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The scope for and potential impacts of the adoption of electric vehicles in UK surface transport

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1. Transport and Energy in the UK

In 2008 transport comprised 35.5 per cent of total UK final energy consumption (by user). The breakdown of this demand by energy source is shown in Table 1 (BERR, 2009). Electricity currently provides only 1.2% of the transport sector's energy demands, although it provides almost half of the energy used by the rail sector. The two most important users of energy are road transport (71.7 per cent) and air transport (21.8 per cent). Domestic shipping comprises only 3 per cent of energy consumed. Overall domestic transport was responsible for 131.4 Million tonnes of carbon dioxide in 2007 which corresponds to 24.2% of the national total (DfT, 2009a). Whilst the future demand for aviation remains a very significant policy issue for climate change, there appears little prospect of switching propulsion technology in aviation or shipping in the medium term and no further consideration is given to them in this Chapter.

Table 1: Energy Consumption in the Transport Sector (000s Tonnes oil equivalent)

Mode	Petroleum	Biomass	Primary Electricity	2008 Total	% Change 1998-2008
Road	41331	821		42152	+2.8
Rail	747		725	1472	+9.9
Aviation	13426			13426	+31.1
Domestic Shipping	1764			1764	+8.9
Total	57268	821	725	58814	+9.4

Traffic has grown by 13.9% over the period from 1997 to 2007 and is forecast to grow by a further twenty five per cent by 2025[1] (DfT, 2008a). The key drivers of this growth in demand are income, employment, population and travel costs. Table 2 shows how the demand for petroleum products has varied across cars, light and heavy goods vehicles over the period 1997-2007 alongside the

[1] Relative to 2003 levels

change in kilometres driven. There have been advances in engine efficiency and a shift to diesel cars which have kept the rise in energy demand at 2.8 per cent, well below the rise in kilometres. There has been a significant increase in vehicle kilometres in recent years in the light goods vehicle sector. Bus and coach travel account for only 4.2% of all petroleum products.

Table 2: Petroleum Consumption for road transport 1997-2007 (Million Tonnes) Source: DfT (2008b)

<table>
<tr><td>Mode*</td><td colspan="2">1997</td><td colspan="2">2002</td><td colspan="2">2007</td><td colspan="3">% change 1997-2007</td></tr>
<tr><td></td><td>Million Tonnes</td><td>Billion Vehicle Kms</td><td>Million Tonnes</td><td>Billion Vehicle Kms</td><td>Million Tonnes</td><td>Billion Vehicle Kms</td><td colspan="2">Million Tonnes</td><td>Billion Vehicle Kms</td></tr>
<tr><td>PTW (petrol)</td><td>0.14</td><td>4.0</td><td>0.15</td><td>5.1</td><td>0.14</td><td>5.6</td><td colspan="2">0.0</td><td>+40</td></tr>
<tr><td>Car (petrol)</td><td>20.58</td><td rowspan="2">365.8</td><td>19.73</td><td rowspan="2">392.9</td><td>16.76</td><td rowspan="2">404.1</td><td>-18.6</td><td rowspan="2">-6.4</td><td rowspan="2">+10.5</td></tr>
<tr><td>Car (diesel)</td><td>2.42</td><td>3.37</td><td>4.78</td><td>+97.6</td></tr>
<tr><td>LGV (petrol)</td><td>1.27</td><td rowspan="2">48.6</td><td>0.67</td><td rowspan="2">55.0</td><td>0.42</td><td rowspan="2">68.2</td><td>-66.9</td><td rowspan="2">+48.3</td><td rowspan="2">+40.3</td></tr>
<tr><td>LGV (diesel)</td><td>3.13</td><td>4.10</td><td>6.11</td><td>+95.3</td></tr>
<tr><td>HGV (diesel)</td><td>7.87</td><td>26.9</td><td>8.15</td><td>28.3</td><td>8.53</td><td>29.4</td><td colspan="2">+8.3</td><td>+9.3</td></tr>
<tr><td>Bus & Coach</td><td>1.55</td><td>5.2</td><td>1.30</td><td>5.2</td><td>1.62</td><td>5.7</td><td colspan="2">+4.1</td><td>+9.6</td></tr>
<tr><td>Total</td><td>36.96</td><td>450.3</td><td>37.46</td><td>486.5</td><td>38.35</td><td>513.0</td><td colspan="2">+4.1</td><td>+13.9</td></tr>
</table>

* PTW = Powered Two Wheeler, LGV = Light Goods Vehicle, HGV = Heavy Goods Vehicle, Cars include taxis

The difficulty in achieving substantial cuts in petroleum consumption from existing technologies, and hence CO_2 emissions, is a prime motivation for turning to the potential for electrification of the transport sector. The UK reduced its greenhouse gas emissions by twenty one per cent between 1990 to 2007 (DECC, 2009).[2] Despite the overall downwards trajectory for the UK, emissions from transport rose by just over eleven per cent over the same period (EEA, 2009). The UK government has adopted the interim recommendations of the Committee on Climate Change of achieving a thirty four per cent reduction in CO_2 emissions by 2020 relative to 1990 and, should further international agreements be successfully negotiated, then this may be extended to forty two per cent. A longer term goal of eighty per cent cuts by 2050 also exists. The government's low carbon transport strategy currently expects to deliver a ten per cent cut in emissions by 2020 compared with a five per cent rise without the policies proposed (DfT, 2009b). The short to medium term proposals include adopting more efficient vehicles, increasing the use of biofuels and promoting alternatives to driving. There is also a strong technology push with incentives for ultra-low carbon vehicle cars, vans and buses. This technology push follows from the Treasury backed King Review of low carbon cars which concluded that:

[2] The reduction in greenhouse gas emissions can, in large part, be attributed to the 'dash for gas'

"*If substantial progress can be made in solving electric or other innovative vehicle and fuel technology challenges and, critically, the power sector can be decarbonised and expanded to supply a large proportion of road transport demand, per kilometre emissions reductions of around 90 per cent could be achievable for cars. If the rate of road transport growth projected by Eddington continues, and road use in the UK approximately doubles by 2050, this would deliver an 80 per cent reduction in total road transport CO_2 emissions, relative to 2000 levels.*" (King, 2008, p4).

Given the importance of technological change in meeting the climate change targets, this Chapter reviews the potential for and the potential implications of the widespread electrification of the transport sector.

2. Technological Prospects

Electric vehicles have existed for over 100 years but the internal combustion engine has dominated vehicle technology since 1910. This dominance presents a major challenge to competing technologies entering the market (Struben and Sterman, 2008). In 2007 in the UK only 2000 of the registered 28.2 million cars and 4000 of the 3.2 million light goods vehicles were electric. Interestingly though, despite some cost disadvantages, 16,000 non plug-in electric hybrids (such as the Toyota Prius) were registered for the first time in the same year (BERR and DfT, 2008). Demand and supply co-evolve and currently the market availability of electric vehicles is limited due to the limited range and high battery costs. The section first describes the potential for electric cars before discussing goods vehicles, buses and rail.

Three broad types of electric vehicle are considered in this Chapter:

1. Electric Vehicles (EV) – driven entirely using a battery and electric motor with recharging undertaken by plugging in to the grid
2. Hybrid Electric Vehicle (HEV) – in which an electric motor operates in parallel or in series with a traditional combustion engine to power the vehicle
3. Plug-In Hybrid Vehicle (PHEV) – A hybrid vehicle which is also able to connect to the grid to recharge its batteries. PHEV can run entirely as electric over shorter ranges unlike HEVs which require a combination of electric and combustion engine.

A recent study of the potential for EV and PHEV technology suggests that all of the major manufacturers currently have HEVs either available or in their forward product line (BERR and DfT, 2008). It is anticipated that such products will be competitive up to around 2015-2020 when there will be a migration to PHEV (*Ibid*.). As discussed later, the exact timing and nature of any migration will be strongly determined by the price and performance of the vehicles. The prime focus of this section will therefore be to review the technology issues surrounding EV and PHEV. We acknowledge that a further pathway to electric vehicles is through hydrogen fuel cells and that there is much active research in this area. However, the evidence currently points to nearer term applications of EV and PHEV with fuel cell vehicles and infrastructure unlikely to emerge before 2030 (Kalhammer et al., 2007; Jun et al., 2007). We therefore consider these developments to be beyond the scope of this Chapter.

Table 3 below summarises the range, charge times and vehicle costs of a sample of early to market EVs. Costs and technological capabilities should therefore not be extrapolated.

Table 3: Electric Vehicle Specifications (source: manufacture specifications except where indicated)

Model	Range (miles)	Charge Time	Total Energy	Price
Mitsubishi iMiEV*	100	7 hours (200V, 15A)	16 kWh	£20-25k**
NISSAN Leaf*	100	8 hours (240V, 13A)	24 kWh	£20k** + battery lease
Telsa Roadster	244	8 hours (240V, 30A)	55 kWh	£86k

*Due on the market in 2010/2011

** Cost estimates from technical press and not yet launch prices

Both the Mitsubishi and Nissan offers are expected to compete in the small family car market and are therefore expected to be priced at levels similar to those for top of the range petrol or diesel specifications. The range is limited compared to that of a typical petrol or diesel vehicle (around 300 miles) although the Department for Transport suggests that 93% of all two-way journeys are 75 miles or less (*Ibid*.). The extent to which these system attributes are important are explored in the next section.

Crucial to the development and roll-out of EV and PHEV are advances in battery technology. The current HEV market uses nickel metal hydride batteries which have limited range. Lithium ion batteries have up to twice the energy density (up to 120 Wh/kg) of current batteries and therefore longer range (*Ibid*.). For PHEV the energy density of the battery determines how long the vehicle can travel in solely electric mode (and therefore the carbon savings) before switching to HEV style operation. The prices of lithium ion batteries are reportedly at least twice as high as they need to be for widespread adoption. Two studies have estimated that the cost of lithium ion batteries may fall from a level of around $1000/kWh to between $240/kWh and $300/kWh once production levels reach 100 000 per annum (EUROBAT, 2005; Kalhammer et al., 2007) over the next 10 to 15 years. The degree to which this makes EVs and PHEVs competitive will depend on oil prices, electricity prices, subsidies and consumer preferences as well as battery price. We return to likely forecasts of uptake in Section 4.

Different options also exist for the charging infrastructure. It is anticipated that most charging would be done at home and that this could be relatively easily facilitated for many homes with an external 240V/13A or 16A connection with a surge protection device (*Ibid*.). However, only 64% of households park their car in a garage, car port or other off-street parking area (RAC Foundation, 2005). On-street public charging points would be necessary therefore in some residential areas. On-street provision is also necessary to provide confidence in using vehicles away from the home without fear of getting stranded (for EVs). Current pilot systems are 240V/13A trickle conductive charge systems[3], although inductive charging is also being investigated. Public charging points also require a payment infrastructure to be established and will require standardisation. Trickle charging is likely to be appropriate for locations where vehicles remain for a long period, such as home. Public charging points in particular may need to be able to provide a rapid charge which can take a battery from twenty per cent charge to eight per cent charge in ten to fifteen minutes (BERR and DfT, 2008). The substantial roll out of quick charge capabilities will have different impacts for the grid (see Section 5). Other proposals are also actively under development to overcome the problems of limited range for EVs. Most notably battery swap stations are being developed (e.g. Project Better Place) where, rather than filling up with petrol, an automated battery swapping station would be used to overcome barriers to longer distance travel (DfT, 2009c). Concerns exist however over the standardisation of batteries for different configurations of vehicles (BERR and DfT, 2008).

After cars, the light goods vehicle market offers some opportunities and electric vehicles are already being sold up to the 7.5 to 12.5 tonne category (Baker et al., 2009). A technology review of the goods vehicle sector suggested that depot based operations with daily mileage of less than 100 miles are most suited to the adoption of this type of vehicle (*Ibid*.). Whilst the up-front capital costs are substantial the daily operating costs are around three quarters lower than a diesel vehicle. Charge times are of the order of 6 to 8 hours (Smith, 2009). Developments are also possible in the PHEV

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[3] Trickle charging means charging a battery at around the same rate that it self-discharges

market for these types of vehicle but the costs of dual propulsion[4] are higher whilst the environmental benefits are reduced. There currently seems little prospect of EVs or PHEVs impacting on the heavy goods vehicle market due to the weight, power and range requirements of these vehicles. There are far more promising technological developments to be made with regards to powering auxiliary units and refrigeration loads in that sector (Baker et al., 2009.)

Electric buses have been demonstrated but hybrid and fuel cell buses appear to be the current major technology development pathways for low carbon bus technology (London has an aim for all new buses from 2012 to be hybrid). Fuel cell buses have been successfully demonstrated and can work as the fuelling infrastructure can be provided at the depot. The current cost of a fuel cell bus is between 3 and 6 times that of a conventional bus and the near to medium term potential for their adoption seems limited given the need for public transport operators to keep costs down to compete with the car. Low carbon buses[5] currently make up only 0.2% of the fleet of 179,000 buses and coaches and whilst some incentives are in place now to encourage uptake this is anticipated to lead to an increase of 450 low carbon buses over the next two years, a further 0.2% of the fleet (DfT, 2010).

Table 1 shows that rail comprises only 2.5% of all energy use from transport. 40% of the UK's rail network is already electrified and this carries 60% of passenger kilometres (DfT, 2008c). Even if all of the remaining rail network were to be converted to electric then this would have a negligible impact on overall electricity demand. There are currently plans to electrify the London to Cardiff line and an additional stretch around Manchester (DfT, 2009d). Electric trains are faster, cheaper to run and purchase and are lighter, resulting in lower track repair costs. Whilst there may be strong arguments for a wider electrification programme the scope is limited in the near term. There has already been a significant investment in rolling stock in recent years such that the average age of the fleet is now 13 years. As the average operational life of an engine unit is 30-35 years there will be limited opportunity to replace them. In addition, rail freight operators will continue to choose diesel engines as they require go-anywhere flexibility (*Ibid*.).

[4] The inclusion of a petrol or diesel engine and an electric motor

[5] The Department for Transport defines a low carbon bus as one which has at least a 30% reduction in its Greenhouse Gas Emissions compared to a current Euro 3 diesel bus of the same total passenger capacity

In summary, the main market for the adoption of electric vehicles is likely to be the car market and this is certainly the area which may have largest potential impact on electricity supply.

3. Consumer Preferences and Adoption Rates

For a number of years researchers have been seeking to understand the relative preferences of respondents for new vehicle types compared to their conventional internal combustion engine counterparts. Most studies have been framed in a wider alternative-fuel vehicle context rather than just electric. Typically, these applications make use of discrete choice structures belonging to the family of random utility models (RUM), a state-of-the-art technique for analysing human behaviour (cf. Train, 2003). Additionally, given the emphasis on vehicle types with currently only marginal market shares, the majority of these applications make use of Stated Preference (SP) data (cf. Louviere et al., 2000), where each respondent is faced with a number of hypothetical scenarios, each time involving the choice between a finite set of mutually exclusive options, in this case different vehicles. The present section provides a brief overview of such studies, focusing on the main factors likely to influence the demand for electric vehicles.

The preferences for electric vehicles are difficult to predict, not least because of the strong relationship between fuel type (i.e. petroleum vs electric) and other attributes such as range, performance, annual costs as well as incentives (e.g. tax breaks). At the same time, there is a very strong link between fuel type and vehicle type, with certain types of fuels being more appropriate for specific vehicle types. As an example, current generation hybrid electric cars tend to be small size family cars. The aim of studies looking at the potential demand for electric vehicles has thus generally been an analysis of the relative sensitivities to these core factors.

There are numerous examples of studies looking at the choice processes undertaken by potential customers in the context of purchasing a new car. These studies have generally been framed in the wider context of alternative fuel vehicles, i.e. not limited to just electric vehicles, partly with a view to ensuring a richer choice set. See Mabit (2009) giving recent overview of the literature. In this chapter, we focus in particular on two studies carried out in California, an area with a long standing interest in electric vehicles. The first of these two studies is discussed in detail in Train & Hudson (2000), with additional results in Train & Sonnier (2005), with the second study being discussed in Hess et al. (2009). The time difference between the two studies conducted in the same general area allows for interesting comparisons, although the two studies were completely independent of one another.

The work by Train & Hudson (2000) is based on a survey in which respondents faced, in each task, a choice between a petrol vehicle, an EV, and a HEV. A main aim of this study was to determine the impact of information on customers' choices, where this information related to electric vehicles and hybrid vehicles, and their impact on air quality relative to petrol vehicles. Only half the sample was presented with this detailed additional information, with the respondents being randomly allocated to one of the two groups. The three alternatives were described by body type (ten different types), purchase price, operating cost, performance (in terms of time taken to reach a speed of 60mph), and the range for electric vehicles.

All else being equal, for respondents without the additional information, hybrid vehicles are about as 'attractive' as petrol vehicles, while electric vehicles are valued significantly below these two other groups. Respondents with the additional information on air quality still value electric vehicles the lowest, although the gap is reduced somewhat, while they now value hybrid vehicles higher than petrol vehicles. A useful comparison in this context is to look at the range required before an electric vehicle is valued as highly as a petrol vehicle. In the base group, electric vehicles would, all else being equal, require on average a range of 460 miles to be valued as highly as petrol vehicles. While this varies considerably across respondents, the required range is clearly unrealistic, compared with those shown in Table 3. In the group with additional information, the average required range drops to 338 miles, which is still unrealistic. Additional incentives are thus required to make electric vehicles more desirable. However, the results imply that an average discount of $28,000 would be required to make an electric vehicle with a 100 mile range have the same probability of being chosen as a petrol car in the base group, where this drops to just below $20,000 in the group with additional information. As the authors point out, these results show that possible concerns about recharging and uncertainty about technology or other issues seem to outweigh the air quality benefits of electric vehicles. Hybrid vehicles on the other hand receive a far more positive response, especially in the group with additional information.

The study discussed in Hess et al. (2009) presents respondents with a choice between a current reference vehicle and three alternative vehicles. This survey makes use of seven different fuel types, namely standard petrol, EV, HEV, PHEV, flex fuel/E85, clean diesel, and compressed natural gas. Along with fifteen different body types, the alternatives were described on the basis of vehicle price, maintenance cost, running costs, age, purchase incentives for certain low emission cars, fuel availability, refuelling time, range, and acceleration.

Results show strong vehicle type and fuel type inertia[6] by respondents in the sample. After taking this inertia into account, and using petrol vehicles as the base, EVs are the lowest ranked of seven fuel types, with only compressed natural gas also being ranked lower than petrol. In order of increasing preference, this is then followed by HEV, clean diesel, flex fuel/E85, and PHEV. Across all vehicle types, an EV with a range of 100 miles would have to be almost $37,000 cheaper than a petrol car in order to be valued the same way by a respondent in the lowest income group, where this increases with income. HEVs can be $2,600 more expensive than petrol vehicles and PHEVs $6,800 more expensive. All else being equal, a range of over 1,000 miles would be required for an EV to be valued as highly as a petrol car, though this can be reduced somewhat with the help of incentives, vehicle performance, and the possibility to recharge the vehicles at work or other locations.

The overall findings from these two separate studies by Train & Hudson (2000) and Hess et al. (2009) are thus remarkably similar, showing that technically unfeasible ranges or unrealistic subsidies would be required to make EVs as desirable as standard petrol vehicles. While there are of course substantial variations across people in these cut-off points, the overall picture is very negative, and the potential interest in EVs seems to have only decreased further from 2000 to 2009. On the other hand, there is growing interest in HEV and PHEVs. The importance of range as a constraint on consumer uptake seems very high, explaining the difference between preferences for EV and PHEV.

4. Impacts on the Demand for Electricity

A number of studies have attempted to consider the implications of different projections of future EV and PHEV ownership on the demand for electricity under a range of charging assumptions (e.g. Electric Power Research Institute, 2007; BERR and DfT, 2008 and Kang and Recker, 2009). In particular, the UK study considered the impacts of four different vehicle penetration scenarios. The work in Section 3 suggests that the most extreme positive adoption scenarios for electric vehicles seem unlikely to be realised over the next two decades. Whilst consumer attitudes may change significantly with exposure to the new EV models, this process will take time (Struben and Sterman, 2008). The scale of the demand on the grid is set out below in Table 4.

[6] Inertia in this context explains an underlying preference by the respondent for the vehicle and fuel type of their current automobile. In other words, all else being equal, a respondent is more likely to choose an option that uses the same vehicle type or fuel type that they currently possess.

In the UK, the average journey length is just under seven miles and ninety three per cent of journeys are less than seventy five miles round trip (DfT, 2008d; DfT, 2009a). It is therefore anticipated that most vehicles could be used without stopping to charge during the day. Nonetheless, the modelling work in Section 3 highlights the importance of the availability and option of public charging points (either at work or in parking areas) to provide enhanced range. Such charging facilities are likely to require the delivery of fast charging (which can take a vehicle from twenty to eighty per cent charge in fifteen minutes) as vehicles will be parked for shorter periods of time. The introduction of large numbers of daytime fast charges may have ‘potentially significant impacts on the generation and transmission/distribution networks’ (BERR and DfT, 2008, p.44). Kang and Recker (2009) estimate that with home charging, forty to fifty per cent of the distances travelled by internal combustion engine vehicles could be travelled with a PHEV with a twenty mile range and seventy to eighty per cent for a PHEV with a sixty mile range. This rises to between sixty and seventy per cent and eighty to ninety per cent respectively where public charging points are available.

Table 4: Projections of Demand for Electricity from EV and PHEV (adapted from BERR and DfT, 2008)

	2020				2030			
Generating Capacity	100GW				120GW			
Projected Annual UK Demand	360TWh				390TWh			
	EVs	PHEVs	GWh	%NEP	EVs	PHEVs	GWh	%NEP
Business as Usual	70k	200k	400	0.1	500k	2500k	4200	1.1
Mid-Range	600k	200k	1800	0.5	1600k	2500k	6700	1.7
High Range	1200k	350k	3500	1.0	3300k	7900k	17000	4.4

NEP = GB National Electric Production

In all of the studies it is anticipated that most people would wish to plug in their vehicles to charge as soon as they return home. Unrestricted charging would place a significant demand on the grid given that this would coincide with the winter peak hour demands on the grid (BERR and DfT, 2008). It is therefore assumed that smart metering will be introduced before or alongside the widespread adoption of electric vehicles which will allow charging to occur at night. Smart metering is more than simply a timer switch as it could allow consumers and producers to set parameters which allow the optimisation of charging times and tariffs. This will have the potential advantages of spreading the demand for electricity which will better map to a profile generated by an increasing renewable mix and improve generating efficiency (*Ibid.*). There is also the potential for vehicles to operate as a storage point for electricity which can be fed back into the grid although these considerations are beyond the scope of this Chapter. The decision to move to a Grid which has smart metering technology for managing the consumer producer interface is far bigger than transport and will not be determined by individual vehicle purchases. In all but the most unlikely high range scenarios the proportion of the national electricity production required by the vehicle fleet remains below 1.7% by 2030 which suggests that the absence of smart metering in the short to medium term will not be critical.

Overall, it appears that under a mid-range assumption about the adoption of EVs and PHEVs (around 3 million vehicles or ten per cent of the fleet) the demands for electricity will be under two per cent of total production by 2030. More aggressive assumptions push this to 4.4 per cent by 2030. Given the current reluctance of consumers to adopt EVs in particular, we see this as a probable upper bound. Whilst there remains a degree of uncertainty as to what the standardised charging solutions might be for home and public charge points it has been suggested that smart metering will be important if this demand is not to place significant extra generation or distribution costs on the grid. Whilst some consumers are currently on dual rate Economy 7 type tariffs which encourage overnight use of electricity, many are on a flat rate. Further pricing differentiation by the suppliers would assist in making this an attractive option (BERR and DfT, 2008).

5. Other Supporting Policies

It is clear from Sections 3 and 4 that the upfront purchase costs of EVs and PHEVs will act as a deterrent to their purchase if left to the market. Whilst PHEVs are currently viewed more favourably than EVs there is still a price premium to be overcome. This is particularly problematic as the average period of time for which a driver holds a new vehicle is around 3 to 4 years – which provides a very short payback period. The risks to consumers are also significant as the second hand market value of these emerging technologies is not yet well understood. This is being countered across Europe with a range of incentives to encourage the purchase of very low carbon vehicles. In the UK, a long-term programme is scheduled to commence in 2011 with a budget of £250m set aside to provide subsidies of between £2000 and £5000 per vehicle for ultra-low carbon vehicles. A budget of £30m is also available for low carbon buses. Reforms have also been made to the annual circulation tax (Vehicle Excise Duty) to incentivise low carbon vehicles with a price differential of as much as £435 per year.

The introduction of EVs and PHEVs generates a profound change in the way that users will pay for travel. Fuel Excise Duty has been levied at the pump since 1909 and currently forms around half of the pump price of fuel (before VAT). In 2007/08 fuel duty from the road sector raised £23.3 billion for the Exchequer. A shift to EV and PHEVs will mean that travellers are only paying VAT at the rates levied on domestic energy – a substantial reduction on the variable costs of motoring. Whilst this reduction in variable costs helps to offset the additional purchase costs of these vehicles, it also has much broader impacts. A reduction in per mile driving costs will be economically inefficient as it will further weaken the link between the perceived and full marginal social costs for journeys. Fuel duty currently ensures that drivers pay the average social costs of their journeys although it is not spatially or temporally targeted and so does little to tackle the externalities of congestion (DfT, 2006). A large shift to EVs and PHEVs will incentivise additional travel, referred to as the rebound effect (Potter, 2009), which will create more delays on the transport network.

Taken together, the reductions in income from VED changes and a loss of fuel duty are forecast to cost the Exchequer of £4bn per annum by 2020, when take up of PHEV is only just forecast to be beginning (CCC, 2008). Whilst the extent to which this tax loss is offset within transport or elsewhere in the economy is a matter of public policy, leaving variable transport costs to decline will lead to extra traffic and worsen the competitive position of bus and rail. Many studies advocate a shift to a national road user charging scheme (e.g. Glaister and Graham, 2003; DfT, 2006). Such a move would help to ensure that the rebound effect is managed and that prices are brought more in line with congestion costs. However, this is a delicate balancing act as this would likely weaken the running cost advantage for consumers considering investing in EVs and PHEVS if it is introduced as a part replacement for fuel tax.

6. Conclusions

The 'dash to electric' will be concentrated largely in the car market with a mix of EVs and PHEVs. There will also be some important opportunities in the light goods vehicle market for urban multi-drop delivery services operating from a depot. Further electrification of the rail network will have very limited impact on overall electricity demand. Even with fairly aggressive assumptions about uptake rates in the car market recharging is unlikely to require more than five per cent of total electric production by 2030. If home charging is managed with smart meters then there will be little impact on the grid and such an approach could even out demand and support more efficient generation. Some local distributional issues may need to be overcome to support a substantial network of publicly available fast charging points and these seem a necessary part of any full EV future to overcome consumer concerns over operating range.

The research base to date suggests considerable barriers to the uptake of PHEVs and EVs in particular. Whilst governments are proposing a range of incentives to offset the initial higher purchase costs of these technologies to encourage the purchase of ultra-low carbon vehicles, the technologies are still maturing and consumers have little experience of real market place products. The shape and gradient of the adoption curve remain unknown and it is not clear how effective the incentives will be in stimulating widespread uptake. The effectiveness is also dependent on other factors such as the price of electricity and fuel, the availability of infrastructure and the development of battery technology. The next decade will provide a fertile learning ground in which the real long-term impacts on electricity supply can be more fully understood. For now, the 'dash' to electric looks more like a 'brisk stroll'.

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