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Electric Vehicles

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Section 1. Overview

Is this for me?

Are you a TECs Member who is considering getting an Electric Vehicle (**EV**)? You may already have an EV but want to know how best to use it. For example to make sure you are contributing to CO_2 and other emission reductions.

The information provided here should help you make a better, more informed decision. It will also provide you with lots of details on EVs and their possible impact. You can decide how much detail you'll need.

If you only want to get a quick and general overview of the benefits/costs of owning an EV and how they compare to other options, this section provides it. The information in the rest of the document backs up these conclusions and recommendations.

Why would I want to buy an EV?

As with any expenditure, there are many personal reasons why we decide to buy something. Given quite a wide range of options, the one we choose will also depend on what we are looking to achieve and the budget we have available.

The main reasons for purchasing an EV tends to be:

1. Reducing my Carbon Footprint.
2. Reducing other harmful transport emissions like Nitrogen Oxides (NOx) and particulates.
3. Saving on transport costs.
4. As an area of interest/investigation and/or a social statement.

The first three reasons are probably the ones that are more difficult to evaluate, which is why they are covered here. They should be determined by calculating the overall reductions during the expected life of the EV and ensuring these are greater than for other options available, now and into the future.

The evaluation of the third reason listed above is more subjective and probably limited only by the balance between the desire to do something and its affordability. So this is a lifestyle choice. Nevertheless it is worth understanding what the various parameters are in making a particular decision as price and efficacy can vary significantly.

Is it worth it and how much will it cost?

Whether this is 'worth it' depends on the reasons for having it and how it compares to a comparable vehicle or other modes of transport.

In general, most modes of public transport, cycling or walking, if feasible, will have lower overall emissions and be cheaper. We will not be looking into these here, but please do ask Dr Watt if you are interested in finding out more.

You are certainly going to significantly reduce your overall Carbon Emissions if you are able to charge your EV from a known renewable source. Similarly, when charging from the current electricity grid, you're likely to reduce your life-time Carbon emissions, albeit at a lower rate and by a smaller total. You can find details on this in later sections.

EVs cost more to buy, but less to run. In general, you should expect to save on life-time costs when compared to equivalent petrol/diesel vehicles. The exact comparison will depend on the model you buy and how/where you drive it. Based on certain assumptions we've provided some comparison figures of a range of vehicles.

One of the best ways to ensure you have the lowest possible emissions (CO_2 and NOx) are:

- Charge your EV from a known renewable source, e.g. spare generation from your PV system.
- Buy the lightest possible EV, this may not have the long range. So alternative modes of travel and/or intermediate charging facilities will be needed for longer journeys.

We all have different needs for what forms of transport we use. To take full advantage of the general information we've provided, it is important to know what your personal current usage is, and what changes you are prepared to make.

If in doubt, please contact Prof. Joules or Dr. Watt

Section 2. Technical Introduction to Electric Vehicles

Electric Vehicles are powered by electricity stored in the vehicle's battery.

There are two types of vehicle that can be powered by charging from mains electricity.

- Plug-in Hybrid Electric Vehicles (**PHEV**)
- Battery Electric Vehicles (**BEV**)

In this document the abbreviation **EV** refers equally to BEVs and PHEVs.

EVs are much more efficient in their use of energy than Petrol or Diesel vehicles, at least twice as efficient. For the vehicles used in the comparison in section 2.8 electric vehicles use about 25% of the energy used by conventionally powered ones, but electric vehicles generally cost more than conventionally fuelled ones. This price relationship is likely to change fairly quickly as EVs are more mass-produced and are designed to be powered only by electricity.

The amount of energy that can be held in batteries of a given size and mass has also increased considerably over the last 10 years. In 2009 Mini produced a prototype EV whose battery took up the boot and back seat. In 2020 the Mini EV will have a battery of the same capacity which fits in the transmission tunnel and does not compromise interior space.

The government has announced that new sales of Petrol and Diesel powered vehicles will cease by 2040.

An EV is much quieter for passengers and drivers than conventionally powered vehicles. When driving at low speeds you therefore need to be aware that pedestrians and cyclists may not be aware of you.

There are other vehicle types with electric motors working in conjunction with a petrol or diesel engine that cannot be charged from the mains. These are not considered further in this document.

Most car journeys are short. From the 2016 Analysis of national travel the average person did 814 trips and covered 6557 miles, so their average daily distance was 18 miles. This is about the real range of most plug in hybrids, and much less than the range of a BEV. This means that in most cases an EV can be recharged overnight at home, which is more convenient than going to a filling station.

The average person in the South West does 10[1] trips over 100 miles per year by all modes, some of these will be by public transport (train or air). This means that for most journeys an effective range of 100 miles is adequate. For confidence you probably need a range of 150 miles based on Worldwide Harmonised Light Vehicle Test Procedure (**WLTP**) calculations.

BEVs have no tail-pipe emissions, but may cause emissions if charged from an electricity supplier that is not zero carbon, such as the current electricity grid.

2.1 Plug-in Hybrid Electric Vehicles

PHEVs have an internal combustion engine (**ICE**) as well as an electric motor (or motors) and battery. Typically they are capable of travelling between 20 and 30 miles on electricity only, then the ICE takes over.

If most of your journeys are relatively short a PHEV can run on electricity most of the time, but longer journeys can still be undertaken without worrying about where to recharge. Charging will become less of a worry as BEVs become more common, and the charging network expands.

[1] National Transport Survey - Table NTS9911

PHEVs are mechanically quite complicated, the ICE, motor and battery take up quite a lot of space (and weight). PHEVs are typically based on conventionally driven vehicles.

There is no longer a government grant available to assist with the purchase of PHEVs.

According to the Society of Motor Manufacturers and Traders (SMMT) , July 2019 sales of PHEVs were down 49.6% on July 2018, whereas sales of Battery Electric Vehicles were up 158.1%.

For July 2019 PHEVs represent 1.1% of the total UK car market.

2.2 Battery Electric Vehicles

BEVs are powered by an electric motor (or motors) and battery only. They typically have a range of 70 to 360 miles. Though some BEVs are based on conventionally driven vehicles, it is more likely they will be designed to be electrically driven only.

Electric motors are much simpler than ICE, so should be more reliable. Electric motors are also smaller than ICE, which can lead to more interior space in a vehicle design to be electric only. Most manufacturers are now producing BEVs.

The initial cost of a BEV is significantly higher than an equivalent conventionally driven model, but the running costs are much lower. The cost of electricity used is much lower than the cost of petrol or diesel for the same distance. As the vehicle is simpler, servicing costs should be lower, and vehicle excise duty (VED) is also lower. The cost of pure BEVs is reducing as new models are introduced, and should eventually achieve parity.

Deloitte estimates that the market will reach a tipping point in 2022 – when the cost of ownership of a BEV is on a par with its internal combustion engine counterpart.

There is currently a government grant of £3500 available when a new BEV is purchased.

According to SMMT BEVs represented 1.4% of vehicle sales in July 2019.

2.3 Other smaller EV types

Other smaller EV types include:

- e-bikes
- e-scooters
- Electric Motorcycles
- Electric Quadriclyes

e-bikes

e-bikes are bikes that have a small electric motor that is used to boost the power to the wheels when the user pedals. You do not need a licence to use an e-bike, but must be over 14 years of age. An e-bike must:

- Only provide electric assistance below 25 kph (15.5 mph)
- Have a motor whose continuous rated power is 250W or less.
- The pedals must be in motion for motor assistance to be provided.

https://www.cyclinguk.org/cyclists-library/regulations/eapc-regulations

If an e-bike meets these rules it is classed as a normal pedal bike and can be used anywhere a pedal bike can go.

https://www.gov.uk/electric-bike-rules

Battery sizes for e-bikes range from 180Wh to 1000Wh.

https://www.cyclinguk.org/article/guide-e-bike-batteries

Bosch has a range calculator for e-bikes.

A 300kWh battery would provide a working range of 25km to over 100km depending on conditions, riding style and weight of rider and bike.

Larger batteries will have proportionately longer ranges.

e-scooters

In several cities abroad you will see e-scooters, which are scooters with a platform you stand on and electric motor. These are often available for rent using an App. These are not currently street legal in the UK.

Electric Motorcycles

Most manufacturers (Vespa, BMW, Harley Davidson, etc.) are producing electric models. The obligation to do this is similar to that placed on motor manufacturers.

Electric Quadricycles

An electric quadricycle is a four wheeled vehicle which has a central driving position, with possibly a passenger seat behind the driver. The Renault Twizzy is an example of an electric quadricycle.

https://en.wikipedia.org/wiki/Quadricycle_(EU_vehicle_classification)

An electric quadricycle must:

- Have an unladen weight no more than 450 kg excluding batteries.
- Have an engine power no more than 15kW.

To drive a heavy electric quadricycle, you need a class B driving licence, the same as for driving a normal car.

2.4 History of BEVs

There have been BEVs for a long time, but these have not gained popular acceptance except for specialist applications (e.g. Milk float, Buggy, etc.)

The first modern BEV in mass production available in the UK was the Nissan Leaf introduced in 2012 with a 24KwH battery giving a range of about 80 miles.

The luxury Tesla model S was also introduced 2012 with a 60KwH battery and range of 200 miles. Tesla recognised that public charging would be an issue, and so built its own Supercharger network for exclusive use with Tesla vehicles. Initially the Supercharger network was available to customers at no charge.

These were followed by the Renault Zoe and Renault Twizzy in 2013; Renault adopted the practice of selling the car, but leasing the battery, this can be reassuring when buying secondhand. The Twizzy is classified as a quadricycle, rather than a car.

BMW also introduced the i3 in 2013, this used light-weight carbon fibre, and had a 22KWH battery with a range of about 80 miles. It gave good performance at a fairly reasonable price.

Since then these initial models have evolved to have greater range and better performance, an new models have been introduced.

The public charging network has been slow to develop, so in practice most charging is done at home.

At the same time PHEV versions of ICE models started to be introduced by many manufacturers. These accounted for the majority of the market in the mid to late 2010s, as they can run on conventional fuel as well as electricity. Many of these will now be available on the secondhand market.

Recent development of battery technology has led to greater energy density, which has enabled vehicles with greater range to be practical, and the public charging network is more mature. Government policy indicates that new sales of ICE vehicles will have to end by 2040, and there Is pressure to bring this date forward. Most manufacturers are now introducing pure electric models. Against this background BEVs are the only sector of the vehicle market that is expanding.

Demand for BEVs is currently outstripping production.

2.5 Travel Range

The Range of a BEV is the distance that it can travel starting with a fully charged battery.

The range of new BEVs is quoted using the World harmonised Light vehicle Testing Procedure (WLTP), which came into force in 2017. Prior to this, vehicles had been tested according to the New European Driving Cycle (**NEDC**). WLTP better represents real world driving conditions.

The introduction of WLTP has resulted in many models near the end of their life-cycle being withdrawn from the market, as manufacturers could not justify the cost of testing.

Range is quoted as:

- Combined Cycle
- City Cycle

A winter range is also sometimes quoted, generally for BEVs the winter range is about 2/3 of the overall range. This reduction in range is due in part to lower battery efficiency at lower temperatures, and in part due to use of heating.

From anecdotal experience with a PHEV with an NEDC range of 31 miles, this is only obtained on a sunny day in April, in December the range is nearer 20 miles.

Unlike ICE vehicles BEVs are more efficient on the city cycle than the combined cycle. This is because vehicles average lower speeds in the city cycle, electric motors give most torque at start-up, and so require less energy in start-stop conditions; At the higher speeds encountered in the combined cycle wind resistance is a more important factor, the power needed to overcome wind resistance is proportional to the cube of speed, and so the energy required for a given distance is proportional to the square of speed. So travelling at 80mph requires ~31% more energy compared to 70mph for the same vehicle/conditions to travel the same distance.

Technical explanation for this (which may be skipped)

Power at higher velocities is given by

$P = \frac{1}{2} \rho v^3 A C_d$ (https://en.wikipedia.org/wiki/Drag_(physics))

Where v = velocity, A = frontal cross sectional area, C_d is the drag coefficient, ρ is the density of air.

So to travel at 80mph rather than 70mph requires 49% more power, and 49% more energy to travel for a given time; to travel a given distance at 80mph rather than 70mph requires 31% more energy.

Recently manufacturers have introduced heat pumps which reduce heating demand in winter. According to https://www.greencarreports.com/news/1124387_can-heat-pumps-solve-cold-weather-range-loss-for-evs heat pumps can increase winter range by 30%.

The ev-database.uk site quotes a real range which is generally lower than the WLTP range, this is probably a more realistic figures. This is because manufacturers will run the WLTP tests under optimal conditions.

2.6 Emissions

When electrically powered there are no exhaust emissions directly from the vehicle, though there can be emissions at the power generator.

There are several Greenhouse Gas Emissions (**GHG**) which cause Climate Change. Collectively these are referred to as CO_2 equivalent (**CO_2 e**) emissions.

If UK grid electricity is used then this emits 255g CO_2 e/KWH (based on 2018 data), so that a typical BEV might cause emissions of between 36 and 69 g CO_2 e/km, but if an all renewable source is used, this drops to zero.

There are emissions from the manufacture, maintenance and disposal of EVs. Apart from these, there is also some environmental pollution from BEVs due to things like tyre wear. These emissions are comparable to ICE vehicles so the move to BEVs should still play a major role in improving overall environmental impacts such as air quality.

The pod-point.com/guides/vehicles site has a calculated g CO_2 e/km for each vehicle.

NOx

NOx refers to the gasses Nitrous Oxide (N_2O), Nitrogen Oxide (NO) and Nitrogen Dioxide (NO_2).

NO is not harmful to health. NO_2 is toxic and is associated with a variety of environmental and health problems. N_2O (also known as laughing gas) is a powerful greenhouse gas, which scavenges ozone.

For EVs NOx emissions occur where the electricity is generated, whereas other fuel types emit NOx at the tailpipe.

The following table is extracted from https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/715425/Conversion_Factors_2018_-_Condensed_set__for_most_users__v01-01.xls for a lower medium segment vehicle such as a VW Golf. Note that CO_2 e includes the other three GHG emissions.

	kg CO_2e /mile	**kg CO_2 /mile**	**CH_4 kg CO_2e / mile**	**N_2O kg CO_2e / mile**
Diesel	**0.24217**	**0.23917**	**0.00002**	**0.00298**
Petrol	**0.29425**	**0.29304**	**0.00054**	**0.00067**
PHEV - Scope 1	0.10742	0.10692	0.00033	0.00017
PHEV - Scope 2	0.05763	0.05719	0.00013	0.00031
PHEV - Scope 3	0.00491	0.00487	0.00001	0.00003
PHEV - Total	**0.16996**	**0.16898**	**0.00047**	**0.00051**
BEV - Scope 1	0	0	0	0
BEV - Scope 2	0.09491	0.09418	0.00022	0.00051
BEV - Scope 3	0.00809	0.00803	0.00002	0.00004
BEV - Total	**0.103**	**0.10221**	**0.00024**	**0.00055**

In this table units are CO_2 equivalents. To get the mass of gas emitted these need to be divided by the Global Warming Potential (**GWP**) for the gas. For N_2O this is 298, and CH_4 this is 25. See https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/726911/2018_methodology_paper_FINAL_v01-00.pdf paragraph 1.4 for further details.

For EVs:

Scope 1 is at the tailpipe

Scope 2 is emissions in generation of grid electricity

Scope 3 is losses due to transmission of grid electricity.

The table below is equivalent to the one above but showing the mass of gas / mile after division by the relevant GWP constant.

	kg CO_2e /mile	kg CO_2 /mile	g CH_4 / mile	g N_2O / mile
Diesel	0.24217	0.23917	0.0008	0.01
Petrol	0.29425	0.29304	0.0216	0.002248
PHEV - Scope 1	0.10742	0.10692	0.0132	0.00057
PHEV - Scope 2	0.05763	0.05719	0.0052	0.00104
PHEV - Scope 3	0.00491	0.00487	0.0004	0.000101
PHEV - Total	0.16996	0.16898	0.0188	0.001711
BEV - Scope 1	0	0	0	0
BEV - Scope 2	0.09491	0.09418	0.0088	0.001711
BEV - Scope 3	0.00809	0.00803	0.0008	0.000134
BEV - Total	0.103	0.10221	0.0096	0.001846

These figures are representative of the current fleet.

Diesel New diesel engine vehicles must comply with Euro 6, which mandates NOx emissions of 0.08g/km or 0.129g/mile. This is much higher than the reporting emissions stated in the table above., this is because the majority of NOx emissions from diesel engines are NO and NO_2, rather than N_2O. The proportion of NO_2 in older diesel engines is about 5% of NOx, but in more recent engines it is between 12% and 70%. For a Euro 6 this would equate to 0.0096 - 0.056 g/km .

Until recently vehicles have been tested using the NEDC procedure where the emissions test has been passed. When tested in real world driving conditions it has been found that NOx emissions are more like 0.6g/km. See https://www.eea.europa.eu/publications/explaining-road-transport-emissions

EVs can also cause NOx emissions, but these are at stationary generating plant. In 2017 power and heat generation accounted for 109 kilotonnes of NOx emissions, whereas passenger cars accounted for 140 kilotonnes. https://naei.beis.gov.uk/overview/pollutants?pollutant_id=6. As power plant is stationary, the emissions will mainly affect the surrounding area of the plant. Most power plant emissions now come from Natural Gas fired power stations.

It is difficult to estimate NOx from electricity generation from the 2017 figures because power and heat generation have been combined in the emissions figure. If we assume that the NOx emissions figure for power and heat generation is due to electricity and heat sold demand in 2017 of 315 TWh, then this equates to NOx emissions of 0.346 g/kWh.

The following table shows estimated NOx emissions from four electric cars as a result of electricity generation using this estimated emissions rate:

Model	Make	kWh/100km	NOx g/km
i-Pace	Jaguar	23	0.080170
e-Golf	VW	14	0.047373
e-208 Allure	Peugeot	15	0.053568
ZS EV Excite	MG	20	0.067780

So the worst emissions at generation from BEVs are about the same as the Euro 6 limit.

This emissions rate will depend on the fuel mix used for electricity generation which is shown in the following table extracted from DUKES 5.3 for 2017

Mix of fuel sources in electricity 2017			
Source	ktoe	percentage	weight
Coal (5)	5.55	8.94%	2
Oil (3)(4)	0.54	0.87%	1
Gas (6)	24.6	39.63%	1
Nuclear	15.12	24.36%	
Hydro (natural flow) (7)	0.51	0.82%	
Wind, wave and solar photovoltaics	5.25	8.46%	
Other renewables (7)	7.09	11.42%	
Other fuels (8)	2.14	3.45%	
Net imports	1.27	2.05%	1
Total all generating companies	62.08		

Weights in the above table represent NOx emissions relative to Gas.

From this table fossil fuels (Coal, Oil, Gas) and imports account for 51.5% of electricity generation.

When weights are applied the proportion of fossil fuels is 60.42%, dividing emissions of NOx from power and heat generation by this gives an emissions rate for gas of 0.573 g/kWh.

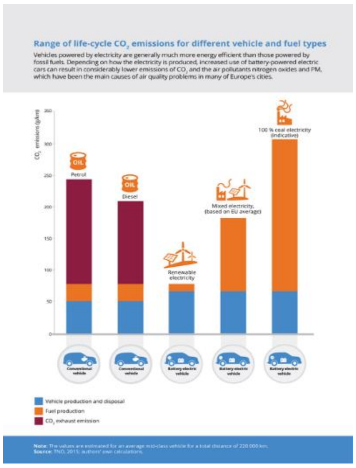
A 1MW gas fired station running for an hour would emit 573g of NOx (5 tonnes per year).

From https://blog.ucsusa.org/mark-specht/natural-gas-power-plants-are-not-clean it is suggested that when a power plant starts up its NOx emissions are 3 to 7 times more than when running.

2.7 Manufacture and disposal

Emissions

Emissions from manufacture of BEVs are generally regarded to be about 50% more than for an equivalent ICEV.



The graphic left shows lifetime CO2 emissions for different vehicle types in 2015. It shows that emissions from EV production are higher than for conventional vehicles. Most of these emissions are caused by use of more steel and aluminium in a heavier vehicle, together with emissions from battery production. Production techniques are evolving fast, VW claim that their new factory at Zwichau will make EV production carbon neutral. They use 100% renewable energy in production, use recycled materials and invest in certified climate projects to offset unavoidable emissions.

Reproduced from https://www.eea.europa.eu/signals/signals-2017/infographics/range-of-life-cycle-co2/view under creative commons licence.

https://www.sciencedirect.com/science/article/pii/S1876610217309049 compares ICEV and EV production. This paper suggests that CO_2 emissions in EV production in China are 14642kg/vehicle against 9172kg/vehicle for ICEVs. This is based on conditions at the time China, where only 11% of steel is recycled and electricity is assumed to have far higher emissions than other sources. This is not the European case. Emissions relate mainly to the increased weight and production of the Li-ion battery. Production of Li-ion batteries in the US leads to one third the emissions of a Chinese ones. Similarly use of recycled steel substantially reduces emissions.

Environmental impact of Lithium mining

EVs use Lithium Ion batteries, the production and disposal of these has an environmental impact.

The two main sources of lithium are mines and brine water and mining, most coming from brine. According to Friends of the Earth, the main production areas are South America (Chile, Bolivia, Argentina), Australia, China and the United States. Lithium carbonate is recovered from brine by natural evaporation, which leaves lithium, magnesium, calcium, sodium and potassium. The production process can lead to severe water pollution and depletion near the extraction site, leading to contamination of streams used by humans, animals and for crop irrigation. There isn't much quantitative information available on this subject. Looking forward there are technological developments being researched which could improve the efficiency and side effects of lithium extraction. Lithium is present in sea water at very low concentrations, research is being done into its extraction.

Recycling Li-ion batteries

In 2010 the quantity of Lithium ION batteries that were recycled was only 5% of those manufactured, at that time there was no plant in the UK. There are now plans to develop Lithium battery recycling plant in the UK. Fortum in Finland claim a low carbon process to recycle 80% of Lithium batteries. Again, there is little quantitative information available.

When EV batteries fail it is likely that a small number of cells will have failed, and only these will need to be replaced. When an EV batteries capacity drops to 80% of its original capacity it can still be used for other purposes, for example as a domestic storage battery which are still usable down to 50% Depth of Discharge (**DoD**).

Lifespan

As BEVs are much simpler than conventional vehicles, it is likely that their useable lifespan is longer. It is even possible that vehicles can be kept up to date by software upgrades, and occasional hardware upgrades. Most manufacturers guarantee the battery for 8 years or 100,000 miles; this is because the vehicle electronics limits the State of Charge(**SoC**) so that the battery is never completely discharged or completely charged. According to https://insideevs.com/news/368591/electric-car-battery-lifespan/ many of the original Teslas are still running on their original batteries with little sign of deterioration.

2.8 Efficiency

In Section 2 it was stated that EVs are much more efficient in their use of energy than Petrol or Diesel vehicles, at least twice as efficient.

In general, lighter weight BEVs would be more efficient, because:

- The energy required to accelerate a vehicle is proportional to its mass (proportional to its weight)
- The energy required to go up a hill is proportional to mass and the height of the hill.

As the battery has significant mass, vehicles with larger batteries should be less efficient. It's difficult to quantify this as vehicles where the only difference is battery size are difficult to find. A possible comparison is the Kia e-Nero 39kWh and 64kWh. The following table summarises these:

Battery kWh	Unladen Weight	WLTP range	Wh/mile
39	1592	180	260
64	1812	282	270

This suggests that though there is a significant weight and range increase consumption is not that much higher.

The following table compares some electric models with equivalent petrol and diesel models at various price points. Note that this excludes the higher embodied energy in BEVs, see section 2.7

								£ Break even		
Manufacturer	Model	Price	Fuel	WLTP Combined Range	Power KW	KWH/ 100km	g CO2 e/km	km	miles	Tonnes CO2 at breakeven
Jaguar	F-Pace 5.0 Petrol	75335	Petrol		405	119.1	272	-89208.4	-55309	0
Jaguar	F-Pace 3.0 Diesel	54990	Diesel		220	90.33	170			21.6999929
Jaguar	i-Pace	64495	Electric	292	294	23.16	50	127647	79141.2	6.38235086
VW	Golf Match 1.6TDi manual	22080	Diesel		84.5824	58.07	109			12.057793
VW	e-Golf	27575	Electric	143	99	13.68	41	110622	68585.6	4.53550011
Peugeot	208 Puretech 130 EAT8 S&S Allure	21500	Petrol		96	58.12	108			9.67204168
Peugeot	e-208 Allure	26250	Electric	211	101	15.47	38	89555.9	55524.7	3.40312578
MG	ZS Excite 1.0T Gdi Auto	16045	Diesel		81.6404	78.69	145			19.732276
MG	ZS EV Excite	24995	Electric	163	105	19.58	45	136085	84372.5	6.12380979

Colour coding in the above table indicates paired vehicles.

The comparator model was chosen to have about the same performance characteristics and as near as possible the same trim level.

The energy used by electric models is only 22 to 25% of that used by the equivalent petrol or diesel. Energy lost in charging is much higher when using rapid DC charging than standard 7KW charging. Charging at 7KW is generally about 95% efficient (from comparing charge time with battery capacity), the quoted consumptions for EVs in the table above have been divided by 0.95 to account for this.

The costs used for fuels in the above table were

Fuel	Cost/Litre	Cost/KWH
Diesel	1.3	0.121
Petrol	1.25	0.131
Electricity		0.150

Both evdatabase and podpoint have efficiency figures for BEVs.

Podpoint gives either an NEDC or WLTP figure.

Evdatabase gives NEDC, WLTP and EVDB (Evdatabase) figures in the Energy consumption section of a vehicle's page. It also has a more detailed Real Energy Consumption section, which gives Cold and Mild weather set of figures for City, Highway and Combined.

Efficiency of Rapid Charging

Rapid charging is charging at 50 kW and above. With Rapid charging a useful amount of charge can be gained in a few minutes. Rapid charging is generally stopped when the battery is 80% charged, as charging past this point becomes inefficient and high currents when the battery is near fully charged can damage the battery.

Evaluation of Fast Charging Efficiency under Extreme Temperatures studies efficiency of a number of chargers ranging from 20kWdc to 120kWdc. At 25°C at higher charging rates (37.6kW to 48.9kW) the chargers were between 90% and 92% efficient. At -15°C efficiencies were between 43% and 89% efficient. This study measured the efficiency of converting electricity from a 400V, 125A 50Hz supply to DC voltage for charging.

Other factors need to be considered:

- How the charging rate affects the useful charge returned from the battery.
- The effect of high demand on the electricity supply network.
- How high charge rates affect the life of the battery.

Battery University's article on Fast and Ultra-fast chargers discusses the relationship between charge rate, efficiency and battery life. If a battery is charged in an hour, after 500 cycles it would retain 83% of its capacity. If it charged in 30 minutes, after 500 cycles it would retain 48% of its capacity. If it charged in 20 minutes it would be dead before 400 cycles had passed.

A high charge rate is only applied during the first few minutes of charging. https://batteryuniversity.com/learn/article/bu_1004_charging_an_electric_vehicle states that tests show that charging with a 24kW dc charger takes 30 minutes, whereas charging with a 50kW dc charger only reduces this to 20 minutes.

2.9 Driving

There are some important differences when driving a BEV:

- All BEVs are automatic, pure BEVs normally only have one gear.
- The motor has most torque (pulling power) when it is starting, which means that a BEV accelerates much faster from a standing start.
- Many newer BEVs incorporate semi-autonomous features such as adaptive cruise control, collision avoidance, speed limit recognition.
- Most BEVs implement regenerative braking, when braking the motor functions as a generator which charges the battery. Some can be driven most of the time using just the accelerator pedal.
- All BEVs need charging with electricity which can be done at home, destination or at a rapid charger.
- The battery in a BEV is heavy and is usually placed low down in the vehicle, this lowers its centre of gravity. Some drivers may notice the increased weight.

- BEVs are quiet so other road users may not hear your approach, particularly pedestrians and cyclists. From 2019 newly approved models will have to emit a sound of at least 56 db when reversing and at speeds less that 20kph (12mph). From 2021 this will apply to new EV sales.

2.10 Towing

Most EVs do not have type approval for towing, so towing will invalidate your insurance and warranty. There are some exceptions at the high end (Tesla Model X, Jaguar i-Pace, Mercedes EQC and Audi e-Tron).

There are a number of reasons why manufacturers have chosen not get vehicles type approved:

- EVs are heavier because of the battery.
- Weight of vehicle and trailer places additional loads on brakes and suspension.
- Damage to the drive-train when using regenerative braking.
- Adverse publicity caused by reduced range.

If a vehicle does not have approval for towing nobody knows how it will handle in situations likely to be found when towing.

For more information see:

https://www.rac.co.uk/drive/advice/know-how/can-electric-cars-tow/

https://www.drivingelectric.com/your-questions-answered/131/can-i-tow-caravan-electric-or-hybrid-car

Section 3. Charging an Electric Vehicle

BEVs and PHEVs need to be charged. This can be with:

- A plug in charger
- A home charger
- On street residential chargers
- A charger at work
- At a public charging point

The charging circuitry for an EV consists of:

- Stationary charging unit
- Charging cable
- On-board charger which converts incoming AC from the mains to a DC voltage to charge the battery.
- Battery.

Most home and destination charging use either single-phase or three-phase mains electricity. This requires rectification and voltage conversion to charge the battery.

Rapid charging is often DC electricity, where the static charger does the conversion from mains to DC. A converter to handle the high currents required by rapid charging is expensive (and substantial), so is provided by a static unit, rather than the car. Rapid charging requires a lot of current from the grid, and so may be backed by storage batteries.

Charging with a 7KW wall unit is quite efficient, from comparing charging times with battery capacity it should be about 95%.

3.1 Connector Types

There are a number of different connector types so you will need to use a charger with an appropriate connector for the vehicle. The most common is a generic type 2 connector.

The following table summarises the available connector types:

Connector Type	Supplies	Notes
IEC Type 1	3 KW or 7KW AC	Compatible with old Nissan Leaf and some other early models. No current new models use this type of connector.
IEC Type 2	3 KW, 7KW single phase AC 22KW, 43KW three phase AC Also Tesla 120KW DC	This appears to be the most common connector, and is used by the majority of new models.
CCS	50 KW DC	The CCS connector is an IEC Type 2 Connector with an extra 2 pin connector for DC. Compatible vehicles include BMW i3, VW e-Golf and Hyundai Ioniq Electric.
CHAdeMO	50 KW DC	A separate connector normally in addition to a type 1 connector. Compatible vehicles include Nissan Leaf, Mitsubishi Outlander PHEV, Kia Soul EV.

3.2 Plug-in chargers

These are chargers that plug in to a normal 3 pin socket (delivering ~2.4kW of power). They are the slowest means of charging, e.g. a PHEV with a 7kWh battery takes nearly 4 hours to charge with one of these.

A plug-in charger can be useful if you are away overnight and there is no other means of charging available.

3.3 Home chargers

If you have off street parking, then you should get a home charger. This is a dedicated charger that has its own circuit which is typically rated at 32 Amps. This means that a home charger can charge at 7KW from a single phase supply. 7KW is the highest charge rate that is available from a single phase supply.

A 7KW charger can completely recharge most currently available EVs in 12 hours (up to 84KWH), this should be enough for a large BEV to do about 250 miles.

A government grant is available to fund up to 75% of the cost (up to a maximum of £500) of a home charger. From July 2019 funding will only be available for smart chargers which are capable of being remotely controlled, this will enable loading of the grid to be controlled so that charging at peak times is avoided. The charge-point must be installed by an authorised installer.

If you have a 3 phase supply a 22KW charger can be installed.

In practice most EV charging is done at home.

Roughly 80%[2] of overnight parking in Teignbridge is either in a garage or on private property, so most parking is suitable for home charging.

3.4 On street residential chargers

A barrier to EV take up is dwellings that do not have off street parking, and so cannot have a home charger. To deal with this there is a government grant available to local authorities. This scheme is supported by the Energy Saving Trust.

The Office for Low Emission Vehicles (OLEV) has allocated £1.5m of funding for 17/18 and £4.5m for 18/19 and 19/20 for on-street residential projects. This funding is available to Local Authorities for eligible projects, on a first come, first-served basis.

There is only one authority in the South-West that has successfully applied under this scheme(see map).

The energy saving trust have just published a guide, which gives more information for authorities.

Roughly 20%[2] of overnight parking is on street in Teignbridge.

3.5 Workplace chargers

The Workplace Charging Scheme is a voucher based scheme that provides support towards the up-front costs of the purchase and installation of electric vehicle charge-points, for eligible business, charities and public sector organisations. This scheme is for up to 20 sockets across all sites for each applicant.

3.6 Public Charging Points

Public charging points are available in many places. ZapMap publishes a map which shows the current location of these and includes the current status of each charger.

As well as the 7KW and 22KW charging types described for home use, there are Rapid charging points which charge at much faster rates 43KW for AC and up to 150KW for DC, even 350KW is mentioned on the ZapMap site. These can charge compatible BEVs to 80% in 20-40 minutes. Though fast this method of charging is less efficient than slower chargers. It potentially places significant loads on the electricity network, so expect to see rapid charging points associated with storage.

There are a number of operators for charging points, access to these varies:

- Some operators have a membership scheme, though they may also offer a pay as you go scheme.
- Some provide access via a Smartphone App.
- Some provide access via an RFID card.

[2] Derived from weighting table NTS0908 for 2018 by Teignbridge classification of Urban-rural type from 2001-la-class-dataset-post0409-boundaries.

- Most Tesla points are for the use of Tesla drivers only, though Generic Type 2 7KW and 22KW points on the Tesla Destination network can be accessed by non-Tesla drivers.

For more information on charge-point operators see here. Though the situation is improving planning is still essential when using public charging.

ZapMaps claims there are now more charging points than filling stations in the UK. Though that isn't really a fair comparison because each filling station probably has 10 or more pumps and the pumps are occupied for significantly less time.

Many manufacturers offer charging packages when purchasing a new vehicle, these provide access to specific charge network operators.

There needs to be significant growth in provision to deal with the expected growth in BEV sales. Provision in Teignbridge is below the national average.

Section 4. Available vehicles

At the time of writing many new models are appearing on the market.

4.1 Associated spreadsheet

Key parameters of available BEVs are summarised in the spreadsheet, please ask TECs for this information.

TECs Electric Vehicles.xlsx

This spreadsheet includes data for models currently available, and has been extracted from manufacturers specifications, as well as other sources.

The columns in the spreadsheet are:

- Manufacturer
- Model
- First production – year when model was/will be introduced
- Last production – year when production ceased
- Battery capacity in Kilowatt Hours (KWH)
- Power stated – engine power stated in units used by manufacturer
- Power units – units in which engine power is stated.
- Power in KiloWatts
- Unladen Weight
- Gross Weight – maximum including luggage and passengers
- Seats – Number of
- Luggage Capacity – min and max in litres
- Adaptive Cruise – does vehicle have cruise control which adapts to speed of vehicle in front (and possibly other things like bends)
- Lane Assist – does vehicle have assistance with staying in lane.
- Speed limit monitoring – does vehicle detect speed limit and stick to it?
- Charging times:
  - From 3 pin socket
  - From IEC Type1 connector (if fitted)
  - From IEC Type2 connector using home charger <= 7KW

- From IEC Type2 connector using rapid AC charging (if available)
- From CCS DC connector (if fitted)
- From CHAdeMO DC connector (if fitted)
- From Suc (Tesla only)

- Maximum Fast charge power KW
- Consumption Wh/km on WLTP general cycle
- Consumption Wh/km on WLTP city cycle
- Combined cycle range miles (WLTP is available)
- Combined cycle standard (normally WLTP but NEDC or other if not)
- WLTP City Range
- Drive – 2F Front wheels, 2R Rear wheels, 4 Four wheels
- Grid electricity CO2 – g CO2 e / km using 2018 conversion of 0.2556 / Wh

Some models are included that were not in production at the time of compilation.

This spreadsheet was compiled from the following sources:

- Manufacturer's brochures and price lists.
- https://ev-database.uk/
- https://pod-point.com/guides/vehicles?

4.2 What is available new in 2019

Available BEVs range from the Renault Twizzy from £6,000 exclusive of battery rental to the Tesla model X at up to £100,000.

The Twizzy is technically an electric quadricycle, is very basic (doors are an extra) its main advantage is that it only uses 61 Wh/mile equivalent to 16 g CO_2 e/km on grid electricity. The battery is leased. Second-hand prices start at about £4,000 for a 2013 model with 4,200 miles. (This is the highest mileage listed!)

Somewhat more practical is the Smart electric at about £21,000 (though there are deals available as low as £15,200 on the outgoing model at the time of writing). This uses 127 Wh/mile equivalent to 38 g CO_2 e/km[3].

The VW e-UP Gen2 will be available from December 2019 at an estimated price of £16,000 consumption of 127 Wh/mile equivalent to 32.5 g CO_2/km[4] and range of 161 miles. There are also Skoda and Seat versions with similar price and other statistics coming available at about the same time.

The Tesla model X uses 230 Wh/km equivalent to 57 g CO_2 e/km.

The following table summarises what is available in each price band

[3] Taken from podpoint database for outgoing model

[4] Based on UK grid electricity emissions of 255g CO_2e/kWh applied to WLTP consumption

Price Range	Wh/Mile		G CO_2 e/km		Range		Manufacturers
	min	max	Min	max	min	max	
Under £25,000	61	186	16	45	62	163	Renault, Smart, VW, MG
£25,000 - £30,000	130	206	36	45	143	211	Peugeot, MG, Renault, VW, Nissan, Vauxhall, Hyundai
£30,000 - £35,000	136	206	36	45	155	282	Kia, Hyundai, Nissan, BMW
£35,000 - £40,000	147	180	39	45	239	281	Hyundai, Kia, Nissan, Tesla
Over £40,000	155	235	39	69	237	375	Tesla, Jaguar, Mercedes, Audi

Apart from a few outliers there is remarkably little correlation between price and consumption.

For further details see spreadsheet described in section 4.1

A number of manufacturers are currently producing electric vans these include:

- Nissan e-NV200
- Renault Kangoo Z.E. 33
- Peugeot Partner Electric/ Citroen Berlingo

4.3 What is coming

There have been lots of announcements of new models from manufacturers.

2020 should see:

Fiat 500 Electric

New Renault Zoe

Mini 3 door hatch EV

VW ID.3

Honda e

Peugeot e-2008 SUV

Seat El-Born

Volvo XC40

BMW iX3

Many of these will cost below £30,000 and will have reasonable range.

See spreadsheet linked in Section 4.1 for further details.