An Operational Report on 30 months of Battery Electric Vehicle usage in the UK

Authors:
Alison and Trevor Owen

Abstract

This Institution was founded in 1913 to exchange operational data and experience with a new technology which happened to be a diesel engine. This paper follows in that tradition by providing feedback for those considering the use of a battery powered vehicle or for those who have already adopted such technology.

Many governments are incentivising the use of electric vehicles as a part of an ongoing campaign to reduce car emissions. In driving away from a dealership in an electric vehicle there are many aspects of ownership and usage which are not generally covered by instruction manuals or dealership handover routines and are only gained by experience.

This article covers the experience gained across both technical and commercial fronts by two Chartered Engineers and represent personal views as opposed to those of any manufacturer or supplier. Whilst the experience and feedback relate to one make of BEV operating in the UK many of the issues raised could apply to any make of BEV in any location.

Nomenclature

EV	Electric Vehicle
BEV	Battery Electric Vehicle
PHEV	Plug-in hybrid electric vehicle
Whpm	Watt hours per mile

Introduction – The decision to buy a battery electric vehicle

In 2017 our existing car was approaching the ten-year mark and it was anticipated that expenditure would rise significantly starting with the next service and MOT. A review of replacement options was undertaken without reaching any firm conclusion as there were negative factors relating to various possible replacements including a significant shift in image with diesel powered cars.

Back in 2015 we met a couple in a coffee shop whilst on vacation where the dialogue between them concerned battery capacities in kWh. This seemed to be an unusual topic for a couple to discuss over coffee! We learned that they had a Tesla electric car and in various subsequent conversations we found out a lot about the practicalities of using a BEV. They had driven to Italy and Spain on vacation and we were shown details of how they had progressed from the UK via various charging points to their destination and vice versa. They appeared totally confident in using their car both in the UK and Europe. Those exchanges fired our initial interest in electric cars, but we did not consider the option to be viable for our own use at that stage.

Whilst researching for a replacement car we visited a BEV display in a local shopping centre on several occasions and also had a demonstration drive. At one point we became aware of a favourable offer to entice more UK customers to make the change which resulted in our order for a Tesla Model X. This vehicle has a 75kWh battery with four-wheel drive using two motor drive assemblies. We regarded the move as an experiment which would stimulate interest for both of us as retired Chartered Engineers.

Five months later we set off from the centre of Leeds on the start of our BEV experience with the car charged to 90% battery level and showing a range of 184 miles. We have recorded herein the various practical aspects of owning and operating an EV.

Vehicle Range and Range Anxiety

We became focused on the remaining battery capacity right from the outset since running out of power would be very inconvenient.

Our car has two methods of forecasting the remaining battery range – one based on a long-term historic average for the vehicle, and another based on the actual consumption in the past 30 miles. There can be a big variation between the two forecasts if for example one is driving uphill and/or against strong winds for an extended period where the short-term forecast will show a dramatic reduction in range. The opposite then occurs with a long downhill stretch with significant reverse power feeding into the batteries. These variations are shown in graphic form on the central visual display, with periods of high usage being coloured red and significant periods of regeneration shown as green. With experience one takes a more balanced view of the battery range remaining.

Figure 1: Tesla Model X with 75 kWh battery

By way of an example Figure 2 shows the power usage graph for a trip which included a steady climb up the eastern side of Sutton Bank on the A170 (orange sector on the left of the graph) followed by a 25% downhill gradient on the western side where the car was generating up to 50 kW in reverse power (shown in green).

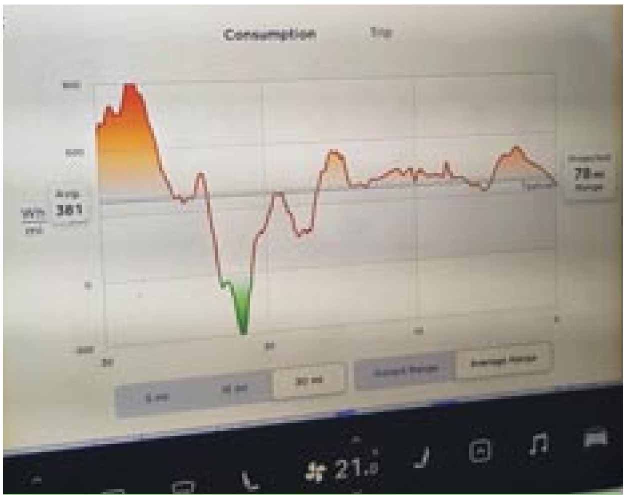

Figure 2: Car visual display showing power usage over the past 30 miles along with the projected range based on the average achieved

There is a big difference in power consumption between driving a BEV in winter as opposed to summer as the incidental loads for heating or cooling the cabin and battery, lights, and wipers have a significant impact. In typical summer usage we would expect 300 to 375 Whpm whereas in winter the figure could rise to 450 Whpm. By comparison, the manufacturer's quoted range of 230 miles for the vehicle equates to 306 Whpm. As with petrol and diesel cars the quoted performance figures for EVs are rarely achieved under real life conditions.

Hence range calculations and routing need careful consideration in winter with a more conservative approach. The vehicle navigation system will show available options for recharging en route but some charging points are less desirable than others (too busy, too difficult to reach, no services on site, onerous parking limitations, etc). We make a considered choice for the stops based on experience, the details shown on the car mapping system, and a phone-based charger location app. The car-based system shows the live current status of Tesla Superchargers at any one location (i.e., how many are available) and where there are options we obviously prefer locations with multiple chargers to minimise the risk of queuing.

There is also a considerable difference in consumption relative to the speed of the vehicle. This was demonstrated on one occasion when we attended a funeral in mid-winter in Bedford with no fast-charging options within a wide radius. On the outbound journey we visited the Supercharger installation at Grantham and checked via the navigation system on the likely remaining power if we drove to Bedford with no deviations and then returned directly back to the same chargers at Grantham. The system forecast that the battery would be down to 7.5% capacity, based on driving at 70 mph where permitted. We considered that this would be too tight a margin allowing for the cold weather and the risk of closure of major routes. We decided to drop the maximum speed down to 65 mph and then re-evaluate later, with a fall-back option of going home via a different longer route using some fast chargers at Northampton which were normally busy each evening with potential delays. We set the cruise control to 65 mph, reduced the cabin temperature to 20C, and enabled a power saving setting on the car management system. We made good progress at 65 mph and attended the event on time. On setting off for the return journey the car showed 60%

battery capacity and we made it back to the same charging location with 20% in reserve using the same limitations as before.

The style of driving also has a considerable effect on power consumption. If full acceleration is used constantly then the range will be dramatically reduced. We have found that by driving the car in a sympathetic way we can achieve a good range combined with good journey times.

In keeping an eye on power consumption figures we came across an interesting result. We have shown that going North along the A1(M) in Yorkshire is really going uphill whereas the return journey is downhill, per the average consumption figures recorded by the car on regular journeys. Hence, we confirmed there is some truth in the expression 'going up North'!

Regenerative braking

The first skill to be developed in driving an EV was to achieve a smooth drive without sudden acceleration and braking whilst taking full advantage of regenerative braking. We quickly mastered the use of regenerative braking to slow the car at most intersections, only using the brakes for a final halt. The car produces up to 50 kW of reverse power in regenerative braking and that is enough to slow the car adequately in most circumstances, even when encountering motorway exits with a downhill slope. The regenerative braking has proven adequate to control speed on the 25% downhill gradient on Sutton Bank. Consequently, the brake pads show little sign of wear!

Full regenerative braking is not available when the battery is fully charged and/or cold and one needs to take heed of the visual warning which appears on the display. It can take perhaps 20 miles of driving in winter to restore full regenerative braking but sub-zero temperatures can further extend this.

Vehicle operational modes

We have driven our car with 'chill' mode engaged from the day that we took delivery. That mode limits the acceleration of the vehicle. We find this suits our style of driving with a vehicle which is capable of incredibly fast acceleration even in this mode! Other owners are happy with the normal mode whilst others crave a 'ludicrous' setting which is only available on selected vehicles.

We have also activated the 'creep' mode where the car will slowly creep forward without touching the accelerator. This mimics the action of many automatic cars and is good for manoeuvring in traffic or in parking.

Vehicle charging systems

BEVs are provided with onboard AC to DC charging systems and this determines the maximum charging rate possible with an AC connection. A direct DC charging capability is provided as standard on some BEVs, or is available on some as an option, or is not available at all with other vehicles. It is the DC charging capability which enables fast charging.

The battery management software system determines the rate of charge under any given circumstances and controls the cooling and heating systems. It is claimed that the battery management system is a key factor in battery life and overall system efficiency. There appears to be considerable variation in such systems between manufacturers judging by user feedback on various makes of BEVs on social media sites.

The location of the charging socket differs between manufacturers which can create interesting issues when considering the best position to park at chargers. So one has similar issues as with the location of the fuel filler on petrol or diesel vehicles.

Battery charging at home

Many users recharge the car batteries at home and if using overnight charging then the charging rate is not so critical as when charging on a journey.

Most home chargers now being installed are rated at 7 kW using a 32-amp single phase supply which is the practical upper limit for many households. If a three-phase supply is available, then the maximum charger output rises to 21 kW. That is one side of the equation whilst the other side is what the car can accept.

There is often an issue with household power supply ratings in terms of the main supply fuse and the addition of 7kW charging circuits. Older properties with 60-amp main fuses might need upgrading to cope with an extra 32-amp demand in addition to the normal loads. For a household with two EVs and two 7kW chargers an upgrade of a 100-amp single phase system to a 3-phase supply may be required

There is also a question of location and the length of any connecting lead. The most convenient arrangement is to have a permanently connected lead on the charger to avoid having to extract leads from the boot every time that the car is connected.

We have a 40-amp fused supply feeding a small consumer unit in the garage and a 7 kW charger as shown in Figure 3. The other key decisions were

- The location of the charger, and
- The length of the cable (if specifying one with an integral cable).

We opted for a seven-metre connecting cable and fitted the charger inside the garage positioned adjacent to the charging socket location on the car when parked in the garage. The cable is just long enough to also permit charging with the car parked outside the garage should circumstances require this.

A neat finishing touch has been the use of a galvanised garden hose bracket which is ideal for storing the coils of cable.

A prime objective is to make connection and disconnection of the charger as easy and safe as possible as this action may be required twice daily. We opted for the car manufacturer's own charger where the charging flap on the car will open in response to the push of a button on the charger plug. The same button will both stop the charging power supply (e.g. when preheating the car ready for departure) and release the plug lock when disconnecting. A further plus point is that the manufacturer can remotely interrogate both the car and the charger in the event of charging issues.


Figure 3: 7kW charger with garage consumer unit and cable reel (plus wifi extender!)

7 kW is the smallest capacity charger for regular use as even that would take 11 hours to recharge a 75 kWh battery from near zero. In preparing the car for departure in winter we initiate the option to condition the car and battery for departure. There are heaters in the car for both the cabin and the battery, so it makes sense to use mains power to raise the car to its normal operating temperature prior to departure. A 7 kW charger can cope with this duty, whereas a 3.5 kW charger would not.

We leave the car connected to the charger whenever it is parked at home although it only charges the battery when scheduled to do so. Some owners only recharge every few days, but we prefer to have the car available each morning with 90% battery capacity.

Ideally a separate meter should be fitted to the charger supply to be able to accurately record the total power used by the vehicle. A smart meter does however provide us with details of the charging profile in 30 minute segments to confirm that the correct timing has been maintained and to provide some idea of the power used in charging.

Charging Tariffs

We have used an off-peak charging tariff where the car automatically connects to the power supply at a time which can be set on the car control system. The cost of power for the car is low on such an arrangement – even a full charge would cost less than £5 for a notional 200-mile range. More utility companies are recognising the requirement for charging of vehicles with special tariffs and it is likely that this market will develop further as there is considerable variation at present in the cost of EV tariffs.

One company has introduced a dynamic EV tariff where rates are set at 1600 hrs for each 30 minute period in the following day and reflect the commercial supply market. The rates are high for the evening maximum demand period but more favourable at other times. This tariff provides suitable incentives to assist in the efforts to balance the grid loading with negative pricing during periods of excess power! This tariff is ideal for BEV user's who are willing to time shift their charging periods. In using this tariff for a short period, we encountered rates varying from -8 p per kWh (yes minus!) to +35 p but achieved an acceptable average cost per kWh. After a trial period we reverted to a tariff with a fixed off-peak period to simplify our car charging routine.

Charging away from home.

The EV charging system in the UK is not comprehensive in coverage or reliable as can be seen in reports by various motoring magazine and TV programme evaluations. A quick scan of any social media groups focusing on EVs will confirm regular issues with charging on commercial systems.

Tesla currently has the most developed charging network with present ratings of up to 250 kW on their latest V3 Superchargers. Their established network was a key selling point in our decision to buy their product.

Other manufacturers have been slow to recognise this element in marketing EVs and have focused on the vehicle specification without fully recognising the importance of the charging requirements from a customer viewpoint. In 2019 we attended a local promotion of a new BEV from a UK supplier with some of the key design staff present and were astounded to be told that all we needed was a mobile phone app to find a charger and all would be fine! They had at that stage made no provision for any form of preferential charging service for their customers.

There has however been progress over the past year or so in that several manufacturers now offer their customers a fast-charging network in conjunction with Ionity. This includes Audi, BMW, Ford, Hyundai, Kia, Mercedes, Porsche and VW. This is still at the early stages and the number of such chargers is limited.

In a further move to enhance the UK charging structure specialist EV charging centres complete with service facilities have been developed with the first being the Gridserve site at Chelmsford. This site opened in December 2020 with 30 charging bays

Figure 4: Our car connected to a Tesla Type 2 charger

Figure 5: Our car charging at an Engenie 50 kW charger using a Type 2 socket converter attached to a blue CHAdeMO connector)

offering all three connection types as described in this article with ratings up to 350 kW. Further similar facilities are planned for 2021 onwards.

If one accepts the need to have a regular break from driving, then a stop every two hours for recharging can fit well into this pattern if recharging slots are available when required to avoid undue delays to the journey.

Another issue when charging away from home is security in relation to the charging leads and adapters since these are expensive pieces of kit. Fortunately locking the car also locks the charging plug in place on the car. This has the benefit of preventing both the loss of kit and also the unplugging of the power supply by those wishing to hi-jack the charger (as has been occasionally reported on a number of user group sites). The Tesla phone app keeps track of the charging scenario so there is full visibility of the rate of charge and time remaining.

Route Planning

Mobile phone applications such as Zapmap become useful aides in planning a longer trip as these can provide an overview of the charging facilities along an intended route in addition to information provided by the car system. The apps can be interrogated to provide details of the type of chargers and service providers at any site and are useful when planning a trip.

The time taken to recharge en route is a key issue and currently there are relatively few fast chargers with outputs above 50 kW. Whilst the latest ultra-fast chargers have claimed outputs of up to 350 kW, the actual charging rate achieved varies considerably as mentioned later and dividing the battery capacity by the charge rate will not give the time required for fast charging.

Another issue with recharging is the precise location of the chargers as some chargers are difficult to locate particularly on motorway service sites. Some locations are signed but many are not and specific directions are recommended to avoid problems on a first visit. At the Woodall South Services on the M1 the chargers are located on a spur road just before re-joining the motorway and require a sharp turn past no entry signs (EVs permitted) to gain access. It can be un-nerving to drive right through a service area to the point of almost re-joining the motorway with a low battery scenario before finding the chargers!

We prefer charging locations with toilet and refreshment facilities on-site, but we know of locations requiring a long walk and good local knowledge to the nearest supermarket with such facilities.

Charging Connections

There are three different socket arrangements in common use and most rapid chargers have two or three different connections available. (See Appendix 1

Figure 6: Gridserve Chelmsford site

Figure 7: Vehicle navigation system view for a planned journey showing the location of fast Tesla chargers around Leeds in red. The nearest fast Tesla superchargers to the North are just off the map at Scotch Corner but there are none to the East

Figure 8: Steering wheel binnacle view showing immediate routing along with range and power usage

for specific details of the charging socket types).

Our car has a Type 2 socket which is the most common one in use at present. The later CCS socket is now gaining ground for faster charging rates and the CHAdeMO is still available as a third alternative.

We carry converter cable/adapters (see Appendix 2 for details) which enables us to connect to all three fast charging connectors and this has been vital in securing a charge in certain locations. In addition, we have the ultimate emergency option of a 13-amp plug connector with a suitably rated 20 metre cable which fortunately has not been required so far.

Commercial factors on charging en route

A major problem is the multitude of companies offering a charging service with a substantial variation in the charging cost and procedures. Some require specific cards or phone apps to work whilst others simply use credit/debit cards on a 'pay as you charge' basis. The charging costs vary considerably with figures as high as 65p/kWh quoted for some fast chargers but generally something in the region of 25 to 40 p/kWh is normal.

Originally some free low output charging systems were available, but these have reduced considerably in number as higher rated chargers have been introduced and a stronger commercial market has developed. We have also encountered a fixed fee charging logic on occasions and for example have paid a flat fee of £4 for one hour of combined charging and parking where we achieved perhaps 35 kWh from a 50 kW charger in an hour.

There has been a move in more recent times for organisations to offer a consolidated access to a number of different charging companies but so far there is no dominant provider. This is one area which is likely to change as the number of EVs increases.

Technical factors in charging en route

With certain chargers the power supply is shared between two charging bays - so if a second vehicle is connected then the charging rate will drop for both. With such chargers there is an established etiquette amongst seasoned users of leaving a vacant slot between charging vehicles when there are plenty of spare bays so that maximum charging rate is achieved by all.

The key issue with any charging is the rate at which the battery will accept the charge. If the battery is cold or near full or empty it will only take a limited rate of charge. We have seen charging rates of anything from 10 to 110 kW when coupled to a fast charger. The charge rate drops off significantly once the battery reaches 90% charge, and the last 10 percent can take a long time to complete!

One regular request for help on a Tesla user forum relates to low charging rates encountered on a Supercharger on first connecting. The user perhaps sees only 20 kW on a Supercharger rated at 150 kW which can initially create a panic mode. This almost always relates to the battery condition at the time as opposed to the charger or the connector being faulty. The charging rate increases once the battery is warm enough and at the right charge state to accept a higher rate of charge.

We generally plan our charging at two hour intervals if there are adequate chargers on the selected route and typically it has taken about 45 minutes to charge sufficiently to continue the journey. Charging is combined with a coffee and comfort break.

A mobile phone application reports on the current status of the car and permits one to complete certain tasks remotely. On our first charging experience away from home as total 'newbies' we had literally just sat down with cups of coffee in a nearby service area after connecting the car when a message was received via a mobile phone advising that charging would be finished soon and it was time to come back. The system was a little hasty in issuing such warning as there was still 20 minutes remaining.

A recent Tesla update has included the preconditioning of the battery if one sets the destination as a Supercharger location. In using this option, the battery is pre-warmed and ready to receive a faster charge on arrival.

Black holes in the charging network

In contemplating longer journeys one looks at the various applications which list all available charging facilities on a mapping system where one can assess possible options where one's regular network doesn't have any facilities. It quickly became clear to us that certain areas of the UK are poor in charging provision whereas other regions were well provided for. For example, Wales currently has limited fast charging facilities whereas Scotland has good coverage on the main routes.

EV Charger Problems

Several issues can arise concerning chargers. There are regular reports of commercial chargers not working and another issue is the parking of cars in the EV charging bays. This latter issue relates to both conventional and electric vehicles using the charging bays for parking. Signing is improving at charging locations but there needs to be further improvement.

Many power suppliers now charge a fee per minute where users fail to disconnect an EV from a charging station once charging is complete. This is particularly relevant where chargers are in shopping centre car parks where some shoppers abandoned their vehicle whilst shopping. That system does not cover for those EV drivers who simply unplug the charging lead without moving the car! There are however some more advanced systems appearing which can detect a vehicle occupying a bay.

We have encountered some antisocial issues when stopping at a charging facility in a supermarket car park in Wilmslow where parking fees applied. Three out of four bays were already occupied, and we reversed into the vacant bay to commence charging. Upon closer examination of the scenario, we concluded that we were the only ones that had paid the combined £4 charging and parking fee and were charging. The other three occupants had made it look as though they were charging to presumably avoid paying the parking fees.

In the time since we first started driving an EV things have changed considerably as more EVs have appeared. In the early days there was much camaraderie amongst owners particularly at charging stations with help readily available for anyone having problems. This has changed with the increased volumes of BEVs in circulation. Charger rage has been reported at times as there is no easy way of working a fair queuing system at many charging locations. This could become a major issue if a substantial shift to EVs occurs without a huge increase in charging capacity. Each EV typically requires a charging time of 30 minutes to an hour on a fast charger and hence there needs to be a huge increase in charging facilities by 2030 if current plans continue to stop sales of petrol and diesel vehicles This explains why on some planning applications numbers as high as 48 bays have been specified.

Some supermarket groups have recently become proactive in providing better charging facilities in conjunction with established charging entities.

The provision of power is a major issue in providing EV charging stations and for example a new facility with say 48 chargers rated at 250 kW would require 12 mW of power which is generally way beyond what was originally planned for most service areas until recently. So there will be ongoing challenges in terms of both the grid network and generation capacity.

There are already issues with availability of power as in some locations chargers have been installed for more than three years (for example Tesla Superchargers located at the M62 Hartshead Moor Services) but have not yet been connected to a power supply.

Parasitic Losses when parking

Allowance must be made for parasitic losses with a BEV which occur in the parked position when considering long term parking. We have found that our battery loses around 1 to 2 % per day if parked with everything set to minimise usage. This figure can rise dramatically if certain options are left on, or if the car is interrogated frequently using a mobile app, thus waking the car. We have parked our car for 14 nights leaving it with 180 miles range and returning to find 140 miles left on our return.

In short term parking there can be a higher loss (1% per hour) if a security monitoring option is active as every close encounter with a person or object causes the system to reactivate. Experience with such a mode shows that it will activate when other cars park nearby or pedestrians walk close to the vehicle or inspect it. We have quite a lot of video clips of individuals thoroughly inspecting the car but fortunately all appeared to be for genuine interest rather than for criminal activities!

When parking for short periods where occupants remain within the vehicle the air conditioning and lighting systems remain active resulting in some loss of range.

Parking at airports or ports can be an issue with a BEV as few locations offer EV charging on site. Some companies are recognising the need for parking with a charging option such that on return owners can drive off with a fully charged vehicle. This option needs to increase substantially as the population of EVs increases.

Over the air updates

An important feature from our experience is the facility for automatic updates to the car operating system using wifi or a data connection which is offered by some manufacturers but not all.

In our period of our car ownership the operating system has been updated regularly resulting in several significant improvements including

- Camera video capture from multiple positions around the car recording to a USB memory stick in case of an accident or problems when parked
- ‘PIN to drive’ security facility for added protection against theft
- ‘Sentry Mode’ option on leaving the car which activates the camera recording and various other measures if any person or vehicle gets too close
- ‘Doggy Mode’ to provide air conditioning for any pets left in the vehicle for a short period along with a message on the visual display for any concerned persons
- Remote or timed control of the heating and battery systems to prepare for departure

Wifi Connection

As a considerable volume of data is downloaded to the car on a regular basis, we fitted the garage with a wifi range extender, and this has proven to be a wise move. The car has a built-in mobile data connection but signal strength can vary a lot just as with mobile phones. The system will automatically connect to any known wifi system upon parking and will regularly check for any updates. A good connection is also vital for any remote diagnostic activity should any problems be encountered.

Rebooting the car

Those familiar with IT equipment will be aware that rebooting is required from time to time if a system starts to behave erratically. We were initially surprised to find that the same logic can apply to BEV control systems! Hence, we are now familiar with the reboot procedure if the car system behaves oddly. We have learnt that our system has a problem if, for example, the mapping display freezes, or the warning click for a turn signal disappears. It requires a few minutes in a parked position to achieve a reboot.

There is a known issue with our vehicle where the components on a circuit board degrade with use resulting in the requirement to reboot more frequently. The resolution is for the manufacturer to replace the board with a later version with increased memory but that is an ongoing issue as total failure is the required trigger point to secure warrantee action.

At the opposite end of the scale a manufacturer can also use updates to change the car’s operating parameters including changing the battery rating or charging capability. A ‘battery gate’ scenario has arisen for certain owners where the battery capacity/range was reduced overnight following a software update. This is an ongoing issue with possible resolution by a further software update rather than litigation.

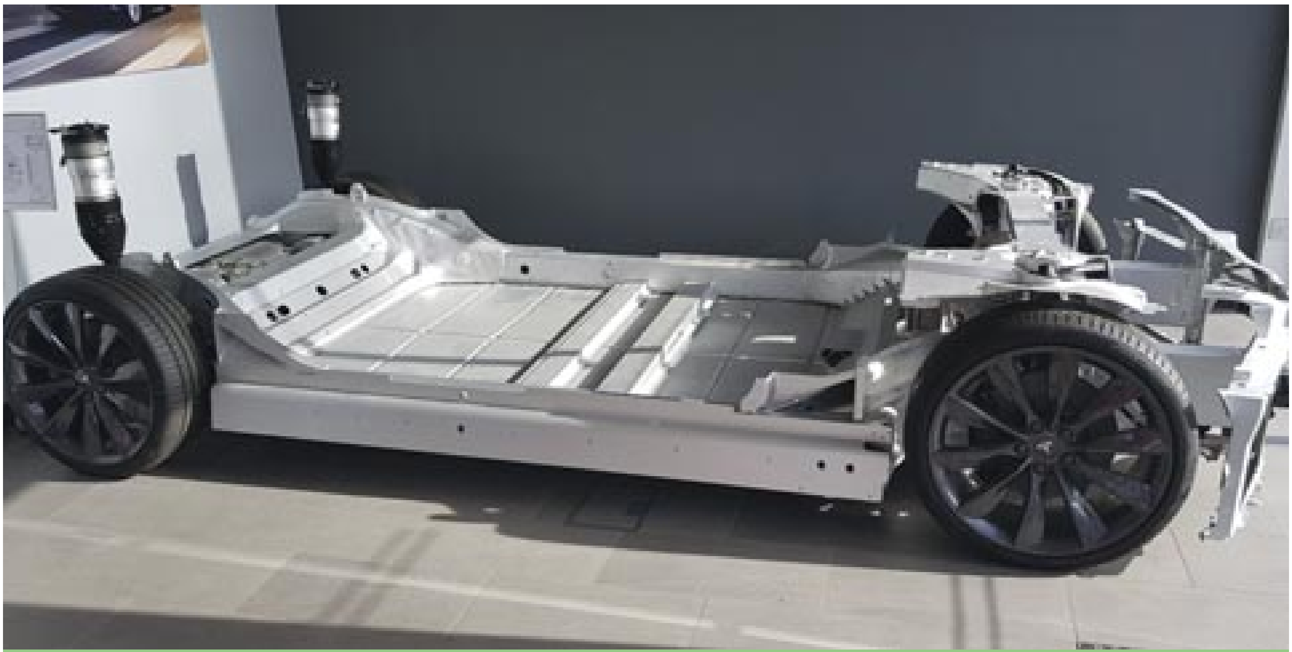

Figure 9: Skateboard design with a battery pack forming the base of the vehicle

Design logic – Traditional car manufacturer versus the new market entrants

Some manufacturers have designed their electric cars with a clean sheet approach whereas others have designed a chassis capable of multi power configurations.

The clean sheet approach often uses the battery module to form the base of the platform (sometimes called the 'skateboard' design) which is good for lowering the centre of gravity. Such design can also facilitate changing the battery should the need arise. At one stage in the early development phase consideration was given to the concept of exchanging batteries at service areas to provide a fully charged replacement unit within a few minutes. The exchange concept was tried out in the USA but proved to be unsuccessful. Other manufacturers have designed their battery structures to fill defined spaces on cars which are offered with multiple power options where there is space for engines, transmission systems and fuel tanks.

We can tell that our vehicle was not designed by a traditional car maker in several ways. The automatic wipers have been poor in operational sensitivity such that the wipers have failed to operate in many circumstances ranging from a deluge to light rain and operate at times when not required! This has improved with software updates but still we still manually intervene on most trips in rain. The systems used by most traditional manufacturers for automatic wiper control for a decade or two have been reliable and required minimal intervention per experience with our own vehicles and multiple hire cars.

Another factor with our vehicle is the noise level encountered on a motorway. It seems incredible to record that our previous diesel power car was far quieter with no increase in volume required in either speaking or in listening to the sound system at 70 mph. Our EV exhibits noticeable road noise even though it is fitted with noise reducing tyres! The use of aluminium in the bodywork may be a factor along with the desire to keep weight down.

Screen based control systems

Another clean sheet approach has been to adopt far bigger visual displays on BEVs. This means that almost all functions use screen- based controls leaving only items such as the direction indicators and windscreen wipers controlled by physical switches. The traditional car manufacturer has generally compromised on their BEV designs by retaining more manual controls whilst using a large visual display for much of the operational data. Figure 12 shows the central display on our EV.

Our experience with almost totally screen-based system is that there are some practical snags with such a system. For example, switching on and off the fog lights requires one to use the menu structure on the screen-based system to achieve action. This is fine if a passenger can act, but if driving alone when suddenly encountering a sudden fog bank then it is impossible to switch on the fog lights without taking one's eyes off the road ahead. With stricter legislation on the use of mobile phones at the wheel we wonder if some screen-based systems might also fall foul of legislation in due course. We prefer to have a traditional switch for the lighting functions. Here again we have noted that in looking at a few demonstration BEVs designed by traditional car manufacturers that some control functions remain as physical switches rather than screen-based switches.

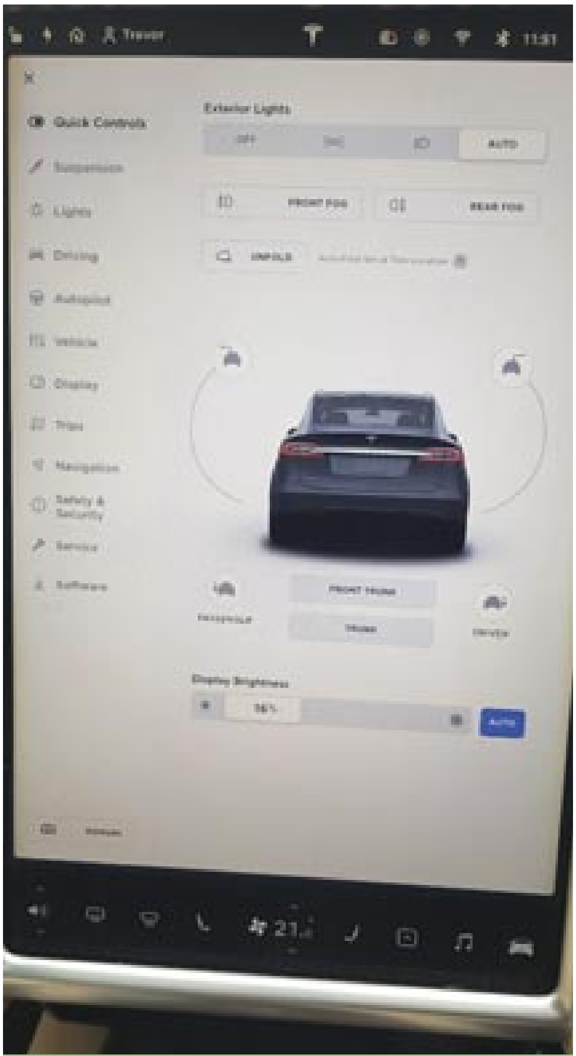

Figure 10: Central system display which controls most of the car systems

Drive Systems

Most BEVs incorporate a motor driving a differential gear assembly driving a pair of wheels which is duplicated at each end for four-wheel drive. A move to a combined motor wheel assembly seems a possibility to reduce cost and weight if adequate control could be maintained under all conditions and it is understood that such a concept is active with some designers.

Battery capacity – some practical issues

The net available battery capacity is lower than the advertised figure for any BEV in practical terms. The golden rule is never to allow the battery to reach zero as a dead car will need recovery until such time as roadside services can offer mobile battery charging facilities. In general use we have set a minimum target at 10% for longer journeys and we closely monitor the 'end of journey forecast' of remaining battery capacity as displayed on the satellite navigation system. In most of our driving we find that the forecast figure improves by a few percentage points along the journey but if one drives in adverse conditions then the figure might deteriorate towards the minimum target. In such circumstances one would activate various power saving options, reduce speed, and consider an additional charging stop.

Many manufacturers suggest a maximum regular charging figure of 90% as being conducive to optimum battery life. We have found that the time taken to move between 90 and 100% is long – sometimes doubling the time spent on charging. We have seen charging rates of over 100 kW gradually reduce until at 90% the figure might be only 20 kW and still declining. Time is not generally an issue in

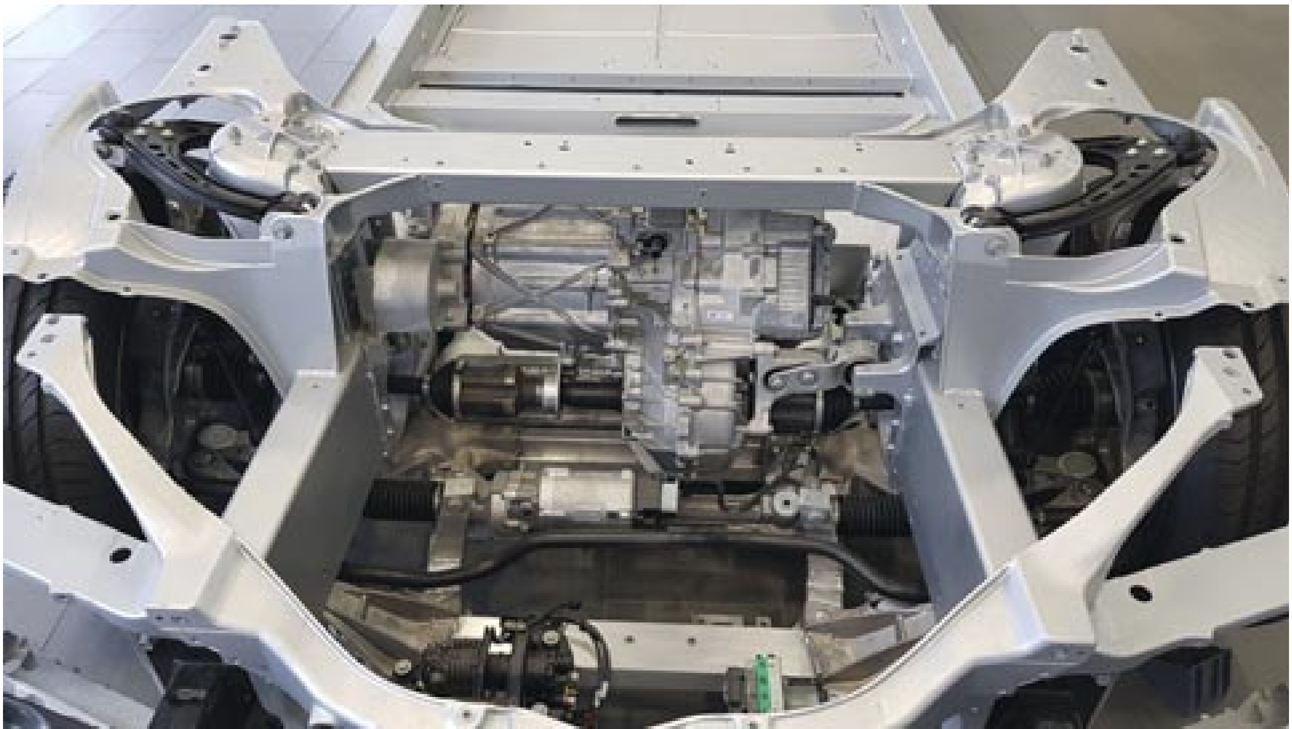

Figure 11: Motor and drive assembly

charging overnight at home so we can set off on a long journey with 100% battery capacity if required.

Taking these factors into account we estimate a maximum range in our vehicle (with 75 kWh battery) of 160/180 miles in summer or 120/140 miles in winter, based on driving at the prescribed maximum speed for the roads with heating and/or air conditioning on, and with lights and wipers as required.

Another factor affecting range is the size of the wheels as fitted. Optional larger wheel sizes result in a lower vehicle range (and reduced ride comfort!)

In planning a journey with an EV it pays to have a 'Plan B' in mind in case the chosen charging location has issues or for example the authorities close a motorway or major road requiring a long diversion. On our longer journeys we have tended to be conservative in making two stops on a journey where perhaps one could have reached the destination with only one stop if all factors remained favourable.

Another factor that can apply at busy times is an imposed limitation on charging. Tesla for instance may limit charging to a maximum of 80% at locations where there is significant demand and few vacant chargers

About 5 years ago Tesla adopted one battery design for two differently rated vehicles and varied the capacity via the battery management system. Owners could upgrade from the lower rating by paying a fee and the capacity restriction was removed. Cars with the lower capacity rating would probably suffer less degradation as the physical battery was larger than specified. This logic appears to have been discontinued as manufacturing volume increased and the number of options was reduced.

Battery Cooling

Battery cooling systems are based on water or air systems with manufacturers claiming benefits for their chosen option. Cooling requirements are quite substantial, and the cooling fans on our car can be heard working hard under certain circumstances such as fast charging or a hot day.

Battery Degradation

Another key factor with EVs is battery degradation. In 30 months of usage, we have seen little degradation such that the mileage figure at 100% charge is within 2% of the newly delivered figure.

In reading user feedback for various individual makes one becomes aware that there is considerable variation in degradation depending on the manufacturer and the type of battery, the effectiveness of the battery management and control system, the method of battery cooling, and the type of driving encountered.

Frequent use of maximum acceleration and regular use of ultra-fast high input charging are factors which may affect degradation. This subject is likely to produce more detailed comparisons as global EV usage increases.

Most manufacturers offer an extended warranty on the motor and battery – typically 8 years, but the required degradation for replacement is typically 30 % which represents a substantial drop in range.

Auxiliary Battery

The car is provided with a 12 volt battery which powers the control system and all the normal auxiliary equipment including lights, wipers, heating and ventilation and which has its own charging system. This is a critical item of equipment since failure can render the vehicle totally inoperative and requiring recovery back to a service centre. We have fortunately not encountered any problems with this battery so far but are aware that this item has caused problems across a wide range of different EVs both in terms of battery and charging system failures.

Autopilot Experience

We have used autopilot facilities on several occasions for a period of perhaps four weeks in total including a free trial week on our own vehicle, plus several weeks of use on loan cars with the facility switched on.

It is an incredible experience when one first switches the system on and the car proceeds to drive on its own with the driver monitoring activity. Our first use of the system during a demonstration drive nearly ended in disaster as when driving on autopilot on a two-lane motorway the system didn't react when a van in the outer lane nearly side swiped the test vehicle. A collision was only avoided by manual intervention before the van driver corrected his mistake. In steering suddenly to the left to avoid a collision the auto control system was fighting against the correction with warning chimes sounding before it reverted to manual control. This was not the best introduction but at least the demonstration car was not damaged!

Following that experience, we started with a somewhat cautious approach in our later trials and have concluded that the system is flawed from our viewpoint. In addition to the above incident, we encountered

- Sudden and unexplained 'phantom' braking
- Sudden reversal of requested lane changes without reason or logic
- The failure of the system to notice an overhanging load on a vehicle resulting in potential collision with the load. A fabricated building on a flatbed truck always gave the same result in that the car reacted correctly to the truck position but didn't react to the substantial overhang.

- The safety requirement to continually apply pressure to the steering wheel is essential but this also leads to issues where the alarm goes off as one is not applying enough pressure.

The system depends on 'seeing' the white lines on the road such that it can keep the car precisely in a central position. Where the lines have worn away or where two sets of lines were visible following road works on motorways the system became confused. Various updates to the software have taken place with claimed improvements since our trials with the system but we have not changed our opinion.

We concluded that it was easier to drive with full direct control than to continually monitor the car's actions whilst also maintaining enough pressure on the steering wheel to avoid the alarm system being activated. We have noted other users on social media recording that they have reached the same conclusion after similar incidents. By contrast there are many who find the system to be perfect for their driving requirements!

We still have the collision warning system activated and have noted numerous false alarms caused by vehicles on the opposite side of a carriageway. We wonder if the system was ever tested on typical UK roads with vehicle passing closely on narrow and winding single carriageway country roads.

The intelligent cruise control function was excellent in operation and maintained the selected speed unless a vehicle came within the specified zone ahead, in which case it changed speed or braked to maintain the gap. There is a useful facility to quickly increase or decrease the distance maintained between vehicles according to traffic conditions.

Power Usage and Cost Comparison

In 30 months the usage figures for our vehicle were as follows

Total distance	23394.4 miles
Power consumed	8343.4 kWh
Average watt hours per mile	357 (*or 2.8 miles per kWh*)
Cost of power	£ 460 (all costed as off-peak charging at home)
Cost per mile	1.97 p
Equivalent cost with previous diesel car	£ 3899
Saving	£ 3482 total for 30 months, or £ 1392 per annum

The above kWh figures are derived from the car system whereas ideally the gross kWh consumed in charging the battery would be the correct figure to use for costing purposes, but we don't have a dedicated meter on the charging circuit. The above costs have been inflated by ten percent to cover for the battery efficiency factor.

Vehicle Service Costs

The service side of EVs is still at the early stages of development and the recommended requirements have changed over time. When we acquired our car the service schedule was extensive with requirements relating to gearbox oil, cooling system service, wheel alignment etc.

By the time we reached the end of the first year of use the situation had changed radically such that there was no recommended service schedule. We opted to have our brakes cleaned and the pivot points lubricated since the brakes get limited use. With regenerative braking taking most of the load there is a tendency for the brakes to rust or seize with time.

Our only other expense has been upgrading the car charging system to handle a CCS connection. This required a revised wiring harness to be fitted along with a software upgrade and was combined with an overall vehicle condition check-up after 30 months usage. The original tyres are still in service and wearing well.

It is likely that system upgrades will be an ongoing expense to incorporate faster processors and larger memories in a motherboard replacement to keep pace with system updates.

The total costs over 30 months have been

- Service £ 174
- Vehicle upgrades £ 280

Remote Monitoring and Servicing

We have benefited from remote technical support where the car system is interrogated, and certain actions taken after viewing the vehicle logs via a data connection. In our case a series of minor problems in the vehicle system software were resolved by clearing out the memory buffers.

Vehicle Reliability

The car has not broken down or failed in use although we once opted not to use the vehicle on one occasion when a software issue arose at home (which subsequently self-corrected following a software update). On this occasion we had an issue with the key not being detected within the vehicle although we could still operate the car using the app on our mobile phones (which acts as an alternative key). We opted for caution as we could envisage being stranded if the mobile phone signal was poor at any point where we parked the car.

We have also encountered varying error messages at times where a reboot of the software has normally produced a correction requiring perhaps a 5 minute delay.

Battery feedback to the Grid

A lot has been written about the possibilities of allowing car batteries to provide backup to the Grid. There are some issues that need clarification on such a concept, and we have not pursued the subject further to date.

The life of a battery is determined by the number of cycles of charge and discharge and hence such an arrangement would require adequate compensation to the vehicle owner as the vehicle battery would encounter more usage than the mileage recorded by the car.

Another issue is whether owners will accept that if the car is needed at short notice at any time the battery might be at a low charge state.

Heating Systems

Many of the first generation of EVs used resistive type heaters which require a high level of power in winter whenever the vehicle is occupied. There has been a move to adopt heat pumps to reduce power usage and such items are standard or optional equipment on many recent designs

EV Education

In the early days of our use of a BEV we encountered numerous occasions when strangers would approach us to ask questions about the car. This has diminished as more EVs are seen on the road.

Conclusions

We are still enthusiastic users and fully enjoy driving our BEV in much the same way as when we first collected it. We are cautious in undertaking any long journeys at short notice unless the route is well covered by Tesla Superchargers. The situation on charging is improving although it would not be easy to access several areas of the UK at present.

If someone had to choose just one vehicle today to be capable of driving anywhere in the UK at short notice, then a PHEV with a battery large enough to cover typical daily local usage would be the ideal compromise. This would use an internal combustion engine to extend the range for longer journeys and thereby avoid issues with battery charging.

As the UK charging network becomes more established and the range of EVs increases with improved battery and motor technology then a BEV will become more acceptable for general use. ■

Acknowledgements

The kind assistance of David Robbins has been much appreciated in providing feedback and suggestions on the original draft.

Type 2 socket

CCS Plug

APPENDICES

APPENDIX 1 EV Power Connection types

The following socket standards are currently being used for new cars and chargers.

Type 2 – This is a well-established connection type used for both low and high rated charging. The lower rated charging is via AC using the onboard charger whilst the DC capability can provide up to 150 kW with certain EVs

Combined charging System (CCS) – The later high output standard with ratings of up to 350 kW. Liquid cooling of charging cables is used.

CHAdeMO – The original fast DC charger rated typically at 50 kW still found in many locations

CHAdeMO socket

Appendix 2 Power Connection Converters

The converters are useful to provide multiple options for charging when faced with a variation in available facilities at any one location. These are substantial pieces of equipment, some rated to take up to 250 kW.

Type 2 to CCS Converter

Type 2 to CHAdeMO converter