3 November 2017

Business, Energy and Industrial Strategy Committee
House of Commons
London
SW1A 0AA

Dear Sir/Madam,

The IET’s response to the inquiry from the Business, Energy and Industrial Strategy Select Committee on Electric Vehicles: Developing the Market and Infrastructure

In response to your call for evidence, we would like to submit our comments to the inquiry questions on the above topic.

The Institution of Engineering and Technology is Europe’s largest professional engineering and technology organisation. The members represent a wide range of expertise, from technical experts to business leaders, encompassing a wealth of professional experience and knowledge.

The response has been compiled on behalf of the IET Board of Trustees by the IET’s Energy and Transport Policy Panels. The policy panels include a diverse range of experts that provide unbiased impartial advice for government and parliamentary stakeholders.

The IET would like to express a strong interest in providing oral evidence to the inquiry and if the organisation can be of any further assistance please do not hesitate to contact me.

Yours faithfully,

Dr Joanna Cox
Head of Strategic Engagement and Partnerships
About the Institution of Engineering and Technology (IET)

The IET is one of the world’s largest engineering institutions with over 168,000 members in 150 countries. It is also the most multidisciplinary – to reflect the increasingly diverse nature of engineering in the 21st century.

The IET is working to engineer a better world by inspiring, informing and influencing our members, engineers and technicians, and all those who are touched by, or touch, the work of engineers.

This submission addresses the following questions:

1. How will increased uptake of electric vehicles, to meet the Government’s 2040 target to end the sale of new diesel and petrol cars, affect the electricity grid? What action is needed to manage impacts, and to make the most of opportunities afforded by vehicle-to-grid technologies?
2. How do charging infrastructure requirements differ for alternative types of vehicle, journey, and user (including fleets)?
3. How should new infrastructure for electric vehicles and associated grid reinforcements be sustainably funded?

The second of these questions is not addressed directly but is discussed in many of the sections of the paper.

1. Future numbers of electric vehicles

Before we can discuss the effects of the uptake of electric vehicles on the grid, we need to establish the numbers and types of vehicles that might be involved. At present, there are about 32 million cars and light vans registered in Britain. Over 70% of British households have regular use of a car and the proportion with the use of two or more has risen to 30%. Of the 32 million, about 120,000 or 0.375% are battery electric vehicles (BEVs) or plug-in hybrid vehicles (PHEVs).

In 1990, mobile phones used analogue technology, were few in number, cumbersome and expensive. Few would have predicted the situation 25 years later when smart phones have largely replaced newspapers, cameras, maps, post cards and conventional phones. The Government’s strategy is to end sales of petrol and diesel cars and light vans by 2040. By then, the number of EVs in use may be expected to increase more than 100-fold. If this happens, many of today’s fears and assumptions about range, charging infrastructure, affordability or taxation could be irrelevant. Making predictions about what sort of electric or hybrid vehicles will be in use by 2040 is as risky as making predictions about mobile phones in 1990. This paper represents our “best guess” of what might happen but we have to stress the uncertainty implicit in any answers to the Committee’s questions.
A 2010 RAEng report on electric vehicles\(^1\) was written on the assumption that the main growth would be in “pure” battery electric vehicles (BEVs) – i.e. those with no alternative energy source other than the battery. It suggested in the conclusions that “an alternative model to the widespread adoption of EVs with their concomitant public infrastructure is the plug-in hybrid electric vehicle (PHEV). While this type of vehicle has most of the environmental benefits of a BEV, it does not rely on a comprehensive network of recharging points at possible destinations and so is far more likely to develop quickly, and with less involvement of multiple agencies, than would a BEV. It has the additional benefit that it could be adopted quickly as a family car or executive car, because it would not be tied to a network of specialist infrastructure facilities, while full EVs would be most likely to achieve initial market penetration as second cars, covering low mileages and thus having little impact on CO\(_2\) emissions.”

It turned out that the alternative scenario is what has actually happened, at least so far. PHEVs have rapidly taken the majority share (65%) of the electric car market (supported by the tax treatment and, in particular, P11D benefit-in-kind values). The most popular is the Mitsubishi Outlander, a 2.3 tonne (GVW) sports utility vehicle. Other popular PHEVs are the Mercedes C 350e, the BMW 330e and the Volvo XC90 Hybrid.\(^2\) This is a dramatic change from 2010 when the RAEng report was written and the vast majority of EVs on the market were small commuter cars.

The significance of the current dominance of PHEVs is that they are not range-limited and can replace high-mileage family/business cars, rather than EVs being limited to a proportion of second cars, used mainly for short distance commuting and the school run. This could allow a much greater penetration of electricity into the transport market and a greater impact on CO\(_2\) emissions.

There are many possible combinations of internal combustion engines and electric drive systems that could be classed as PHEVs. The RAEng report made the assumption that most PHEVs would be *series hybrids* – basically electric vehicles with a small i/c engine and generator “range extender”, available on some models of the BMW i3. However most of the PHEVs being sold today are *parallel hybrids* – vehicles which can be driven either by an i/c engine or, at lower speeds, by an electric motor or, for maximum acceleration, by both. These tend to have a much lower range on batteries than a BEV and thus transfer less transport energy from oil-based fuels to electricity.

It has recently become apparent that battery costs are falling quickly and it is generally accepted in the automotive sector that, within 5 years, the cost of manufacturing a BEV will fall below the cost of manufacturing an internal combustion engine vehicle. This will encourage the automotive manufacturers to invest even further as EVs will progressively become easier to make (far fewer moving parts and few parts), more reliable than conventional engine vehicles and with lower servicing costs. Given this context, hybrid vehicles are increasingly seen as a transition solution only, as they are much more complex to engineer than either conventional powered vehicles or pure BEVs and more costly to


maintain and service. However they serve an essential role during the transition to full-BEVs.

Researchers at Imperial College\(^3\) have used data from the National Travel survey to assess the proportion of trips and cumulative percentage of annual mileage that can be made by a BEV with different battery capacities.

These data suggest that, with a battery capacity of around 12 kWh, as on the Outlander PHEV, about 65% of the annual mileage could be electrically powered. As battery prices drop, it is likely that vehicle manufacturers will increase the battery capacity and thus the proportion of electrically powered miles.

If this trend for PHEVs were to continue, it would reduce the necessity for fast-charge stations on motorways and concentrate the demand for charging at home and at work. There would still be “pure” EVs but they would be mainly limited-range commuter cars, like the Renault Zoë, rather than representing a major growth of very high capacity, high-performance cars, such as the Tesla S. This would be a change from a few years ago when the trend seemed to be towards ever larger batteries, supported by high-capacity chargers – a challenging scenario for network operators.

However, other recent trends include a major reduction in battery costs resulting in EVs with a greater range. It seems likely that the popularity of PHEVs will be a short-term issue on the route to a predominantly pure-BEV vehicle fleet.

---

2. Energy demand by EVs

Annual electricity demand in 2016 was 306 TWh. By 2050 National Grid (NG) expect electricity demand to be somewhere between 321 TWh and 383 TWh. Cars, taxis and light vans cover about 600 billion km p.a. on Britain’s roads. If we assume that, at some time in the future, 80% of light vehicles could be EVs or PHEVs, 75% of their mileage will be provided by electric power and a BEV or PHEV (on electric power) uses 0.15 kWh/km, we could be looking at an annual demand for EVs of 54 TWh, representing an increase of 18% over the present UK consumption. (NG calculations are a long-term increase of anywhere between 15 TWh and 25 TWh, depending on the energy scenario.)

An imponderable question is when this number of EVs will be reached. In 2015, National Grid’s Gone Green scenario envisaged 17% of the car fleet will be electric by 2030. At the time, that was seen as very optimistic and, because high-mileage cars were under-represented in this group, the transfer of energy to electricity would have been less than this. However, recent announcements from Volvo, Renault and other manufacturers suggest that the switch to electric power could come earlier than previously thought. And the current popularity of PHEVs means that high-mileage cars will be well-represented in the electric fleet. This has been reflected in the 2017 FES from National Grid, whose “two degrees” scenario is based on around 29% electric vehicles in 2030, and 100% in 2050.

Another factor that could trigger positive feedback in the numbers of EVs is “range anxiety”. At present, this is a problem for EV owners who are concerned that they would not want to set out on a journey without being certain that there will be charging points available to get them home. As BEVs increase in range and popularity, the EV charging infrastructure will become more widespread but the reduced demand for petrol may result in many more filling stations closing (it is easier and cheaper to install and supply a few 32A charging points than a petrol pump). In sparsely inhabited rural areas, there could be range anxiety for drivers of i/c engine vehicles, encouraging a faster rate of switching to EVs.

3. On-street charging

Several British cities have introduced on-street charging facilities as an incentive to the public acceptance of EVs. Some earlier schemes used BS1363 13A sockets (as used in homes) that provided inadequate charging current, other than for small commuter vehicles. Most recent schemes use the international standard IEC 62196 connectors that support 16A or 32A charging.

Britain’s initial public charging infrastructure was heavily subsidised to promote BEV use. However, there is no appetite in local authorities to fund the millions of charging points that would be needed were the 2040 targets to be met predominantly by this form of energy supply. As a business proposition, installing public charging points used mainly for overnight

---

4 National Grid, Future Energy Scenarios, July 2017

5 The ‘Gone Green’ scenario has in later FES publications been renamed ‘Two Degrees’
charging near users’ homes, is unattractive. Most BEVs currently have a battery of around 30kWh capacity. If the supply-point owner were to bill 20p/kWh (30% above domestic tariffs) the gross income per socket would be £6/night, assuming the BEV started fully-discharged. For PHEVs with smaller batteries and partially-charged BEVs, the income would be proportionately less and nett income would be only a fraction of this.

An on-street charging point is complicated and expensive. It includes overcurrent and earth-leakage circuit breakers with remote reset, so the operator does not need to send an employee every time there is a trip, a weatherproof touch-card reader with the associated wi-fi or wired internet connection to a central server that can obtain payment authorisation, an IEC 62196 connector and a contactor to switch on the supply when authorised. It has to be connected to a mains cable in the street, which involves excavation. Initial costs are in excess of £5,000 per charging point and there are significant maintenance costs as they are vulnerable to accidental damage and vandalism. Financially, public charging points only break-even if used by many users per day paying a premium on the basic cost of electricity.

4. Local power demands

The RAEng study in 2010 considered a situation in which EVs greatly outnumbered PHEVs and most had a limited range of around 70 miles. This was based on the assumption that continued development of internal combustion engines would progressively reduce CO₂ emissions and would continue to provide longer range travel. The June 2011 OLEV paper on charging infrastructure⁶ made similar assumptions. Against this backdrop, it was logical to consider the necessity of providing battery charging facilities at popular venues, such as football grounds, shopping centres and exhibition complexes, where large numbers of EVs would be recharged in a short time. These would have placed high demands in small geographic areas with little opportunity to reschedule the load.

The widespread adoption of charging at the destination would make it difficult to ensure that the electrical load is taken at a time to fit with the availability of surplus low-carbon electricity. Fans parking in Manchester United’s 5000-vehicle capacity car parks during an evening match might put their cars on charge at 17:00 and expect them to be recharged by 20:00 – the peak load period for the grid.

However, reducing battery costs have resulted in an increasing range of EVs. For example, the new Nissan Leaf has a real world driving range of around 150 miles and Tesla cars can run for 200 miles between recharging. This is likely to reduce the need for recharging at leisure or business destinations, allowing users to recharge when and where costs are lowest.

A 2013 study by the Energy Technologies Institute showed that c. 60% of UK homes were suitable for charging off-street; from surveys, they concluded people’s preferred charging solutions, in order of preference, were: 1) at home 2) at a workplace, 3) leisure or shopping location. A public charging infrastructure was seen as necessary to give the public confidence that charging is still possible away from their normal place of charging or on long trips but would not be a major source of transport energy.

The ETI work also showed that people's perceptions of the distances they drive is greater than reality. The average UK passenger vehicle is driven 8000 miles/year (22 miles/day), which is 10% less than a decade ago. The average for cars based in urban areas is much lower – London being the lowest at 2000 miles/year. The combination of greater BEV range and low distance travelled by cars in urban areas implies the need for charging only occasionally, which makes BEV ownership feasible for people without off-street parking and who would not accept the need to park in an EV charging bay, possibly some distance from their house, every night.

5. Motorway service stations

Some earlier studies assumed that, in order to provide longer distance travel, BEV users would need very large numbers of fast-charge battery stations at regular intervals on motorways. However the changing nature of the transition from fossil fuels makes this less likely.

Early Li-ion battery designs had a maximum charge rate of 1C – i.e. it takes an hour to charge the battery, even in optimum conditions. Li-ion phosphate and Li-ion titanate batteries can be charged at higher rates; however one then comes up against the problem of cell interconnections and cell heating. High charging currents require heavy conductors between cells and between the car and the charging station. Some BEV users may need fast charging stations and there are installations providing 50kW, although not all BEVs can accept energy at this rate.

Up-market companies, including Porsche and Tesla, are considering 800V, 350kW chargers which would enable a compatible BEV to take on board 200 miles of range in approximately 10 minutes, almost comparable with a conventional vehicle refuelling experience. Porsche are reported to have installed a 350kW charger at their centre in Berlin-Adlershof but, to date, they have not built a car capable of charging at this rate.

An important consideration is the Butler-Volmer equation, which relates the current to the overpotential. For any battery chemistry, higher charging current implies a higher overpotential (leading to higher losses), which in turn would affect the charge/discharge

____________________

efficiency, thus the CO$_2$ per kilometre figure would be worse. And high rate charging tends to cause faster battery deterioration, thus increasing the cost to the user.

A typical suburban filling station has a dozen pumps to deliver fuel. If converted to fast recharge points for BEV batteries, of the ratings discussed above, the load could be 5 MW. Bearing in mind the “peaky” nature of the load and the likely harmonic content, such a facility would probably have to be fed at 11 kV, the level usually reserved for large commercial or industrial premises. A high-throughput, fast-charge motorway service station would be even higher rating and would almost certainly need to be connected to the 132kV supply.

It is likely that there will be a continuing demand for very fast charging stations but earlier assumptions that these would be a major source of energy for transport seem improbable – not least because the direct and indirect costs of high-rate charging are likely to be significantly greater than the alternative of charging at home. Increasingly it seems that most recharging will be carried out at home or at work, with implications discussed below.

6. How will increased uptake of electric vehicles affect the electricity grid?

This section pulls together the conclusions from the above sections to answer the Select Committee’s question “How will increased uptake of electric vehicles, to meet the Government’s 2040 target to end the sale of new diesel and petrol cars, affect the electricity grid?”

In terms of total electrical energy demand, +18% by 2040 is well within the error tolerances of supply and demand. Somehow Britain will have to cope with transferring much of the gas heating load to renewables via the grid; it is uncertain how on-shore and off-shore wind will develop; the future of nuclear energy is still uncertain and the recent rapid growth in solar energy may continue or could stall. The NG Future Energy Scenarios cover a wide range of outcomes demonstrating the uncertainty of how energy use may develop.

Earlier sections suggest that very high densities of BEV charging points (car parks at motorway service stations, shopping centres or football stadia with 500+ points) will be few. The largest demand will be in residential areas where people will want to charge BEV and PHEV batteries overnight. Some centres of employment may also provide large numbers of charging points, possibly partially fed from solar panels on the buildings.

The major impact of BEVs and PHEVs will thus be on DNOs, not National Grid. It is likely that the growth in EV use will be patchy geographically. Semi-rural, high-income areas where houses have off-street parking are likely to be early adopters and low-income, inner-urban areas, where most people park on the street, will be much later. If no action is taken to spread the load from peak times (when users come home from work and plug in their PHEVs) the additional load on a 30-house cul-de-sac could – at least in theory – be more than 300A/phase, more than enough to overload the local substation. However, the probability of such an event is low as people are more likely to charge at different times on different days. (In the event of a long-term loss of supply in a particular area, it is possible
that large numbers of consumers would attempt to charge at the same time, when the supply was re-established but DNOs are aware of the need to manage this risk.) Properly managed and with time-shifting to when there are few other loads in people’s homes, much of the charging load could be handled by the existing infrastructure. The *My Electric Avenue* project explored this through practical trials using Nissan Leaf vehicles, although average charging loads for EVs have been increasing significantly since the study was completed and will have impacted the work’s conclusions.

There’s a more serious risk associated with unintended consequences from Smart Charging that utilises dynamic ToU tariffs. If whole-system thinking is not applied, a market movement from a high price half hour to a low price half hour could trigger the near-simultaneous switching of a huge number of EV chargers. A simple calculation reveals that with projected EV numbers in the early 2020s, this step-change of demand will be far in excess of the System Operator’s holding of fast reserve generation, potentially triggering a national system failure. Although a co-ordinated technical/market solution should not be too hard to develop, at present there is not an organisation charged with finding it.

7. **Impact on the grid of shared ownership, if the market moves that way**

Much is written about the future of personal mobility moving to a shared ownership model, possibly based around driverless vehicles. The subject of vehicle autonomy and its feasibility for all road and weather conditions is beyond the scope of our response, however if the market were to move towards a sharing model the impact on electricity systems would change from a personal ownership model. We would see:

- Vehicle charging most likely taking place at centralised edge of town locations rather than on street, implying a reduced need for on street charging infrastructure and much less impact on the low voltage networks of DNOs
- Much more intensive vehicle usage, requiring more frequent charging, changing the time of day pattern of charging, and potentially reducing the potential of the vehicle battery to supply power and other services to the electricity system (V2G – see 8 below)
- Fewer vehicles overall

8. **Time-shifting, smart meters and V2G**

Earlier sections have shown that charging BEVs and PHEVs can be accommodated by the grid if the timing and intensity of the load can be suitably managed. There have been many ideas floated on how this could be done, for example, a) through a car’s management system b) through a home energy management system, c) through an energy supplier relationship, all playing into energy system flexibility markets with price signals from

---

8 See the *My Electric Avenue* project: [www.myelectricavenue.info](http://www.myelectricavenue.info)
National Grid or DNOs rewarding modified behaviour automatically behind the scenes, with consent, through the smart meter network and time-of-use tariffs (TOUTs).

Even greater flexibility could be achieved with vehicle-to-grid (V2G) technologies. The principle is that battery chargers are made reversible and, if a car is parked and the user has indicated it is unlikely to be used for a certain number of hours, the charger could partially deplete the battery by directing energy back into the grid to support other loads on the system – perhaps including other cars in the same car park. These “ancillary services”, that could be provided by EV users to the wider network might be structured to attract significant cash flow rewards that would help offset the costs of EVs. Some estimates have discussed figures in the range £200 to £2000/parking space annually, but the IET has not seen the supporting calculations or evidence.

Practically, how these ideas could be implemented in the current UK electricity market is less clear. Time-of-use tariffs (TOUTs) are expected to be managed nationally, through electricity retailers. (So far, none have been introduced as they rely on smart meters, which have not yet gone live in any numbers.) However, TOUTs created by national electricity retailers will be largely useless in managing this geographical disparity of loads and we will need a “postcode” degree of granularity in any arrangements. (This is likely to arouse complaints of a “postcode lottery” for electricity but the alternative would be large-scale reinforcement of the DNO infrastructure in certain areas, with unpopular and expensive roadworks.) Whether such a local load-sharing arrangement would be managed by the DNOs or by local residents’ energy cooperatives or by some other means is unclear.

A number of complex and overlapping systems, integrated with home energy management systems, TOUTs and V2G ancillary services carries some risk – not least that it could result in unforeseen interactions or provide numerous entry points for hacking or disruptive activities. This submission is not the place to discuss the various risks and their mitigation other than to note that introducing these ideas will require careful risk management. The accountability for addressing serious challenges such as this is worryingly unclear as the issues are whole-system in nature, spanning from parties and devices beyond the meter, through distribution networks, transmission networks, and impacting the national System Operator. This is just one example of the serious emerging challenges that cross a host of ownership and governance boundaries, but lack clarity on co-ordination or accountability for delivering secure and effective outcomes. The IET/ESC Future Power System Architecture programme9 (FPSA) is a source of analysis and recommendations here.

To summarise, the electrical demand created by the policy to move road transport energy demand from petrol/diesel to electricity will be manageable but will need carefully-designed control systems and regulation to ensure the charging load is taken at times when the grid has adequate capacity. Smart meters, presently being implemented, could be a component of this control system but, by themselves, they are unable to satisfy the need. Whole-system co-ordination and clarity of accountabilities is an important dimension for resolving the technical, commercial and regulatory issues that are now emerging.

---

9 see the Future Power System Architecture project: [www.theiet.org/fpsa](http://www.theiet.org/fpsa)
9. EVs and social justice

In the development of a future electricity system, addressing the trilemma of emissions, affordability and security of supply is vitally important. As the UK moves from the present electricity system supported by dispatchable fossil fuelled generation to one provided largely by flow renewables, the pricing structure, in which nationwide electricity retailers apply fixed tariffs based on a charge per kWh, will need to change.

If the UK were simply trying to balance energy security and CO₂ emissions with low average costs, one could envisage a market pricing structure based on a consumer’s energy use at times of low capacity margin which would be likely to result in extremely high charges per kWh at certain key times and climactic conditions in winter but near-zero unit costs at other periods. This would give the strongest market signals leading to the maximum diversion of demand from peak to off-peak periods.

*UK Power Networks* project on *Low-carbon London* included a 1,000 customer trial undertaken with EDF Energy to research how dynamic time-of-use (ToU) tariffs can modify consumers’ behaviour. The effect is likely to become increasingly pronounced as more people drive EVs and own “smart” white goods and heating systems that can be programmed to take energy when it is cheap.

Dynamic ToU tariffs and the opportunity for exploiting V2G could work well for technically-minded EV owners who have off-street charging, domestic energy hubs and control over their energy use. It would be more difficult for the increasing numbers of people who live in rented accommodation, without off-street parking, who would have to charge an EV in public parking places or commercial garages.

It is not difficult to envisage energy-efficient personal transport, based round EVs being charged at times of low system demand, but this might be available only to certain groups in society. In the energy trilemma, *affordability* needs to apply to all social groups, not just the well-off and technically literate. This will pose an additional challenge in the design of intelligent charging systems.

10. How should new infrastructure for electric vehicles and associated grid reinforcements be sustainably funded?

This question is only part of a much larger question. At present fuel duty raises more than £20bn p.a. and it is unlikely that any government could tolerate a significant loss in that revenue. Thus it may be necessary to find ways of taxing the energy used by electric vehicles. In addition, governments would lose the annual car tax, which would be another loss to the exchequer. EVs are excused the Congestion Charge in London but that scheme has high running costs and it will be difficult to justify the exemption if they become commonplace.

Practically it would be almost impossible to tax electricity for EVs directly. Anyone with a modicum of DIY competence could connect up an extension cable from a 13A socket to a
BEV and avoid any special charges. It therefore seems likely that tax revenue will have to be raised in other ways.

Compared with petrol or diesel cars, EVs and PHEVs have fairly high first costs and low running costs. There is thus an incentive for owners to use them as much as possible for short journeys, such as commuting, rather than paying for public transport. Thus a switch from petrol/diesel to electric is likely to add to congestion in cities at peak periods. Although politically challenging, widespread congestion charging would be one way of taxing EVs as well as petrol/diesel cars and would have the benefit of reducing commuting on busy routes and making public transport more attractive.

The other question is how investment to increase capacity should be funded. This is related to the way in which all electricity is paid for. An earlier IET report\textsuperscript{10} pointed out that the current arrangements for a fixed price per kWh are inappropriate for a decarbonised grid. Refuelling and operating costs of nuclear power stations are low and operating costs of wind and solar power are effectively zero. However, the costs of the generating assets and associated infrastructure will be substantial. In these circumstances, the concept of \textit{levelised cost of generation}, used for many economic comparisons, becomes largely irrelevant.

In a situation where marginal energy costs (per kWh) could be almost zero and capacity charges (per kW) are very high, it is difficult to see how an electricity market based on an auction of energy (per kWh) is possible as bid prices would no longer be related to operating costs. A free market for electricity would be likely to produce the result of extremely high prices in winter, particularly at periods of peak demand, but very low prices at times when the demand can be met entirely by renewable energy. This could indicate a method of charging for infrastructure improvements and also incentivising communities and individuals to adopt V2G and variable TOUTs. However, the charges would have to reflect local conditions and not just the national balance of generation and demand. These issues are being partially addressed by the Future Power Systems Architecture (FPSA) project.\textsuperscript{11}

\textsuperscript{10} Transforming the Electricity System: how other sectors have met the system design challenge

\textsuperscript{11} FPSA refs