‘The Business Case for Mass-market Deployment of Plug-in Vehicles’

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Abstract

The Energy Technologies Institute has commissioned a portfolio of projects into plug-in vehicles. These projects have undertaken a detailed assessment of the business case for the mass-market deployment of plug-in vehicles in the UK and the required energy infrastructure. New research has been undertaken, together with analysis and modelling where appropriate to understand the interrelationships between government policy, consumer attitudes, automotive industry investment and energy industry investment. The effects of the wider macroeconomic environment have also been evaluated. These projects have conducted new research to develop a world-leading and comprehensive knowledgebase, based on an integrated system approach:

1. Detailed bottom-up projections of future vehicle characteristics, performance (such as electric range and efficiency) and costs to 2050 have been developed for the full range of future power-train options (including plug-in vehicles and more conventional vehicles);

2. Consumer attitudes and behaviours have been researched through real-world trials and extensive surveys with ‘mass-market’ consumers, including a choice experiment to quantify consumers’ willingness to pay for specific vehicle attributes;

3. The requirements and costs for the supporting recharging infrastructure and its integration into the UK electricity system have been identified; and

4. The economics and carbon benefits have been evaluated in the context of plug-in vehicles as a component of the UK’s future low carbon energy and transport systems.

This paper reflects work completed in mid 2011 by a consortium of Arup, Leeds University and E.ON, primarily focusing on item (4) [1] and drawing on insights from separate ETI projects into items (1) to (3).

Keywords: plug-in vehicle, electric vehicle, business case, charging point, policy

1 Background to the Project

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

As a result of the findings from the high-level ESME analysis, the ETI commissioned a number of projects into plug-in vehicles. These projects have undertaken a detailed assessment of the business case for the mass-market deployment of plug-in vehicles in the UK and the required energy infrastructure.

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

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4. The economics and carbon benefits have been evaluated in the context of plug-in vehicles as a component of the UK's future low carbon energy and transport systems.

Three consortia were set up to implement the projects, each with a consortium leader (shown in parenthesis below):

- Consumers and Vehicles (Ricardo)
- Electricity Distribution and Intelligent Infrastructure (IBM)
- Economics and Carbon Benefits (Arup)

In the Economics and Carbon Benefits (E&CB) consortium, Arup led partners E.ON and the University of Leeds Institute for Transport Studies (ITS). This paper reflects work completed in mid 2011 in the E&CB project only, which was primarily focused on item (4) but drew on insights from the separate ETI projects into items (1) to (3).

Arup and Leeds ITS defined the scenarios and variables to be used by all participants within the overall project modelling, following extensive consultation with stakeholders. The E&CB consortium also analysed macroeconomics effects, generated business models and new revenue streams, modelled grid generation, provided fuel price forecasts, modelled the overall economic effect of PiVs and also modelled the carbon benefits and generated associated carbon pricing.

This paper reflects work completed in mid 2011 as just one part of a wider and ongoing ETI investment programme. The findings in this paper are therefore not necessarily those of the wider ETI programme. Any views expressed herein are those of the authors and not necessarily those of the ETI.

2 Carbon Reduction Targets

The Climate Change Act was introduced in the UK in 2008 and set up a legal framework to tackle the issues of climate change. The Act requires that emissions are reduced by at least 80% by 2050, compared to 1990 levels. The UK emissions from greenhouse gases (GHG) in 1990 were 780 $MtCO_2e$ [2].

Figure 1 shows the sectoral GHG emissions from 1990-2009 by 'end-user'. The term 'end-user' is used to signify that the emissions from the energy sector (e.g. due to electricity generation and oil refinement) have been transferred to the end-user. This is equivalent to reporting well-to-wheel (WTW) emissions for each end-user.

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

As transport is a major contributor to UK CO_2 emissions, they must be reduced. However, it is one of the two most costly sectors, the other being the industry sector, in which to reduce energy consumption and carbon emissions. Transport is hence likely to make up much of the residual 2050 emissions.

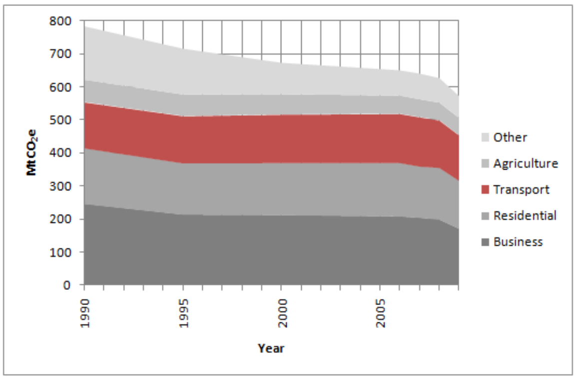

Figure 1: Greenhouse gas emissions by end-user, 1990-2009 ($MtCO_2e$) [3]. Note: Transport does not include International Aviation & Shipping (IA&S)

Modal shift (as can be seen in Figure 2) and demand reduction will have a role to play, but will not be sufficient without very significant technology change as well.

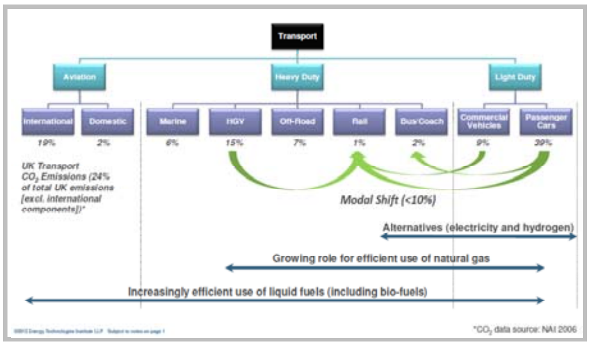

Figure 2: UK Transport CO2 Emissions by vehicle category

PiVs will become just one part of a complex transport landscape. Efficiency measures (in existing vehicle technologies) and exploiting alternatives wherever possible (natural gas, electricity and hydrogen) are therefore two critical priorities. The roadmap for passenger and light duty vehicles (see Figure 3) published by the UK Automotive Council illustrates this point.

This roadmap is based upon interviews with OEMs (Original Equipment Manufacturers – i.e. vehicle manufacturers). The motivation driving the development of lower carbon vehicles is the EU fleet average tailpipe CO_2 target [4] in g/km which reduces with time and has penalties to the vehicle manufacturer for non-compliance.

Initially compliance can be achieved by improvements in conventional vehicles, but as targets become more stringent, there is a need to include hybrids and ultra low emission vehicles in the fleet mix. The timeline shows OEM's expected introduction dates for each type of vehicle.

This project reports WTW emissions in order to provide a true comparison between Internal Combustion Engine Vehicles (ICEVs) and PiVs.

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

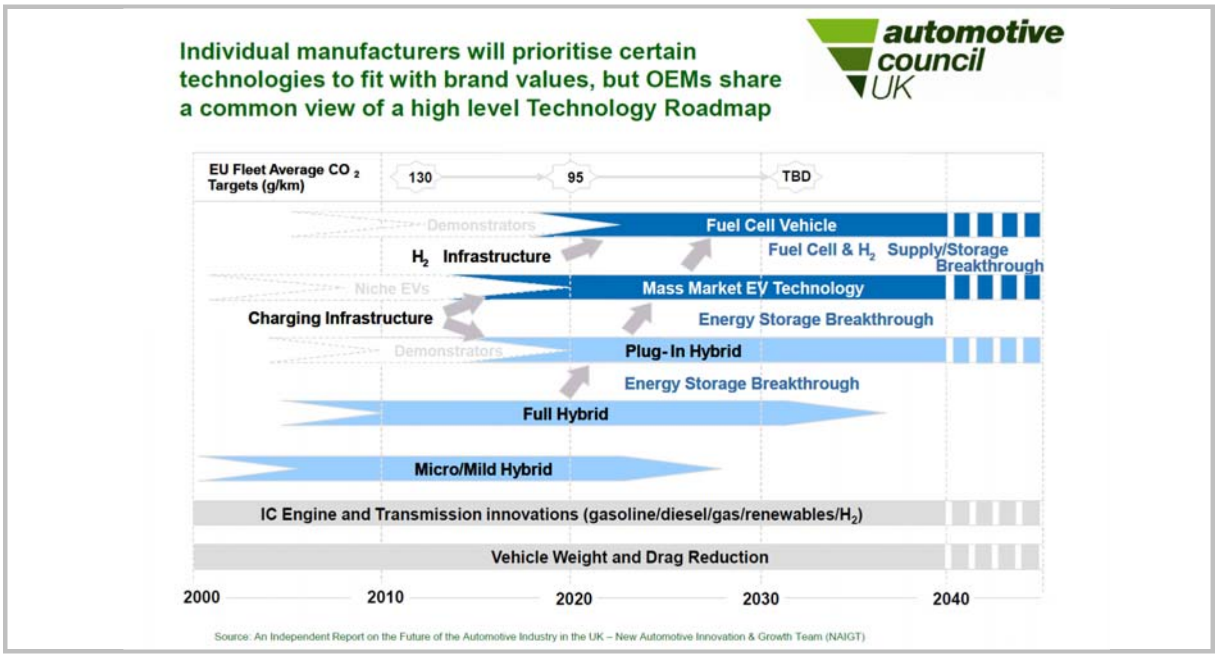

Figure 3: Passenger Car and Light Duty Vehicle Technology Roadmap [5]

3 Modelling & Scenarios

In the creation of a computer representation of the PiV market, it has been necessary to perform new research, to allow the project to determine the influence of the following factors:

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

Much of this new research was conducted in the other ETI projects, providing data for use in the E&CB project modelling work. The high level modelling diagram (Figure 4) shows how these factors have been incorporated into the modelling.

3.1 Input variables

Variables have been defined which characterise these factors; e.g. vehicle range, cost, GDP growth, oil price. Each has been assigned a 'base case' (most likely or moderate viewpoint) and bounding (low and high) values. 29 variables are policy levers available to Government.

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

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

3.2 Scenarios

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

- Sensitivity analyses have been performed by changing each variable to "high" or "low" in turn, keeping the remaining variables at their baseline value. This provides information on the sensitivity of the key outputs to the variable being changed. Note that care should be taken in using these sensitivities away from their datum of the base case scenario.

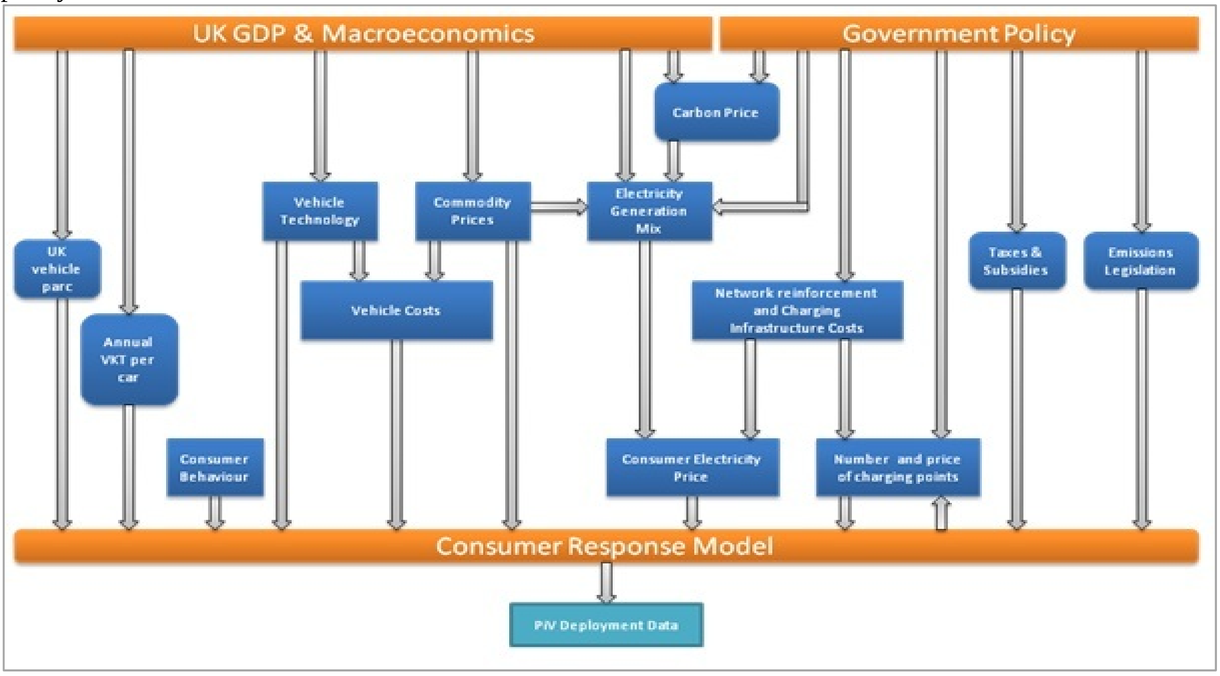

Figure 4: High Level Modelling Diagram

- Optimisation to identify the "best package" of the 29 Government's policies has been performed, maximising their effect for the case where other "external" factors are set to their base case values. "Best package" was defined as the set of values for the 29 available policy levers which, while meeting a target reduction in CO_2 by 2050, did so at minimum cost to the Exchequer. The policy optimisation work has been performed by Leeds ITS.

In addition, a small set of consistent "Themed Scenarios" has been analysed, and reviewed in more detail. These consider specific possible futures, both in terms of Government policy and external factors. The "Themed Scenarios" are designed to answer broad questions such as:

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

The computer models can predict the yearly figures for a variety of outputs associated with PiV deployment between 2010 and 2050. These include the sales of passenger vehicles by segment and type, the deployment of charge points, the carbon emissions from the vehicles, and the net cost to the Exchequer of taxes and incentives. In particular the following four key indicators have been used to classify the scenario results:

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

4 Results

4.1 Base Case Results

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

- In-use CO_2 emissions from passenger cars reduce to 25Mt in 2050 (69% reduction on 1990 levels), driven largely by improvements in the fuel efficiency of non-PiVs (Figure 7)
- Exchequer spend related to PiVs over the period 2010 to 2050 totals £5billion
- PHEV/REEVs make up 19% of the UK vehicle parc in 2050 with BEVs making up 1% (Figure 5)
- PiVs have only a localised effect on grid demand

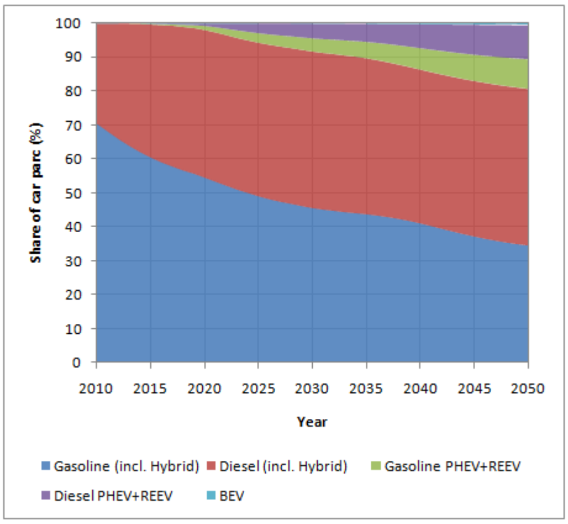

Figure 5: Share of cars in the parc

Between 2010 and 2050 the UK vehicle parc grows from 29million to 45million. The share of PHEV/REEVs and diesel non-PiVs grow at the expense of gasoline non-PiVs.

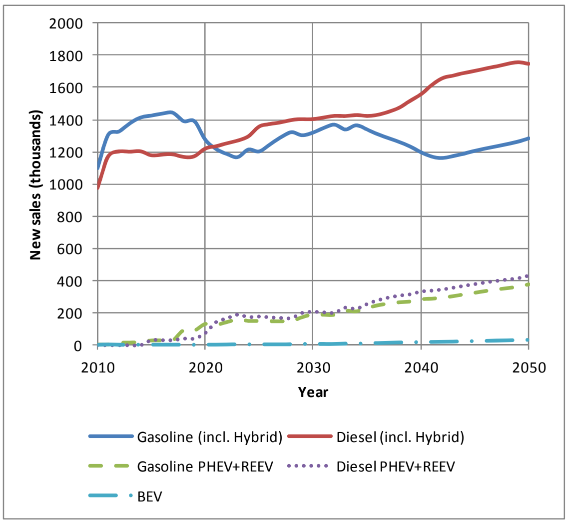

Figure 6: New car sales by type

In 2020, basic petrol and diesel vehicles are discontinued with stop-start vehicles becoming the least hybridised vehicle architecture and OEMs begin to adjust vehicle prices to influence sales to achieve fleet average emissions targets.

Vehicle emissions reduce more slowly than the assumed emissions target, so by 2035 non-PiV emissions near or exceed the fleet average emissions target, so increasing price adjustments are applied. However, these are insufficient to encourage consumers to buy PiVs, so by 2046 the target is exceeded and remains so through to 2050.

CO_2 emissions from car use reduce from 78Mt/year in 2010 to 25Mt/year in 2050, a 69% reduction on 1990 levels, which is far less than the 90% estimated to be required by CCC [6].

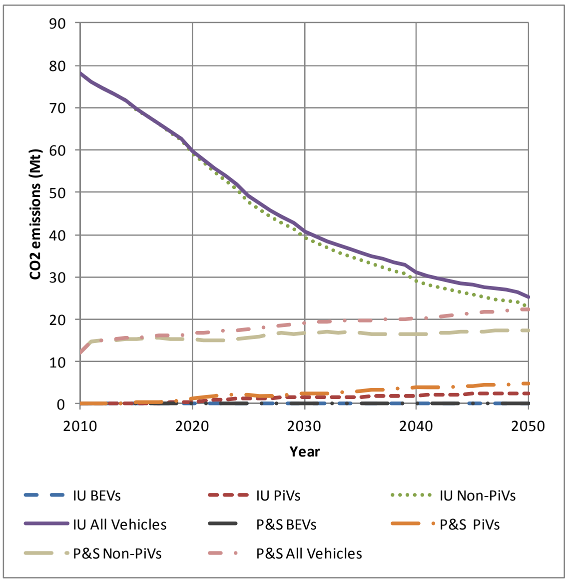

Figure 7: In-use and production and scrappage CO_2 emissions

Most of the in-use emissions reduction comes from the improvement in fuel efficiency of non-PiVs – an entirely non-PiV parc would emit around 28Mt/year in 2050, a 65% reduction on 1990 levels. The CO_2 emissions of PHEV/REEVs are on average 46% of those of non-PiVs. Replacing 19% of the parc with PiVs contributes a further 4% reduction on 1990 levels.

It should be noted, however, that the assumed CO_2 emissions of PHEV/REEVs relative to non-PiVs is based on the very simplified New European Drive Cycle (NEDC) calculation for such vehicles. Work in the wider ETI programme to explore how cars are actually used may reveal a greater benefit from a shift to PHEV/REEVs. Furthermore, the CO_2 emissions of PHEV/REEVs are likely to decrease as the battery size is increased; this trade-off was not explored in the projects, but will be explored in the wider ETI programme.

In the base case scenario, the vehicle parc increases by 55% over this period and the total production and scrappage emissions increase by 53% from 15Mt in 2011 to 22Mt in 2050 due to an assumption that production and scrappage emissions per vehicle decrease slightly over the period. If, however, production and scrappage emissions per vehicle can be reduced more significantly, then this would be expected to fall.

Exchequer spend includes subsidies to PiVs and charging infrastructure and Corporation tax lost to incentives for Low Emission Vehicles (LEVs), which dominates the overall spend (Figure 8).
Lost corporation tax is really delayed receipt of corporation tax, due to faster allowable write-off of LEVs, which shows as a loss in an expanding LEV market (Figure 8).

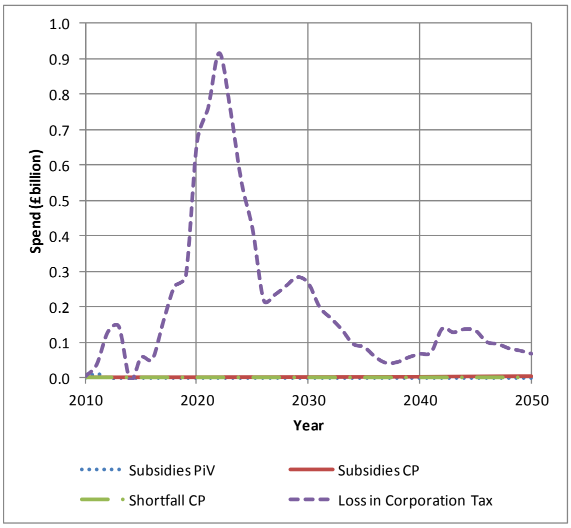

Figure 8: Exchequer spend including 'lost' tax

The demand for electricity due to PiV recharging follows the take-up of vehicles, increasing steadily up to 2050 (Figure 9). Vehicles annual mileage is assumed to not vary with vehicle type, so BEVs draw more than twice as much electricity from the grid as PHEV/REEVs, which use liquid fuels to power some of their annual mileage. However, the low take-up of BEVs means electricity demand from PHEV/REEVs dominates. As explained above for CO_2 emissions, this data is sensitive to both battery size and how PHEV/REEVs are actually used.

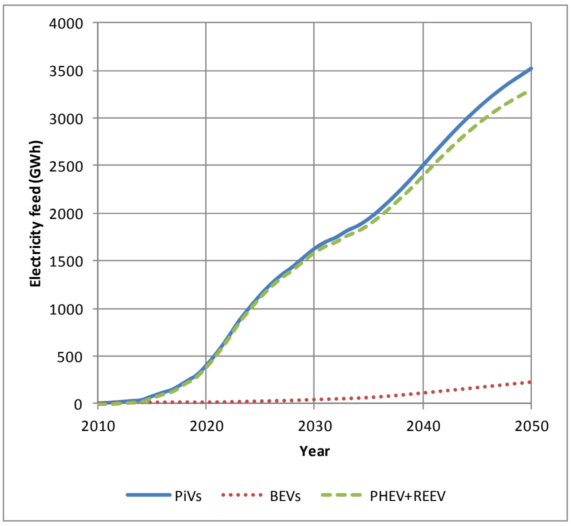

Figure 9: PiV electricity demand

The effect of PiVs on overall electricity demand is small, even in 2050 (Figure 9). Most recharging is assumed to take place overnight, when the base load on the grid is low. However, if the price of liquid fuel increases relative to the price of electricity from non-domestic charge points, PHEV/REEV drivers may seek to recharge away from home instead of using liquid fuel to extend their range. This would put more pressure on public and workplace charge points and increase the amount of recharging carried out during the day.

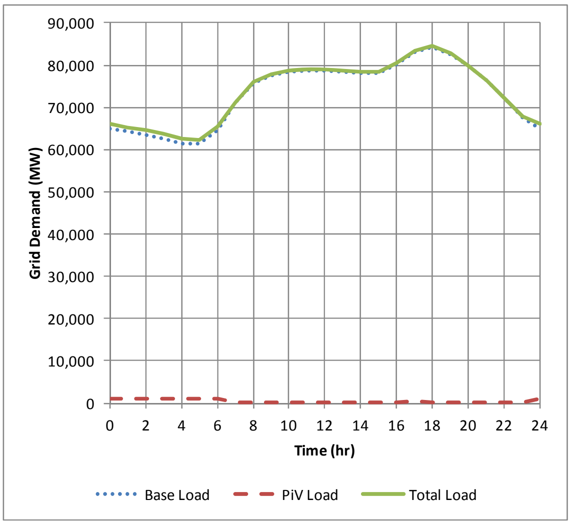

Figure 10: Effect of PiV electricity demand on the grid for winter weekday in 2050

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

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

It should be noted, however, that model outputs on charge point numbers are highly sensitive to the assumptions made about how vehicles are used. Work in the wider ETI programme seeks to increase significantly understanding of car use.

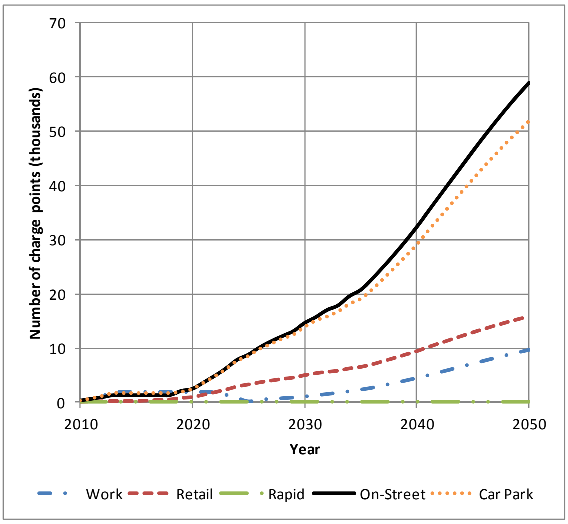

Figure 11: Charge points installed

4.2 Sensitivity Test Results

Please note that the following observations and corresponding insights from the sensitivity results are strictly only applicable in the vicinity of the base case scenario.

The critical market enablers appear to be consumer attitudes and charging infrastructure availability. Vehicle price also appears important.

Modest changes in consumer attitudes may increase the share of the parc of PHEV/REEVs from 19% to 32% and BEVs from 1% to 3%. It should be noted that the consumer attitudes may change further once large number of PiVs are in the marketplace. The model is calibrated on survey work conducted in 2010. In the base case, it was assumed that behavioural preferences remain unchanged until 2050. Further research into consumer attitudes should focus on acceptance of the idea of PiVs and how that might change with time including the effect of product diffusion; and the importance attached to domestic and non-domestic charging infrastructure and how that might change.

The effect of charging infrastructure varies depending on whether it is domestic, workplace or public, and on the level of deployment. For very high levels of non-domestic CP deployment PHEV/REEV market share can reach 48% and BEV share sees a small increase. However, the value consumers attach to non-domestic recharge points (and the corresponding effect on vehicle uptake) may decrease as the technology becomes more familiar. Low vehicle prices are expected to increase PHEV/REEV share to 23% but the BEV share remains static.

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

Non-domestic CPs can be operated profitably with the size of the market limited by consumer demand to around 136,000 charge points. As above, however, this is highly sensitive to the assumptions made on how recharge points are used. Extensive infrastructure deployment at a level that will, in itself, stimulate large increases in PHEV/REEV take-up is likely to require strong and sustained Government support in the order of at least £10billion over the period to 2050.

Conclusions relating to charging infrastructure depend greatly on the recharging behaviour of consumers, about which there is currently very limited data. For example, non-domestic CP deployment in 2050 varies from 136k to 841k between scenarios, but could be as low as zero if needs can be satisfied with home recharging. Work in the wider ETI programme seeks to significantly increase understanding of car use.

4.3 Themed Scenario Results

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

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

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

Minimum emissions are achieved with low cost, advanced vehicles, green consumer attitudes, supportive government policies and low UK growth to reduce the parc and reduce total vehicle kilometres travelled. In-use emissions can then be reduced to 11Mt/year or 13% of 1990 levels.

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

Like the sensitivity analyses, the themed scenarios show that the PiV market will be dominated by PHEV/REEVs. It is therefore critical that a better understanding is developed on how cars are used in order to optimise the trade-off between battery size and CO_2 emissions. The wider ETI programme seeks to do this. If the proportion of mileage in electric mode for a PHEV/REEV can be increased from that assumed in these projects, the CO_2 reduction could be better than noted above.

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

5 Key Findings

PiVs offer the potential to decarbonise a large proportion of passenger car transport. However, consumer attitudes, battery technology and PiV purchase costs are expected to be a significant barrier to PiVs outselling conventional vehicles. In the base case, in 2050, the OEMs provide cross-subsidies between cars to encourage purchase of low emission cars. Penalties of the order of £10,000 are given to the worst CO_2 emitting conventional cars compared to BEVs, but still the conventional vehicles outsell the BEVs many times over.

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

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

If PiVs are around 20% of the vehicle parc in 2050, the vast majority of emissions reduction is likely to come from improvements in the fuel efficiency of conventional vehicles. This improvement is primarily driven by fleet average emissions legislation which is defined in EU Regulation (EC) No 443/2009 until 2020. Setting an appropriate 2050 target and a penalty to incentivise OEMs adequately to develop their showroom offer within that target will form an important part of emissions reduction strategy. Our base scenario assumed a tailpipe target of 42g CO_2/km by 2050.

PHEV/REEVs are very likely to dominate the PiV market as no variables are sufficient to overcome the large consumer bias against BEVs. This conclusion is strongly supported by extensive consumer survey data undertaken. However as noted before this could change with time and familiarity with PiVs. It is therefore critical that a better understanding is developed on how cars are used in order to optimise the trade-off between battery size and CO_2 emissions. The wider ETI programme seeks to do this. If the proportion of mileage in electric mode for a PHEV/REEV can be increased from that assumed in these projects, the CO_2 emissions reduction could be much better than noted above.

Government incentives considered in this study, including vehicle subsidies, have little lasting effect on PiV take-up and CO_2 emissions. Subsidy for the deployment of recharging infrastructure could have a more lasting effect, provided that consumers continue to value non-domestic recharge points in their purchasing decision.

The success of the long term business case for public charging infrastructure is dependent on the scenario, with installation of charge points stalling in unfavourable scenarios and expanding rapidly and profitably in favourable scenarios. The deployment and potential profitability of non-domestic charging infrastructure is highly dependent on recharge behaviour and achievable utilisation, which are currently poorly understood, due to the lack of large scale trial data.

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

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

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

In-use emissions will be greatly reduced by 2050, so production and scrappage emissions will be a more significant proportion of whole life emissions and will need to be mitigated as well.

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Ricardo, IBM, E.ON, EDF, Shell, University of Leeds, Element Energy, TRL, University of Sussex, University of Aberdeen, UKPN and Imperial College London.

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