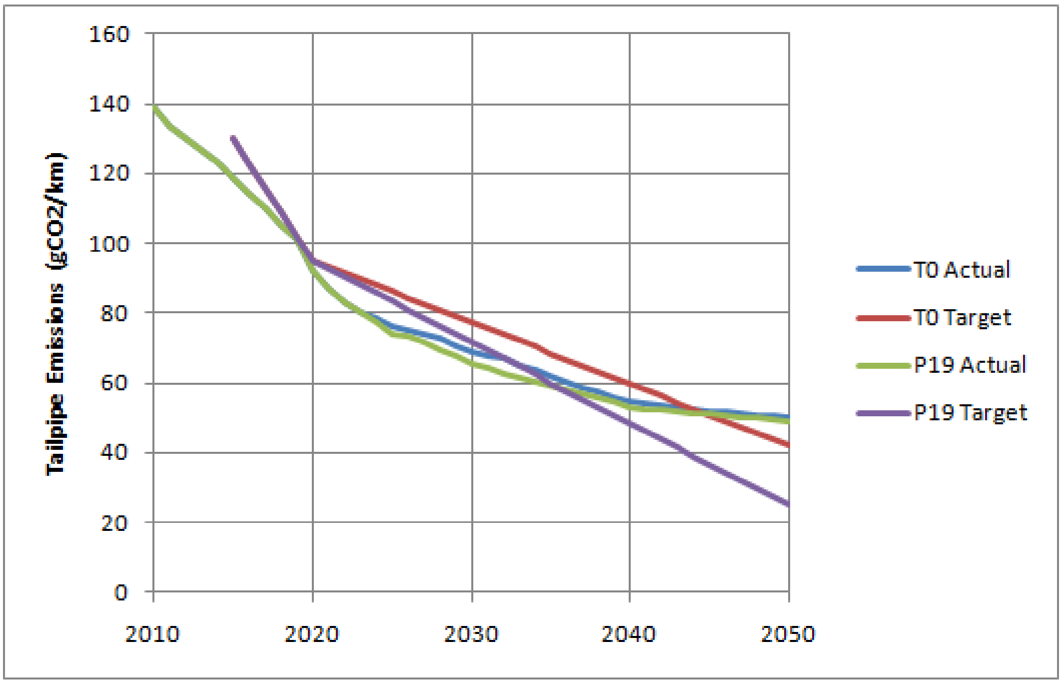


Figure 83 UK new car average emissions compared to fleet average emissions targets for base case and P19

P20 changes the basis of fleet average emissions legislation from tank-to-wheel to well-to-wheel, which greatly increases the emissions of PiVs relative to conventional vehicles. Consequently the penalties applied by manufacturers change (see Figure 85), becoming less favourable to PiVs, and PiV sales decrease. With fewer PiVs in the parc, fewer charge points are required to meet demand.

In P20 in-use emissions increase over the base case, despite the intention that the P20 fleet average emissions basis gives the same overall reduction in CO2 emissions as the base case. This suggests that the definition of the WTW target could be improved.

P21 is similar to P20, and targets the same overall CO2 cap as P19. P21 results in little change to the output metrics compared to the base case because the effects of a well-to-wheel target are opposite to the effects of a more stringent CO2 cap, so the two effects largely cancel out.

P23 is similar to P21, but has a lower emissions target. The effect of the low emissions target is greater than the effect of shifting from tank-to-wheel to well-to-wheel, so small increases in PiV numbers and charge points are seen.

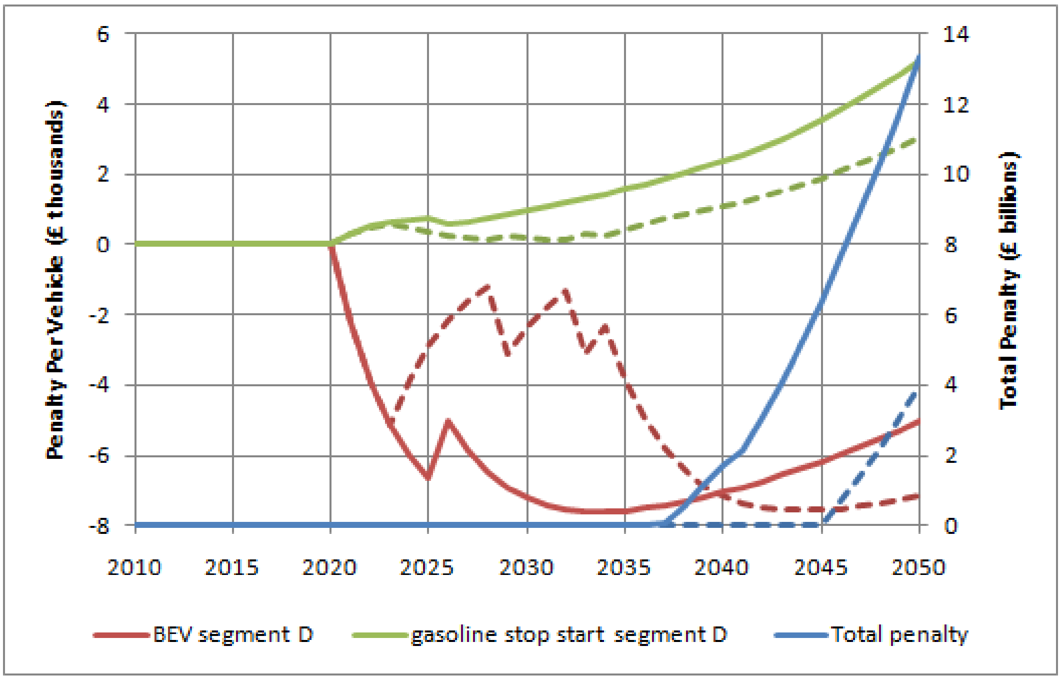


Figure 84 Example manufacturer applied penalties and total fleet average emissions penalties applied in base case (dashed lines) and in P19 (solid lines)

P21 changes the basis of the fleet average emissions legislation to well-to-wheel,

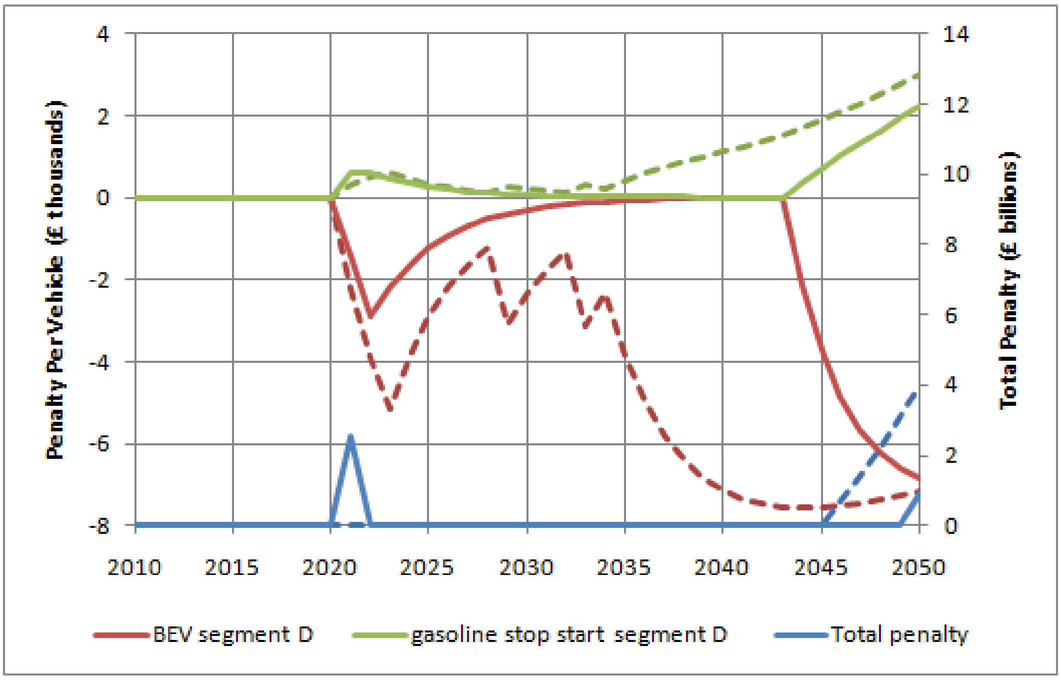


Figure 85 Example manufacturer applied penalties and total fleet average emissions penalties applied in base case (dashed lines) and in P20 (solid lines)

5.7 Vehicle Showroom Tests

Showroom variables describe the attributes of vehicles available to consumers. There is some uncertainty over the future attributes of PiVs, so sensitivity studies have been carried out to check the effect of these variables. Summary results are shown in section 6 of Table 11.

The overall system responds in a reasonable way to showroom variables. Showroom variables have significant effects on the PiV market but perhaps less than would be expected compared to some of the consumer behaviour and charge point supply variables.

5.7.1 Upfront vehicle prices

S1 and S2 test the effect of upfront vehicle prices, implemented as a 20% higher and lower purchase price for PiVs with no change to conventional vehicles, reflecting uncertainty over how PiV prices will change. The price of the batteries is excluded from this increase (and was tested separately in S3 and S4).

Table 26 Effect of vehicle price (% change relative to base case shown in brackets)

	Vehicle Prices	% of Car Parc in 2050		Total Charge Points Installed in 2050 ('000s)	In-use Emissions in 2050 (Mt)	Total Exchequer Spend 2010 to 2050 (£bn)
		BEV	PiV			
S1	High	0.5 (-14.9)	14.5 (-25.2)	89.6 (-34.1)	26.1 (2.8)	5.09 (1.1)
S2	Low	0.6 (2.5)	23.8 (22.7)	184.1 (35.4)	24.9 (-2.1)	4.92 (-2.2)

Increasing PiV prices results in a reduction in PiV share of the UK car parc of 25%, because PiVs are less attractive in the consumer response model. There is a corresponding reduction in charge points installed of 34%, reflecting the reduced demand for public recharging, and an increase in emissions, because conventional vehicles are less fuel efficient (see Section 5.3.1).

Exchequer spend increases because the increase in cost of PiVs slightly outweighs the decrease in PiVs sold over the 40 year period, so the loss in corporation tax due to PiV capital allowances goes up.

Similar effects are seen in reverse for S2.

S1 and S2 show the overall system is behaving reasonably in response to vehicle price variations. Vehicle price is generally considered to be one of the most important factors holding back consumer take-up of PiVs, so it might be expected that it would have a greater effect than seen in S1 and S2 compared to other variables, for example consumer behaviour and charge point deployment variables.

5.7.2 Residual value and average life expectancy

S7 and S8 test the effect of variations in residual value and average life expectancy. The residual value of PiVs is changed by 30% from the base value and the year in which average PiV life reaches that of conventional vehicles changes from 2030 in the base case to 2020 in S7 and 2050 in S8. The residual value and life expectancy of conventional vehicles is unchanged.

Table 27 Effect of average vehicle life expectancy (% change relative to base case shown in brackets)

	Residual value / year of average life parity	% of Car Parc in 2050		Total Charge Points Installed in 2050 ('000s)	In-use Emissions in 2050 (Mt)	Total Exchequer Spend 2010 to 2050 (£bn)
		BEV	PiV			
S7	+30% / 2020	0.6 (2.0)	20.0 (3.2)	151.0 (11.1)	25.3 (-0.4)	5.01 (-0.4)
S8	-30% / 2050	0.5 (-12.2)	15.6 (-19.1)	94.7 (-30.4)	25.9 (2.1)	5.15 (2.3)

In S7 increased residual value reduces the cost of ownership of PiVs resulting in an increase in sales. The greater number of PiVs increases demand for charging, so more charge points are installed and results in lower in-use emissions due to their greater fuel efficiency.

Similar effects are seen in reverse for S8.

The model behaves reasonably for changes in residual value and average life expectancy.

5.7.3 Vehicle showroom maximally favourable to PiVs

S19 and S20 test the effect of a maximally and minimally favourable PiV showroom.

Table 28 Effect of combined vehicle showroom (% change relative to base case shown in brackets)

	PiV Showroom	% of Car Parc in 2050		Total Charge Points Installed in 2050 ('000s)	In-use Emissions in 2050 (Mt)	Total Exchequer Spend 2010 to 2050 (£bn)
		BEV	PiV			
S19	Most favourable	1.2 (110.6)	31.5 (62.8)	428.5 (215.1)	23.7 (-6.8)	4.87 (-3.2)
S20	Least favourable	0.2 (-66.4)	8.3 (-57.2)	22.8 (-83.2)	27.2 (7.0)	5.11 (1.6)

S19 shows that the most favourable showroom to PiVs results in an increase in their share of the parc to 31.5%. Largely this is because PiVs are more attractive in the consumer response model relative to conventional vehicles. Also, the increased demand for charging results in more charge points being installed, so the perceived value of access to infrastructure is greater (see Section 1.2.1), which also encourages PiV take-up.

In-use emissions decrease in proportion to the increase in the numbers of PiVs, which are more fuel efficient than conventional vehicles (see Section 1.2.1).

Exchequer spend reduces because PiV life expectancy is high and cost is low, so lost corporation tax due to PiV capital allowances reduce, despite the larger number of PiVs in the parc.

Similar effects are seen in reverse in S20.

The overall system behaves reasonably in response to vehicle showroom variables. The effects of these variables, although significant, are smaller than certain other variables, for example consumer behaviour and charge point deployment.

5.8 Tests of Factors Related to Electricity Generation

The electricity generation scenarios considered in the sensitivity analyses have little effect on the PiV system (see section 3 of Table 11).

The main reason for the lack of sensitivity to these scenarios are:

- The electricity component of the running costs of PiVs is small, so take-up is relatively insensitive to the changes in electricity price in the different scenarios.
- The small changes in PiV numbers means charge point deployment (which is driven by demand) and exchequer spend (which is driven by lost corporation tax on PiVs) also do not change significantly.
- Emissions change to a greater extent, but the relatively low number of PiVs of which BEVs are a tiny proportion, means emissions are dominated not by electricity but by fossil fuel emissions, which are little affected.

5.9 Tests of Factors related to UK GDP

Growth in UK GDP affects growth in the total UK vehicle parc and the use of vehicles, which in turn affects overall vehicle kilometres travelled. Because overall vehicle usage is affected, UK GDP growth has a significant impact on emissions, without significantly changing the composition of the vehicle parc. A summary of results for this family of variables is shown in section 7 of Table 11.

5.9.1 UK vehicle parc and vehicle kilometres travelled

UK1 and UK2 test the effect of changing the UK vehicle parc and vehicle kilometres travelled (VKT) in line with high and low GDP growth respectively.

Table 29 Effect of UK vehicle parc and VKT (% change relative to base case shown in brackets)

	GDP growth	% of Car Parc in 2050		Total Charge Points Installed in 2050 ('000s)	In-use Emissions in 2050 (Mt)	Total Exchequer Spend 2010 to 2050 (£bn)
		BEV	PiV			
UK1	3%	0.6 (-5.3)	18.2 (-5.8)	114.9 (-15.5)	26.9 (5.8)	6.51 (29.4)
UK2	1%	0.6 (6.2)	20.8 (7.3)	157.2 (15.6)	23.1 (-9.0)	3.90 (-22.5)

The UK vehicle parc is positively correlated to GDP and VKT per vehicle is negatively correlated to GDP. Their combined effect results in total VKT being positively correlated with GDP (see Figure 86).

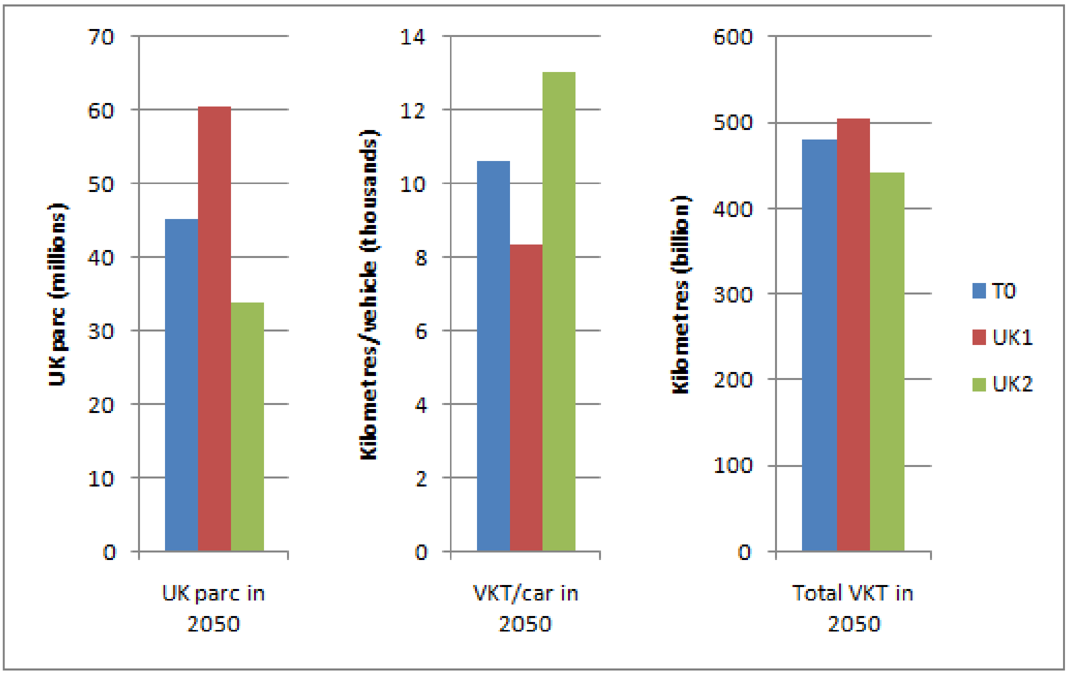


Figure 86 Variation in parc, VKT/vehicle and total VKT with GDP growth

UK1 shows an increase in in-use emissions due to the higher total VKT (higher GDP results in higher VKT). The proportion of PiVs in the parc reduces because VKT per vehicle reduces and therefore running costs are lower, which reduces the overall cost of conventional vehicles more than PiVs.

Fewer charge points are installed in UK1 than in the base case. The total draw of electricity is slightly lower in UK1 (see Table 11) and a smaller proportion of this is drawn from non-domestic charge points (about 12% compared to about 14% in the base case). This is likely to be a consequence of how PiV drivers are categorised in terms of access to different charge point types in the recharge behaviour matrix.

UK1 exchequer spend is increased because PiV numbers increase from 8.8million to 11.0million (the overall increase in the parc outweighs the reduction in the proportion of PiVs in the parc), so the loss in corporation tax due to first year capital allowances on PiVs is greater than in the base case.

Similar effects are seen in reverse in UK2.

6 The Trade-off Between Reduction in Emissions and Cost to The Exchequer

Figure 87 shows, in graphical form, the trade-off between reduction in emissions and cost to the Exchequer. The X-axis shows cost to the Exchequer over the 41 years (discounted at 3.5% p.a.) and the Y-axis shows the total emissions of CO_2 (in Mt) in 2050 - including emissions associated with vehicle production and scrappage. Each point on the graph shows the result of a run of the CRM with a different combination of policy levers in the base scenario (i.e. all variables other than policy levers are set at their base values). The position of each point shows where that combination of policy levers lies on the emissions and cost axes. Points to the west and south of the cluster are on the "frontier" in that they represent a solution that achieves a given reduction in emissions at less cost to the Exchequer than any other run. Run number 1K839 represents minimum expenditure while run 1K640 represents minimum emissions. The definition of runs identified on the graph is shown in Table 28.

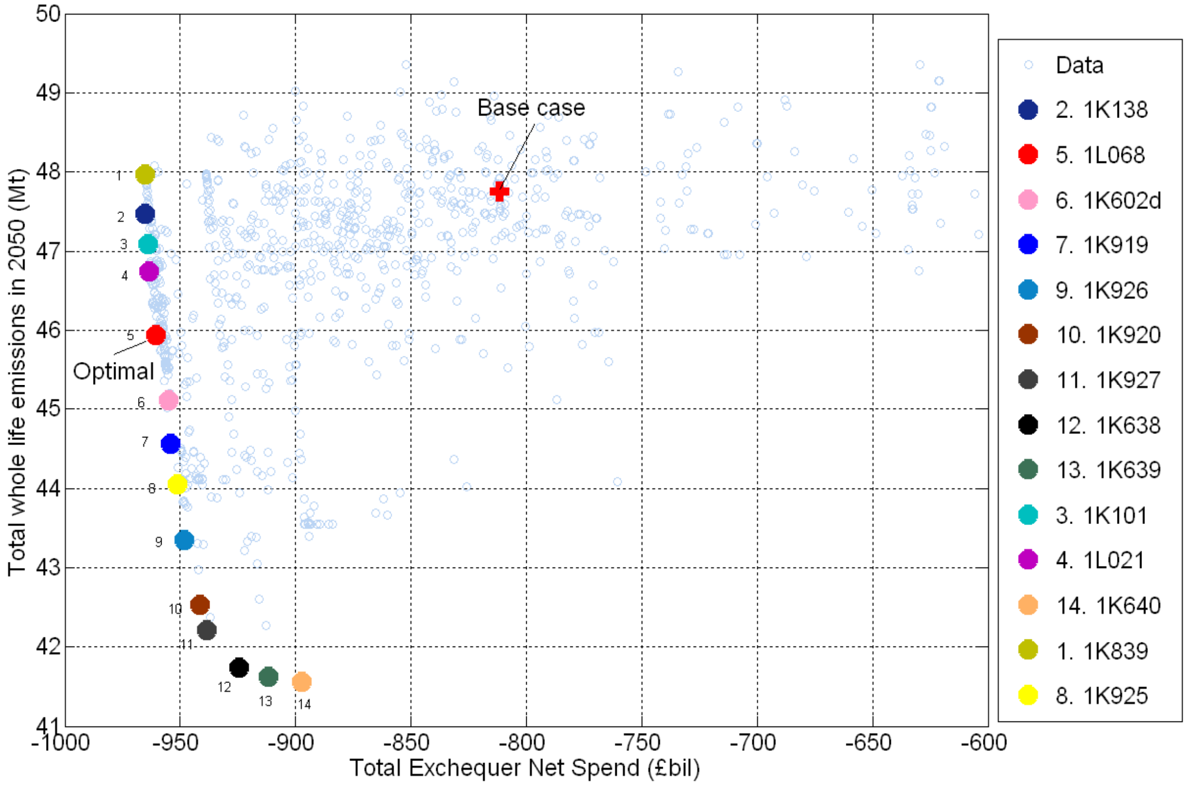


Figure 87 Trade off between emissions and expenditure (in base scenario)

Notice that the base case policy run (T0) lies at some distance from the frontier – indicating that the base policy is far from optimal (in terms of emissions reduction per unit cost to the Exchequer. All the runs further to the south and west of the "base" run are examples of negative abatement costs.Notice also that, although it was defined using a different definition of cost (including the value of 41 years of emissions as a "cost" to the Exchequer) the "optimal" run is on the frontier. However, it is clear that other combinations of policy variables can achieve lower emissions (but at greater cost to the Exchequer) or lower cost to the Exchequer (but with higher emissions) than the "optimal" run described in Section 4.

Table 30 : Value of policy levers for specified runs in the base scenario

Policy Levers	T0	1K839	1K138	1K101	1L021	1L068	1K602d	1K919	1K925	1K926	1K920	1K927	1K638	1K639	1K640
A. Subsidy on purchase of PiVs															
A1. Max budget for subsidy (£m)	43	0	5	0	0	**0**	0	0	0	0	0	0	5k	5k	5k
A2. End yr for PiV subsidy	11	11	12	12	11	**11**	25	11	11	11	11	11	25	25	25
A3. Max subsidy per PiV %	25	0	13	12	0	**0**	25	0	0	0	0	0	25	25	25
A4. Max subsidy per PiV (£k)	5	0	1.5	1.5	0	**0**	5	0	0	0	0	0	5	5	5
A5. End yr for BEV-only subsidy	11	0	12	0	0	**0**	0	0	0	0	0	0	25	25	25
A6. Max subsidy per BEV (%)	25	0	13	0	0	**0**	0	0	0	0	0	0	25	25	25
A7. Max subsidy per BEV (£k)	5	0	2	0	0	**0**	0	0	0	0	0	0	5	5	5
B. Company car tax treatment															
B1. Tighter limit on tax benefit for LEV purchases by companies?		Y	Y	Y	Y	**Y**	Y	Y	Y	Y	Y	Y	Y	Y	Y
B2. Tax treatment of PiVs as company cars based on WTW (rather than tailpipe) emissions?															
C. VAT															
C1. Raise domestic electricity rate to 20%?		Y			Y	**Y**	Y	Y	Y	Y	Y	Y	Y	Y	Y
D. VED															
D1. Multiplier relative to base VED rates	1.0	2.0	2.0	2.0	2.0	**2.0**	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
D2. VED based on WTW (rather than tailpipe) emissions?		Y	Y	Y	Y	**Y**	Y	Y	Y	Y	Y	Y	Y	Y	Y
E. Fuel tax															
E1. Multiplier on current rates	1.0	1.5	1.5	1.5	1.5	**1.5**	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
E2. Relating all fuel taxes to their emissions relative to petrol?					Y										
E3. Recovering any reductions in fuel tax by a fee per vehicle?	Y		Y		Y										
E4. Recovering any reduction from fuel tax by a usage charge?		Y		Y		**Y**	Y	Y	Y	Y	Y	Y	Y	Y	Y
F. Congestion charges															
F1. Extend charging to all major cities?		Y					Y	Y	Y	Y	Y	Y	Y	Y	Y
F2 Exemptions apply only to PiVs?		Y			Y	**Y**	Y	Y	Y	Y	Y	Y	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	Y	Y
G2. Charge points are R.As ?															
G3. Network intelligence is an R.A.?	Y	Y	Y	Y	Y	**Y**	Y	Y	Y	Y	Y	Y	Y	Y	Y
H. Charge point incentives															
H1. Initial deployment multiplier	1.0	2.0	1.85	1.85	2.0	**2.0**	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
H2. Level of capital grants 2013-2015	0	0	20	20	0	**0**	0	0	0	0	0	0	0	0	0
H3. Is tax write-off available?	Y														
H4. Maximum electricity price premium factor	1	0.8	1	1	1	**1**	1	1	1	1	1	1	1	1	1
H5. Excess provision coefficient	1.0	0.52	1.05	1.05	1.15	**1.3**	1.3	1.5	1.4	1.5	2	2	2	2.5	3
H6. Does government cover shortfall beyond 2013?		Y	Y	Y	Y	**Y**	Y	Y	Y	Y	Y	Y	Y	Y	Y
J. Average fleet emissions regulations															
J1. Emission level limit in 2050	42	50	40	40	30	**30**	35	30	30	30	30	30	25	25	25
J2. Measurement ton WTW (rather than tailpipe) emissions?		Y	Y	Y	Y	Y		Y			Y	Y			

Notice also that most of the frontier approximates a straight line. For emissions above 42 Mt, the trade off appears to be fairly stable at £4bn of Exchequer expenditure per Mt reduction in 2050 emissions[22] . However, below about 42 Mt there is a diminishing rate of return; the cost of a unit

[22] Note that, although the graph shows only the emissions in 2050, any reduction in 2050 emissions is likely to have been preceeded by 40 years of reduced emissions ; the benefit gained by the Exchequer expenditure is not simply the reduction in 2050 emissions.

marginal reduction in emissions increases for any further improvement – approaching about £200bn of Exchequer expenditure per Mt reduction in 2050 emissions.

It should be noted that the 42 Mt figure relates to total whole life emissions from the car parc. Since we are dealing with the base case in which the emissions associated with production and scrappage are about 22.4 Mt in 2050, the point of inflection is occurring at a point where emissions associated with vehicle usage are around 19.5 Mt which represents a 76% reduction on the 1990 value.

The point of inflection, where the cost of achieving further reductions in emissions begins to accelerate is at the south- western- most point on the frontier. The gradient of the frontier at this south-western-most point indicates a trade-off of about £30bn Exchequer expenditure per Mt reduction in 2050 emissions.

Runs 1K927, 1K638 and 1K639 are close to the south western corner of the frontier. Run 1K927 differs from the optimal run only in that the government support for charge point installation allows deployment of 2.0 (rather than 1.3) times that which would need a normal demand. Run 1K638 also differ from the optimal run in that respect but also in providing a large budget to subsidise purchase of PiVs up to 2025 and in specifying the average fleet emissions limit on a tail pipe (rather than well-to-wheel) scale. Run 1K639 is the same as 1K638 but allows government support for charge point installation to a factor of 2.5 times that which would need a normal demand. It is clear that these policies do achieve some further reduction in emissions – but only at a higher cost than in the optimal run.

Other runs of note are 1K839 and 1K138 which achieve similar emissions reduction to that achieved by the base policy (T0) – but at much lower net cost to the Exchequer. 1K839 differs from T0 in various respects but most crucially in reducing (or abolishing) the subsidy for purchase of PiVs, increasing Fuel tax, increasing the initial deployment of charge points and providing government support for installation of additional charge points. These policy measures are clearly cost effective.

Whilst the above analysis has considered costs relative to our optimal strategy, the graph can also be used to examine other trade-offs. Changing the assumed target to a lower total emissions will by definition provide a different trade-off. For example, the policies in run 1K640 provide the lowest emissions in 2050 but have a net spend by the Exchequer around £80 bn <u>less</u> than the base, implying that, relative to the base policies, the cost of meeting a more stringent target can actually be negative. Whilst 1K640 is much more expensive than the optimal strategy, it is decidedly preferable to the base policies – and would be preferred to the optimal policy if a more stringent target is applied or if the optimum was defined using higher values of carbon than those provided by DECC.

Figure 87 provided a graphical representation of policy space in the base scenario. Figures 88 to 94 provide similar representations for five other scenarios of interest. Namely: High Oil price (T9), Greenest electricity (EG1), Least green electricity (EG2), High UK GDP (T5), and Low UK GDP (T6). Table 29 provides definitions of the identified packages.

Comparison of the figures, with each other and with that for the base scenario, confirms that the achievable reduction in emissions is similar in the base scenario, the high oil price scenario and the greenest electricity scenario but is more modest in the least green electricity scenario, much lower in the high UK GDP scenario, and much greater in the low UK GDP scenario.

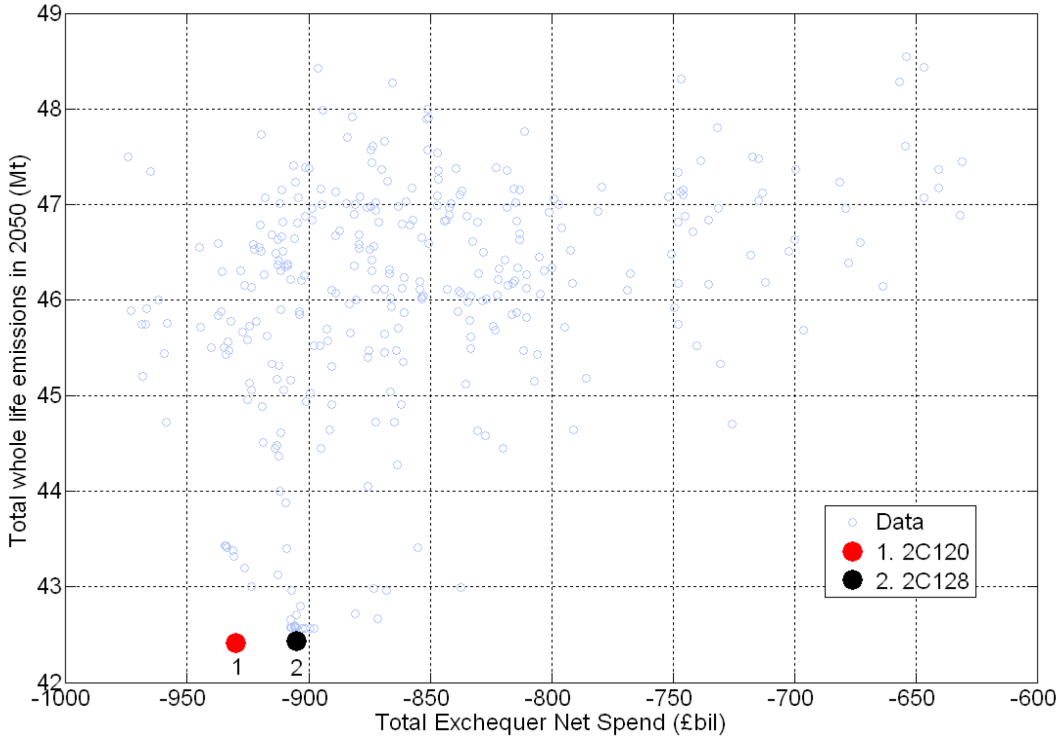


Figure 88 Trade off between emissions and expenditure (in High oil price scenario – T9)

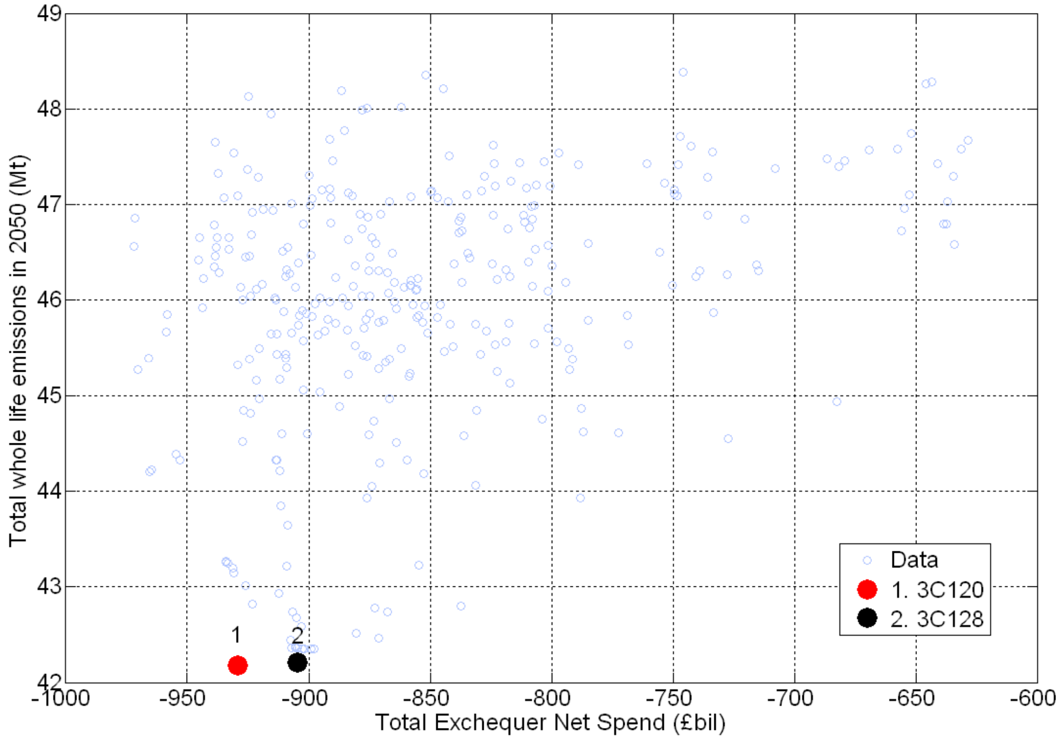


Figure 89 Trade off between emissions and expenditure (in Greenest Electricity scenario- EG1)

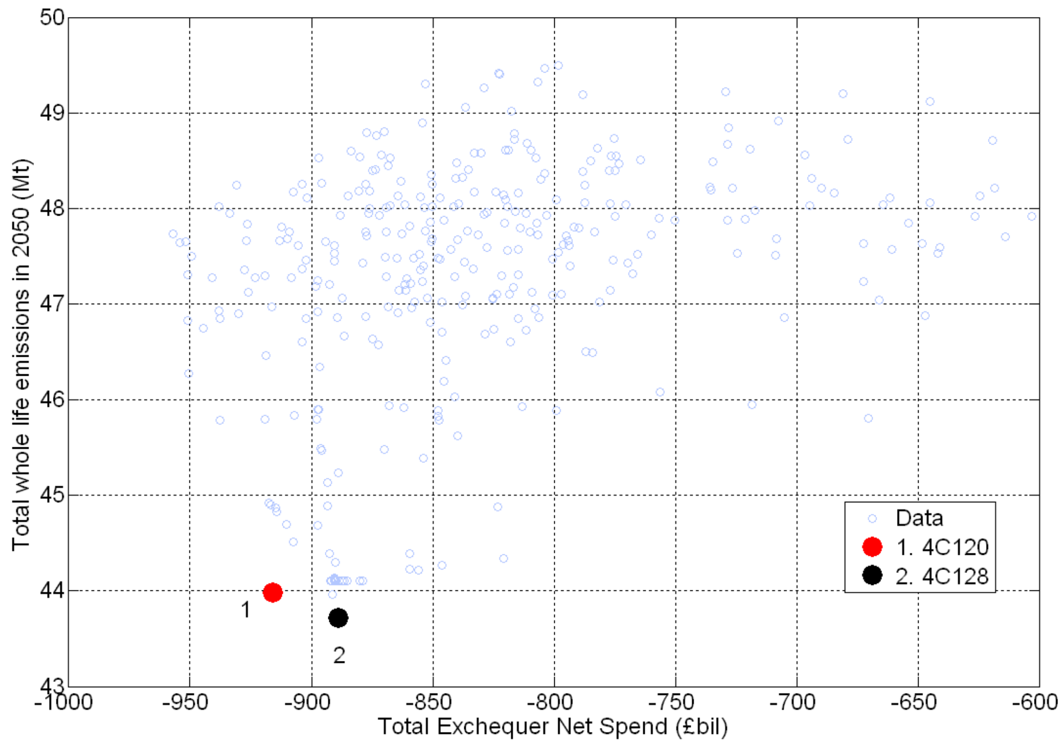


Figure 90 Trade off between emissions and expenditure (in Least Green Electricity Scenario – EG2)

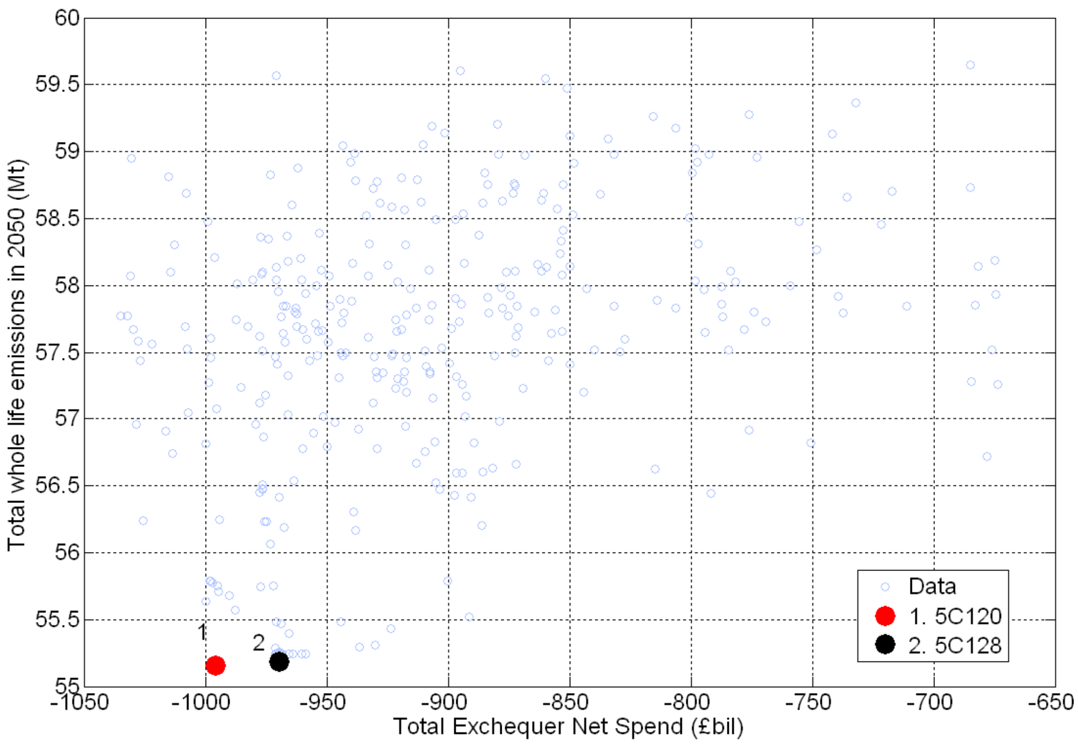


Figure 91 Trade off between emissions and expenditure (in High UK GDP Scenario -T5)

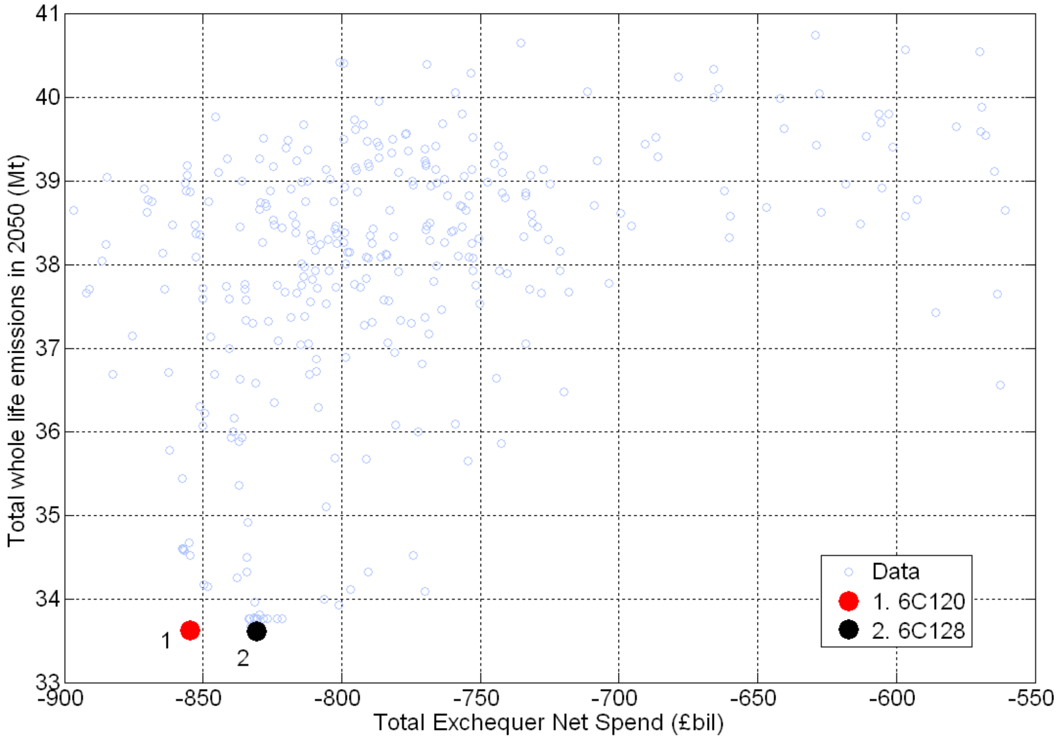


Figure 92 Trade off between emissions and expenditure (in Low UK GDP - T6)

Table 31 : Value of policy levers for specified runs in other scenarios

Policy levers	T0	1L068	C120	C128	1K927	1K638	1K639
A. Subsidy on purchase of PiVs							
A1. Max budget for subsidy (£m)	43	na	na	na	0	5k	5k
A2. End yr for PiV subsidy	11	11	25	25	11	25	25
A3. Max subsidy per PiV %	25	0	25	25	0	25	25
A4. Max subsidy per PiV (£k)	5	0	5	5	0	5	5
A5. End yr for BEV-only subsidy	11	0	0	0	0	25	25
A6. Max subsidy per BEV (%)	25	0	0	0	0	25	25
A7. Max subsidy per BEV (£k)	5	0	0	0	0	5	5
B. Company car tax treatment							
B1 Tighter limit on tax benefit for LEV purchases by companies?		Y	Y	Y	Y	Y	Y
B2. Tax treatment of PiVs as company cars based on WTW (rather than tailpipe) emissions?							
C. VAT							
C1. Raise domestic electricity rate to 20%?		Y			Y	Y	Y
D. VED							
D1. Multiplier relative to base VED rates	1.0	2.0	2.0	2.0	2.0	2.0	2.0
D2. VED based on WTW (rather than tailpipe) emissions?		Y	Y		Y	Y	Y
E. Fuel tax							
E1. Multiplier on current rates	1.0	1.5	1.5	1.5	1.5	1.5	1.5
E2. Relating all fuel taxes to their emissions relative to petrol?							
E3. Recovering any reductions in fuel tax by a fee per vehicle?	Y						
E4. Recovering any reduction from fuel tax by a usage charge?		Y	Y	Y	Y	Y	Y
F. Congestion charges							
F1. Extend charging to all major cities?			Y	Y	Y	Y	Y
F2. Exemptions apply only to PiVs?		Y		Y	Y	Y	Y
G. Regulated assets							
G1. Network reinforcement is an R.A.?	Y	Y	Y	Y	Y	Y	Y
G2. Charge points are R.As ?							
G3. Network intelligence is an R.A.?	Y	Y	Y	Y	Y	Y	Y
H. Charge point incentives							
H1. Initial deployment multiplier	1.0	2.0	2.0	2.0	2.0	2.0	2.0
H2. Level of capital grants 2013-2015	0	0	50	0	0	0	0
H3. Is tax write-off available?	Y		Y	0			
H4. Maximum electricity price premium factor	1	1	1	1	1	1	1
H5. Excess provision coefficient	1.0	1.3	1.3	1.3	2	2	2.5
H6. Does government cover shortfall beyond 2013?		Y	Y	Y	Y	Y	Y
J. Average fleet emissions regulations							
J1. Emission level limit in 2050	42	30	25	25	30	25	25
J2. Measurement ton WTW (rather than tailpipe) emissions?		Y			Y		

The pictures for these additional scenarios are less reliable, and the gradient of the frontier is less easy to measure, than that for the base scenario because they are populated by fewer runs and because those runs were not chosen specifically for that scenario. Nevertheless it is interesting to note that the gradient on the western frontier is similar in all five scenarios - implying a cost of between £10bn and £12bn per Mt of Carbon reduction in 2050.

It is also interesting to note that the same policy packages (C120 and C128) appear in south-western-most corner in all five scenarios. Package C120 is more useful than package C128 because it achieves similar emissions reduction but at lower cost. It differs from the "optimal" package (1L068) in offering subsidies for PiV purchases until 2025, in not raising the rate of VAT on domestic electricity, in extending congestion charging (and not ending the exemptions) , in offering grants and tax incentives for charge point installation and in basing the fleet average emissions limit on tail pipe values. It is very similar, except in respect of the nature of the incentives for ongoing charge point deployment, to run 1K638 (which was at the south west corner for the base scenario). The implication is that these policy packages appear at the cusp of the frontier where further reductions in emissions are achievable only at high cost almost irrespective of the scenario – although this conclusion can only be tentative until further policy packages are explored.

7 Conclusions & Recommendations

The overall project has developed a number of models and datasets to address a range of issues of importance to the ETI. SP3 has combined these models and datasets to investigate the performance of the overall system.

Detailed analysis of the overall system model has been carried out to investigate a "most likely" base case, 12 themed scenarios, optimisation of government policy, and the sensitivity of the system to each input variable. The purpose of the analysis was to address questions posed by the ETI at the outset of the project relating to the development of the PiV market and the resulting economic and carbon benefits[23].

The conclusions from our analyses will be further discussed along with conclusions from earlier stages in our work in our Final Report (WS3/ARUP/19). The following sections provide a summary of our overall conclusions from this stage in our work followed by more detailed conclusions and recommendations from the analysis under three headings:

- Policy related conclusions
- Model-related conclusions, and
- Recommendations for work in Phase Two of the PiVEIP project.

7.1 Overall Conclusions

Our overall conclusions from the work reported in this document are as follows:

- PHEVs and REEVs become competitive with conventional vehicles and sell in large numbers in most scenarios.
- BEVs remain more expensive than competitor vehicles and only sell in large numbers if all circumstances are favourable.
- PiV sales are highly dependent upon the perceived availability of charging points at home, at work and at public locations. More research is required on this aspect.
- The success of the business case for public charging point installations is dependent upon the assumed charging behaviour of consumers. Further research is required to provide data on this aspect.
- Inclusion of network reinforcement, network intelligence and public charging points within the Regulated Asset Base encourages public charge point installation. This leads directly to increased PiV sales.
- The subsidisation of charge point installation is a more cost effective use of government resources than subsidisation of PiV purchase. Government subsidy of PiV purchase can have a significant effect in the short term, but its lasting effect is negligible.
- No amount of public subsidy for PiV purchase and charge point installation can compensate for a poor showroom offer or overcome negative public attitudes towards PiVs.
- Loss of revenue from fuel duty becomes a very significant issue for public finances even when PiV shares are low, the annual VKT is significantly increased and/or fuel duties are raised.
- CO_2 emissions associated with vehicle use reduce significantly by 2050, such that emissions associated with vehicle production and scrappage becomes approximately 50% of the

[23] WS3/ARUP/08, *Agreed Specific Questions*, April 2010

lifetime emissions of the vehicle. Increasing the life of the vehicle thus becomes an important factor in minimising overall emissions.

- CO_2 emissions in 2050 are highly dependent upon assumptions about the size of the UK car parc and about the total vehicle kilometres travelled.
- It is possible to achieve the 80% reduction target for in-use emissions by 2050 without any change in government policy even under high growth assumptions provided that consumer behaviour, electricity supply/pricing behaviour and showroom on offer are all maximally favourable to PiV sales.
- It is not possible to achieve an 80% reduction in whole life emissions by 2050 in any of our scenarios. This is because emissions associated with production and scrappage emissions are rising, due to growth in the fleet, to becoming a greater problem than in-use emissions by 2050.
- In the base scenario, policy actions, notably including significant subsidy to the deployment of charge points, can, by 2050, achieve at least 77% reduction on the 1990 values of emissions associated with vehicle use.
- The trade-off between net expenditure by the Exchequer and reduction in CO_2 emissions in 2050 demonstrates diminishing returns on expenditure. In the base case, the cost per Mt reduction moves from about £4 bn to about £200 bn. The trade-off curve demonstrates a sharp inflection at around £30 bn per Mt at a point where total whole life emissions are 42 Mt and the emissions associated with vehicle use are about 19.5 Mt – which still exceeds 16.3 Mt (the desired 80% reduction on 1990 levels of such emissions).
- The DECC values of carbon are not high enough to give the Exchequer a purely financial justification for achieving the 80% reduction in the 1990 emissions by 2050 because the revenue to the exchequer of a non-PiV in terms of fuel duty, VED and other taxes outweighs the value of carbon saved in changing that vehicle to a PiV of any type.
- The trade-off graph can be used to assess the implications of imposing a more stringent target (or different implicit value of carbon). From the graph we can conclude that it is possible to achieve further reductions in emissions close to the 80% reduction target by including generous subsidies to PiV purchase and to charge point deployment (over and above those in the optimal policy). Despite this much higher investment, the net spend to the exchequer is still reduced by around £80 bn which suggests that the abatement cost of such a strong policy is negative compared to the base policies.
- Widespread deployment of PiVs would not significantly affect the grid demand requirements.

7.2 Policy-related Conclusions

The following conclusions are drawn from the analysis of the themed scenarios:

- Within the themes, whole life emissions associated with vehicle use vary from 10.9 Mt to 26.8 Mt in 2050. Only in themes T1, T3, T8 and T12 is the 80% reduction target (80% reduction from 81.7 Mt in 1990 = 16.3Mt) met in 2050. Achievement of this target requires all scenario variables including fleet and behavioural assumptions to be in favour of PiV sales. The fact that T3, which includes only the base policies with high growth assumptions meets the reduction target, demonstrates that the policy initiatives have much less impact on emissions than the non-policy variables. This could also be interpreted as implying that the 80% reduction target could be met, even in a high GDP scenario, without major policy initiatives.

- However this result is achievable only in the context of the most favourable assumptions about consumers' purchase decisions, about the supply of charge points, about the pricing of electricity, and about the manufacturers' willingness (and ability) to improve the showroom offer. This suggests that policies which affect attitudes and behaviour of consumers and manufacturers might prove worthwhile.

- Within the themes, emissions associated with production and scrappage range from 12 Mt to 31.3 Mt in 2050 – compared to 14 Mt in 1990. The high values result from high growth in the car parc and the only way to reduce these emissions is to improve the emissions rates associated with production and scrappage across the whole fleet offer. This would suggest that more attention should be paid to emissions from production and scrappage either through policies in the production/materials sector or through promoting increased average lifetimes for vehicles. This is backed up by the result of T5 which has the highest total emissions but where the majority of the increase comes from production and scrappage rather than from in-use emissions.

- If emissions associated with production and scrappage are considered to be a component of the total emissions to be reduced by 80% from the 1990 levels, then it is clear that achievement of the target is not possible.

- The showroom on offer is critical to take up of PiVs and to meeting emissions regulations. The optimisation work suggests that, without a favourable showroom in place, the impact of policy initiatives is limited.

- Allowing subsidies for PiV purchase until 2025 could be very costly if, as under T1, all other factors are favourable to PIV sales – the costs of subsidies in T1 is around £70 bn.

- While the PiV subsidies are significant as under T1, they do not seem to be necessary to stimulate the market for PiVs - similar shares can be achieved with no subsidies (T1 *vs.* T3). The net spend is however highly dependent on the GDP assumptions (as demonstrated by the low and high GDP scenarios T5 and T6 which show differences of £50-60 bn in net spend over the period to 2050). The fact that GDP growth is affected by other global factors and by domestic policies must, of course, be borne in mind when developing strategies to reduce the emissions from transport. From a narrow Exchequer perspective, the high revenues associated with high GDP growth are clearly to be welcomed - but this comes at the price of high emissions!

- In terms of policy actions it appears from the above comparisons that while the policies considered here have little impact, more emphasis should be put on improving the showroom on offer and upon changing consumer attitudes (though it should be noted that these two aspects are not included in the general feedback within the CRM - there is no feedback from sales of PiVs to the attributes of the showroom on offer, nor from uptake to consumer attitudes).

- A high or spiking oil price has little impact on PiV share or on emissions but does impact positively on revenue to the Exchequer. This is in part due to the general reluctance to purchase PiVs (as revealed by the consumer surveys) and if this reluctance is overcome, higher oil prices may well have a beneficial impact on PiV sales and on emissions reduction.
- The advanced fleet contributes substantially to the savings in emissions. Reduced emissions are substantial for all categories of vehicle and so overall reductions do not depend on an increased market share for PiVs.
- The advanced fleet results in a shift in PiV share from 18% to 26% (T5 vs. T7).
- Favourable consumer attitudes and patterns of re-charging, together with factors such as a favourable showroom and the provision of free electricity at workplaces and retail outlets, combine to create a shift in PiV share from 26% to 88% (T7-T3). This shift is an order of magnitude greater than the effect of the advanced showroom mentioned above.
- Moving from T3 to T1, all policy variables are set to favour PiV sales. This results in an increase in PiV share from 88.6% to 90.2% with a further reduction in emissions of only 0.5 Mt in 2050. The largest impact is on the revenue streams where PiV subsidy increases in value to a massive £69.2 bn. This outweighs the increased revenues from increases in VED and fuel duty which bring in an additional £34 bn compared to T3 resulting in a higher net spend of -£761 bn. Whilst this is still a surplus to the Exchequer it is an increase of £50 bn. From the comparison of T3 and T1 we may infer that the impact of policy on PiV sales and emissions is limited but that it can have a major effect on net revenues.
- Although deployment of public charge points is dependent on demand for public recharging, and although, according to the CRM, the deployment of public charge points is important to the uptake of PiVs, growth in the overall car parc does not itself greatly assist the uptake of PiVs if deployment of public charge points is fixed in the early years. This is because access to the fixed number of charge points deteriorates due to demand from the additional PiVs (compare T5 and T6)
- In terms of policy actions it appears from the above comparisons that, while the policies considered here have little impact, more emphasis should be put on improving the showroom on offer and upon changing attitudes of consumers.

From the Optimisation work, where we minimised the value of carbon emitted and cost to the Exchequer subject to meeting a specified target for whole-life emissions in 2050 ,we conclude that:-

- The fact that we had to impose a constraint on the optimisation process to achieve a 52% reduction on 1990 levels for whole-life emissions by 2050 (a figure which translates to a 71% reduction in emissions associated with use) implies that the DECC values of carbon are not high enough to give a purely financial justification for achieving this target50% reduction in the 1990 whole –life emissions by 2050 (this is because the revenue to the exchequer of a non-PiV in terms of fuel duty, VED and other taxes outweighs the value of carbon saved in changing that vehicle to a PiV of any type).
- The "optimal" policy was generally therefore concerned with raising money while reducing emissions which naturally lead to the inclusion of increased VED, fuel duty and VAT as win-win policies.
- Another key element of the package is the introduction of the revenue preserving tax to replace the fuel tax lost if/when ICEs fall in number. This tax was found to be better based

on vehicle use than as a per-vehicle charge (as in the Base) – presumably because, when based on usage, it helps to reduce usage. Although improvements in emissions can be achieved without a revenue preserving tax, its removal (as in T1) can be extremely costly to the Exchequer. The introduction of such a tax would, like increases in fuel duty, doubtless be opposed by many motorists and its justification would need to be carefully explained (it might be seen as unfair to promote PiVs with subsidies and to then introduce a fee to replace the lost fuel duty without fully informing the consumers).

- The costs of subsidies to PiVs outweighed the value of any consequential reduction in carbon emissions.
- Subsidies for public charge point deployment were seen to be cost effective (in the context of the model where charge point deployment is the key to breaking the technology lock-in).

From the sensitivity analyses we conclude that:

- Consumer behaviour variables generally have the greatest effect on the PiV system.
- Much of the reduction in emissions between 2010 and 2050 is due to the improvement in the fuel efficiency of conventional vehicles. This is partially offset by the elasticity of use with running costs, which results in higher mileage.
- Variation of overall VKT is an important driver of emissions because it affects the emissions of the whole vehicle parc.
- If recharging is free at retail and workplace locations, PiV take-up increases by 130% in 2050 and the total number of charge points necessary to meet demand increases by 900% in 2050.
- Access to domestic charging has more impact on PiV uptake than does access to non-domestic charge points.
- Many government policy levers have little effect on PiV take-up. Those that appear most effective are; encouraging higher levels of non-domestic charge point deployment by meeting shortfalls in profits, and introduction of tighter fleet average emissions legislation.
- Government subsidy of PiVs has a significant effect in the short term, but the lasting effect is negligible.
- A more stringent capital allowances criterion would reduce exchequer spend by 83% relative to the base case, whilst providing small benefits to PiV take-up, charge point deployment, and emissions.
- European fleet average emissions targets would be more effectively focussed if based on well-to-wheel (rather than tailpipe) emissions. However, the price adjustment mechanism, as represented in the CRM, is insufficiently strong to ensure achievement of the target level of fleet average emissions (consumer purchase behaviour does not adjust sufficiently to result in the target being met towards the end of the modelled period).

From the trade-off graphs we conclude that;

- The Exchequer expenditure required to achieve a unit reduction in 2050 emissions increases as the reduction increases.
- In the base scenario, for whole-life emissions above 42 Mt, the trade off appears to be fairly stable at £4bn of Exchequer expenditure (spread over 41 years) per Mt reduction in 2050 emissions. However, below about 42 Mt there is a diminishing rate of return; the cost of a

unit marginal reduction in emissions increases for any further improvement – approaching about £200bn of Exchequer expenditure per Mt reduction in 2050 emissions. The gradient at the point of inflection, where the cost of achieving further reductions in emissions begins to accelerate is about £30bn Exchequer expenditure per Mt reduction in 2050 emissions. These figures may, at first reading, appear high but it should be noted that the expenditure is spread over 41 years and that the reduced emissions in 2050 will have been preceded by proportionate reductions in the intervening years.

- In other scenarios the gradient above the point of inflection appears relatively stable at between £10bn and £12bn per Mt reduction in 2050.
- Numerous policy packages achieve similar emissions reduction to that achieved by the base policy (T0) – but at much lower net cost to the Exchequer. The cheapest of these differs from the T0 package in various respects but most crucially in reducing (or abolishing) the subsidy for purchase of PiVs, increasing fuel tax, increasing the initial deployment of charge points and providing government support for installation of additional charge points. These policy measures are clearly cost effective.
- In the base scenario, policy actions, notably including significant subsidy to the deployment of charge points, can, by 2050, achieve at least 77% reduction on the 1990 values of emissions associated with vehicle use.
- The trade-off graph can be used to assess the implications of imposing a more stringent target (or different value of carbon). For example, we can conclude that it is possible to achieve further reductions in emissions close to the 80% reduction target by including generous subsidies to PIV purchase and to charge point deployment (over and above those in the optimal policy) and, despite this much higher investment, the net spend is still around £80 bn below that in the base.
- Almost irrespective of the scenario, similar policies can be found at the point where further reductions in emissions are achievable only at high cost - although this conclusion can only be tentative until further policy packages are explored.

7.3 Model-Related Conclusions

Analysis of the overall system model across a wide range of variable settings has highlighted aspects of the overall system model that should be borne in mind when reviewing the results.

- The model's ability to predict the uptake of PiVs is compromised by the fact that it excludes a number of potentially important aspects. These include:
    - Consumers' ability to select from more than one vehicle class
    - The fact that desired patterns of use of range-restricted vehicles might differ substantially from those of conventional vehicles (and how this interacts with the number of vehicles owned by a household).
    - The likelihood that consumer attitudes will evolve over time.
    - The feedback between policies which are thought to stimulate the market for PiVs and the showroom offer.
    - The interaction between emissions regulations and showroom offer.
- The consumer response model puts great weight on the following issues:
    - The availability of public charge points; this dominates system behaviour is very reliant on assumptions about charge point deployment and about the variables that affect charge point deployment.
    - Consumer attitudes to the idea of PiVs although the model has the capability to vary consumer attitudes with time, for example in proportion to PiV sales, the absence of better data means this parameter is held constant in all analyses except CB6. In the base case the overall disutility of PiVs relative to conventional vehicles is so large that most policy changes are of insufficient magnitude to significantly alter PiV sales.
- The model assumes that consumer recharge behaviour strongly affects the demand for non-domestic charging and therefore the deployment of non-domestic charge points. This in turn affects the take-up of PiVs. Particular issues with recharge behaviour are summarised below.
    - There is no link between the cost of recharging at a non-domestic charge point and consumer use of those charge points (the model uses fixed assumptions about recharge patterns which have, through sensitivity testing, been seen to have considerable impact on overall results).
    - The amount of recharging at different types of charge points in different locations depends on the allocation of consumers to the different categories of charge point access in the recharge behaviour look-up tables. No allowance is made for the fact that behaviour would probably be modified in the light of actual availability.
- The charge point deployment algorithm generally aims to balance the number of charge points to forecast demand, with an assumption on the utilisation of charge points. Changing the charge point utilisation used for calculating the required number of charge points to meet a specific level of demand directly affects the number of charge points deployed, with strong knock-on effects on the model.
- The price adjustment mechanism envisaged in the CRM is insufficiently strong to ensure achievement of the target level of fleet average emissions (consumer purchase behaviour does not adjust sufficiently to result in the target being met towards the end of the modelled

period).This is perhaps unsurprising given that the model does not allow consumers to switch between segments and there is no mechanism by which producers can limit the uptake of available models or adjust the model specifications.

- Other work (reported in WS3/ARUP/11) with a meta-model which included a dynamic representation of the PiV market, showed that the impact of policy variables is very dependent on whether the basic scenario includes a successful market or a failing market. All the conclusions from the sensitivity analyses reported in the current document were set in the context of a "base case" in which a market for PiVs did develop. Other scenarios showed a failing market and, if they had been used as the base, different policy conclusions might have been drawn (our meta model work suggested that, while purchase subsidies were generally not seen to be necessary when an unsubsidised market would yield a 2050 market share of 20% or more, purchase subsidies were able to tip a failing market into a sustainable one). Our conclusions on the value of subsidies, and of other variables considered in the sensitivity analysis tests, must be seen in this light.
- Work with the dynamic meta-model of the PiV market (reported in WS3/ARUP/11) also showed that the success or failure of the PiV market was highly sensitive to assumptions about how knowledge of the new technologies spreads among the general population. Factors such as diffusion of positive experiences via word of mouth were seen to be important.

7.4 Recommendations for Work in Phase Two

These recommendations for further work seek to address aspects of the overall system model that are influential and currently subject to high levels of uncertainty and to increase the level of sophistication of the model in areas where the current simplifications are considered to reduce the accuracy of the forecasts. A major emphasis in the next phase of the work will clearly be to replace assumptions, expert opinion and stated preferences by data on actual behaviour by individuals and other actors in the system.

Specific recommendations for collection of new data include:

- Further research to verify the level of importance attached to the availability of public charge points (the perceived value of access). Data on this should begin to become available and is clearly to be preferred to the stated preferences which were necessarily used in the first phase of the work.
- Further work to explore the perceived (and actual) requirements for home charging.
- Further research to explore the factors affecting perceived availability of charge points. This is likely to involve study of actual patterns of utilisation (numbers of visits, dwell times etc) of charge points of different types in different locations, of the micro-location of charge points (because this affects visibility), and of consumer attitudes.
- Further research to verify/amend the assumptions, currently encapsulated in the charge point deployment algorithm, about the deployment of charge points as a function of costs and demand. The algorithms were developed after investigation of the likely business case for charge point deployment but, unsurprisingly, evidence on this was difficult to find in 2010. More evidence should emerge in the coming years.
- Further research to explore how consumer attitudes to PiVs are likely to change with PiV take-up would allow more realistic assumptions about the evolution of attitudes to be incorporated into the model. The dynamic meta-model, and various sensitivity tests (notably CB6) reported in the current document, have demonstrated the importance of this issue but there is, as yet, no data on which to base assumptions about the evolution of attitudes over time.
- Conduct research into consumer recharge behaviour, with particular regard to:
    - the proportion of recharging carried out in different locations (i.e. to explore the realism of the assumptions currently encapsulated in the recharge behaviour look-up table);
    - variation in behaviour in response to changes in the price of electricity in these different locations;
    - variation in behaviour associated with different levels of access;
    - amount/duration of recharging on visits at different times of day and at different types of location; and
    - the strength of any preference for rapid re-charge.
- Showroom variables have significant effects on PiV take-up but less than might be expected compared to some of the consumer behaviour and charge point supply variables. The relative importance of these different categories of variables should be verified in the next phase of the project.
- Published values for the elasticity of car use with respect to running costs are used in the model. However, it is unclear that these apply for PiVs where per-kilometre running costs are very much lower than for conventional vehicles. Further research should address this uncertainty.

- The notional value of charge points to retailers and employers is vitally important to the notional profitability of these types of charge points and is based on assumed values. Phase Two of the project should seek to verify these notional values.

Recommendations for further work on the overall system model:

- Add a link between PiV take-up and the vehicle showroom offer.
- Allow for different patterns of use to be desired for range-restricted vehicles –particularly those intended to be used as second cars in multi-car households..
- Include some representation of the market for other new fuels (notably hydrogen) which might compete with PiVs for market share.
- Allow recharge behaviour to reflect the costs of using different types of charge point.
- Include some representation of the market for second hand cars and the way in which this might affect a vehicle's useful life – and hence the production and scrappage emissions associated with a given level of car ownership.
- Review the algorithm for calculating the penalties applied by vehicle manufacturers to influence sales to meet fleet average emissions targets. Thought should be given to introduction of a mechanism by which manufacturers might respond by limiting supply or varying the specification – rather than just the price – although initial work might begin by investigating the effect of a higher penalty on non-compliant manufacturers.
- Update the consumer response model to allow the proportion of vehicles sold in each segment to vary, i.e. to allow consumers to choose between vehicles in different segments. This would allow sales to respond more realistically to changing price differentials between segments, e.g. resulting from fleet average emissions penalties.
- Similarly, the CRM should be modified to allow the uptake of vehicles of a particular type to be limited by the supply.
- The current model tackles the issue of product diffusion through the access to charge points sub-model and consumer segmentation (optimists, aspirers, etc). Other approaches to product diffusion could be investigated and take into account the evolution of the product and of consumer attitudes to reflect social impacts such as word-of-mouth or changes in social norms

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Appendix A: Base, Sensitivity & Theme Graphs

The full set of detailed graphs output by the ECBM, including many which have not been included in this report, are available as an addendum to this document (the addendum is presented as a separate document to avoid the main report becoming unmanageably large).

This document is titled 'WS3/ITS/02 – Appendix A Plots_v1.0'

The "raw" output from the runs of the Consumer Response Model which were drawn on in this phase of the work is available in WS3/ITS/01.

Appendix B: Definition of the Sensitivity Analysis Tests

Test	Description
T0	Base Case (all variables set to their current, or most likely, values)
CB1	Increased consumer preference for smaller cars
CB2	Increased consumer preference for larger cars
CB3	Increased proportion of private buyers (52%)
CB4	Consumer choice constants 50% more disutility of PiVs compared to ICEs
CB5	Consumer choice constants 50% lower disutility of PiVs compared to ICEs
CB6	Consumer choice constants start with calibrated disutility of PiVs compared to ICEs, which then decreases to zero as PIV sales reach ICE sales
CB7	Consumer choice constants 50% more sensitive to restricted range
CB8	Consumer choice constants 50% less sensitive to restricted range
CB9	Consumer choice constants 50% more sensitive to showroom price
CB10	Consumer choice constants 50% less sensitive to showroom price
CB11	Purchase decision affected by charge point availability as for those who assume highest availability of charge points
CB12	Purchase decision affected by charge point availability as for those who assume lowest availability of charge points
CB13	Ignore elasticity of car use with running costs
CB14	Assume lower percentage of private drivers recharge at home
CB15	Recharge behaviour of private and company drivers altered to reflect non-availability of normal speed public recharging
CB16	End of day recharging is not delayed in response to lower off-peak tariff
CP1	High domestic charge point availability (100% of those with off-street parking)
CP2	Low domestic charge point availability (60% of those with off-street parking)
CP3	Fixed deployment of charge points between 2014 and 2050 at high level, government meets shortfall in profits
CP4	Fixed deployment of charge points between 2014 and 2050 at medium level, government meets shortfall in profits
CP5	Fixed deployment of charge points between 2014 and 2050 at low level, government meets shortfall in profits
CP6	Initial charge point deployment doubled from T0
CP7	Initial charge point deployment quartered from T0
CP8	Government meets shortfall in profits for charge points and sets higher level of service at 1.1
CP9	High likely maximum utilisation of charge points (1.33)
CP10	Low likely maximum utilisation of charge points (0.67)
CP11	Government meets shortfall in profits for charge points
CP12	Government meets shortfall in profits for charge points and sets higher level of service at 1.5
CP13	Fixed deployment of charge points between 2014 and 2050 at very low level, government meets shortfall in profits
CP14	Zero deployment of charge points between 2014 and 2050
EG1	High fossil fuel prices, high carbon price, super ambition 90% CO2 reduction by 2050 target

Test	Description
EG2	Low fossil fuel prices, low carbon price, low 60% CO_2 reduction by 2050 target
EG3	Socially optimal least-cost path to 80% CO_2 reduction by 2050 target
SA1	High base demand, base carbon reduction scenario (80% CO_2 reduction by 2050)
SA2	Low base demand, base carbon reduction scenario (80% CO_2 reduction by 2050)
SA3	Medium base demand, low carbon reduction scenario (60% CO_2 reduction by 2050)
SA4	Medium base demand, socially optimal with least cost path carbon reduction
SA5	Low oil price
EP1	High costs for network reinforcement, network intelligence and charge points
EP2	Low costs for network reinforcement, network intelligence and charge points
EP3	High required rate of return on capital (9%)
EP4	Low required rate of return on capital (4%)
EP5	Charge points, network intelligence and network reinforcement are all regulated assets
EP6	Charge points, network intelligence and network reinforcement are all non-regulated assets
EP7	50% grant until 2015 and 100% WDA in year 1 on non-regulated charge point, network intelligence and network reinforcement costs
EP8	No special incentives on charge point, network intelligence and network reinforcement costs
EP9	Maximum PEP factor 0.5
EP10	Maximum PEP factor 1.5
EP11	Electricity free at workplace and retail charge points with corresponding adjustment to private driver recharge behaviour
EP12	High notional value of recharging to employers (20p/kWhr) and retailers (100p/kWhr)
EP13	Low notional value of recharging to employers (0p/kWhr) and retailers (0p/kWhr)
EP14	High likely minimum utilisation of charge points (double T0)
EP15	Low likely minimum utilisation of charge points (half T0)
EP16	High peak to off-peak electricity price ratio (2.5)
EP17	Low peak to off-peak electricity price ratio (1.0)
P1	No PIV purchase allowances
P2	As T0, but uncapped and extended until 2015
P3	As T0, but uncapped and extended until 2017
P4	As T0, but uncapped and extended until 2022
P5	As T0, but uncapped and extended to 2015 for PHEVs and REEVs and to 2022 for BEVs
P6	Stringent capital allowances for PiVs
P7	Company car tax applied as T0 until 2020 (based on TP) but after 2020 based on WTW emissions and extended to all vehicle types
P8	VAT on electricity increased from 5% to 20%
P9	VED reduced to zero with corresponding increase in fuel tax to double current levels
P10	VED increased to double current levels
P11	VED revised to be based on WTW rather than TP emissions
P12	Fuel tax at half current rate
P13	Fuel tax at double current rate

Test	Description
P14	Fuel tax as currently, except hydrogen taxed according to its WTW contribution to CO2
P15	No revenue preserving tax is introduced
P16	Revenue preserving tax is introduced based on vehicle kilometres travelled rather than as a fixed cost per vehicle
P17	Congestion charging as now (London only) with exemptions for low emissions vehicles continuing beyond 2015 with increasingly stringent criteria
P18	As for P17 but applied in all major cities
P19	Fleet average emissions made stricter 130g TP 2015, 95g TP 2020, 25g TP 2050
P20	Fleet average emissions as T0, but WTW from 2020 to achieve same overall CO2 cap as T0
P21	Fleet average emissions as T0, but WTW from 2020 to achieve same overall CO2 cap as P19
P22	Fleet average emissions made stricter 130g TP 2015, 95g TP 2020, 15g TP 2050
P23	Fleet average emissions made stricter 130g TP 2015, 95g TP 2020, 20g WTW 2050
S1	High upfront vehicle prices, excluding battery (+20% for PiVs, H2 and Fuel Cell; +0% for ICEs)
S2	Low upfront vehicle prices, excluding battery (-20% for PiVs, H2 and Fuel Cell; -0% for ICEs)
S3	High battery prices (+40%)
S4	Low battery prices (-40%)
S5	High other costs of ownership (+10% for PiVs, H2 and Fuel Cell; +0% for ICEs)
S6	Low other costs of ownership (-10% for PiVs, H2 and Fuel Cell; -0% for ICEs)
S7	High average life expectancy (+30% for PiVs, H2 and Fuel Cell; +0% for ICEs)
S8	Low average life expectancy (-30% for PiVs, H2 and Fuel Cell; -0% for ICEs)
S9	High fossil fuel consumption per 100km (+10% for PHEVs, REEVs, ICEs, H2; +0% for BEVs; +20% for Fuel Cell)
S10	Low fossil fuel consumption per 100km (-10% for PHEVs, REEVs, ICEs, H2; -0% for BEVs; -20% for Fuel Cell)
S11	High electricity consumption per 100km (+10% for PiVs, Fuel Cell; +0% for ICEs, H2)
S12	Low electricity consumption per 100km (-10% for PiVs, Fuel Cell; -0% for ICEs, H2)
S13	High maximum fully electric range (+30% for PiVs, Fuel Cell; +0% for ICEs, H2)
S14	Low maximum fully electric range (-30% for PiVs, Fuel Cell; -0% for ICEs, H2)
S15	High performance acceleration 0-100km/hr (-10% PiVs, H2, Fuel Cell; -0% ICEs)
S16	Low performance acceleration 0-100km/hr (+10% PiVs, H2, Fuel Cell; +0% ICEs)
S17	High production and scrappage emissions (+20% all types)
S18	Low production and scrappage emissions (-20% all types)
S19	Maximally favourable PIV showroom
S20	Minimally favourable PIV showroom
UK1	UK vehicle parc and VKT for high GDP growth
UK2	UK vehicle parc and VKT for low GDP growth
UK3	Consumer sensitivity to prices adjusted for high GDP per capita growth
UK4	Consumer sensitivity to prices adjusted for low GDP per capita growth
UK5	Consumer sensitivity to prices not adjusted for GDP per capita growth