

Power plants on wheels

Balancing the grid with electric vehicles

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With thanks to Claire Miller and Octopus EV for their input

EXECUTIVE SUMMARY

The roll-out of Vehicle to Grid technology in electric vehicles could play a major role in balancing the national grid as the UK makes the transition to renewable electricity generation.

Making use of the batteries available in the UK's growing fleet of electric vehicles could be a much cheaper means to balance the grid, resulting in cheaper electricity bills for all UK consumers. Considerable savings could also be made by the owners of V2G capable EVs, with the driver of even a small Nissan Leaf earning up to £850 a year by selling electricity back to the grid at times of peak demand next year.

The extent to which these savings are realised will be determined by the speed at which V2G-capable electric vehicles are introduced on the UK's roads. The government is expected to announce details of its Zero Emission Vehicle (ZEV) Mandate imminently - a policy that will require car manufacturers to ensure an increasing proportion of the cars they sell in the coming years are electric.

If the mandate follows the car industry's 'high' deployment scenario and encourages 'vehicle-to-grid' (V2G) technology, 13.5 million V2G capable electric vehicles could be available to sell electricity to the grid at times of peak demand by 2035, and owners would have earned a total of £7.6bn by that time.

However, should the Government proceed with its current proposed targets and the rollout of V2G technology happens slowly, as few as 2.3 million V2G capable EVs could be available by 2035, and owners would have earned just £1.1bn by 2035.

THE FUTURE ELECTRICITY SYSTEM

The UK's electricity generation mix is changing rapidly - renewable sources of electricity such as solar and wind, the cheapest way to generate electricity, are contributing ever greater quantities of power.

In light of the gas crisis, the Government has increased targets for renewable deployment as part of its energy security strategy which will reduce the need to import gas for power generation. With output of wind and solar energy being naturally variable, the future electricity system will be more flexible making greater use of storage technologies such as batteries and green hydrogen to match supply with demand.

As with any market, when demand goes up relative to supply, so does the price. Peak demand on the UK's electricity grid is around 7pm, when prices are at their highest. Greater competition to provide electricity to the grid will help to bring that cost down. Enter electric cars and 'V2G'...

WHAT IS V2G?

Vehicle-to-grid (V2G) technology provides an electric vehicle with the capacity to feed electricity back to the national grid from its battery. It allows a plugged-in EV to charge up when demand is low and/or generation is high, and to send electricity back to the grid when demand is high and/or generation is low, helping to 'balance' the grid.

In 2022, there were 33.2m cars in the UK¹, which are parked for 96% of the time on average². If all of these vehicles were electric and were able to discharge electricity back to the grid at a rate of 7kW per vehicle then, at times of peak demand, the National Grid would be able to call upon 230GW of power. To put this into context, peak winter demand for electricity in the UK is roughly 50GW.

While the UK is many years away from such a complete electrification of its car fleet, the potential is clear. Only a fraction of this fleet would need to be V2G-capable EVs for it to play a significant role in balancing the grid. This would reduce the UK's reliance on paying high prices to spin up, at short notice, expensive and polluting gas-fired power plants, creating savings for all of the UK's electricity consumers.

V2G EV owners would be paid for the electricity that their vehicles put back into the grid. Recent trials have indicated that these earnings could be as high as £725-£840 a year^{3 4}, with the UK government suggesting they could be worth up to £1,000 in certain circumstances⁵. The analysis in this report focuses on a typical commuter, and finds that they could earn up to £850 next year. Such earnings would come in addition to the savings that EV drivers already experience from owning an EV over an internal combustion engine (ICE) car, through lower fuel and servicing costs. Research by the ECIU recently found that the owner of a second-hand, small to mid-sized EV can save £500–800 a year compared to a petrol equivalent.⁶

¹ <https://www.gov.uk/government/statistics/vehicle-licensing-statistics-july-to-september-2022/vehicle-licensing-statistics-july-to-september-2022>

² <https://www.racfoundation.org/media-centre/cars-parked-23-hours-a-day>

³ <https://www.ofgem.gov.uk/publications/case-study-uk-electric-vehicle-grid-v2g-charging>

⁴ <https://octopus.energy/press/octopus-energy-and-national-grid-eso-demonstrate-future-role-for-electric-vehicles-in-first-for-great-britain/>

⁵ <https://www.gov.uk/government/news/new-plan-for-smart-electric-vehicle-ev-charging-could-save-consumers-up-to-1000-a-year>

⁶ <https://eciu.net/analysis/reports/2023/embargoed-27-feb-the-uks-second-hand-car-market>

HOW DOES V2G WORK?

Firstly, an EV needs to be V2G capable – this means having a charging port that allows for a two-way flow of electricity between the vehicle and the grid. At present, the only available EV in the UK with V2G capability is the Nissan Leaf which is built in Sunderland. However, a variety of car manufacturers, such as VW⁷ and Audi⁸, are developing the technology, whilst Hyundai is already trialing it in the Netherlands⁹.

Secondly, a bi-directional smart charger is required to enable this two-way flow, and to communicate with the grid to manage when the car's battery is to charge up – when demand is low and/or generation is high – and when it is to discharge electricity back to the grid – when demand is high and/or generation is low.

The EV owner would only need to do two things: ensure that their car is plugged in when not being driven; and use an app to set some key parameters, for example the minimum charge they want the EV battery to remain above, and if they were planning a longer car journey and want the vehicle fully charged. A number of trials of V2G technology have already been carried out in the UK^{10 11 12} – information from these allows a scenario to be set out illustrating how this would work in practice, as follows.

A driver owns a V2G Nissan Leaf EV, with a smaller 40kWh battery, and uses their vehicle to commute 20 miles a day (the average length of a round-trip car commute). Setting off in the morning with her car at 80% charge, in average weather conditions her vehicle has a range of 119 miles. Coming back home from her day at work, her vehicle has 99 miles of range left, or around 26.6kWh of charge remaining in the battery. She plugs it in, and heads into her house.

For two hours that evening, when demand for electricity is high, her car discharges 14kWh of energy (7kW of power for two hours). 3kWh is used to power her house (for example lighting, TV and cooking

⁷ <https://cleantechnica.com/2021/12/23/volkswagen-plans-to-offer-v2g-and-plug-charge-technology-in-2022/>

⁸ <https://www.autocar.co.uk/car-news/business/audi-developing-vehicle-grid-charging-system-evs>

⁹ <https://www.hyundai.news/eu/articles/press-releases/how-innovative-vehicle-to-grid-technology-can-support-a-renewable-future.html>

¹⁰ https://energysavingtrust.org.uk/wp-content/uploads/2022/05/Energy-Saving-Trust_Powerloop-Vehicle-to-Grid-Best-Practice-Guide.pdf

¹¹ <https://www.flexi-orb.com/electric-vehicles/vehicle-to-grid/>

¹² <https://www.ofgem.gov.uk/publications/case-study-uk-electric-vehicle-grid-v2g-charging>

dinner), with the remaining 11kWh going back to the National Grid. This would leave her car with 12.6kWh in charge – or 47 miles of range – before being recharged again back up to 80% that night when demand is low. Based on currently electricity prices, for those two hours that evening the driver would save just over £1 in powering her house from her car, rather than the grid, and earn her £3.50 in selling electricity from her car back to the grid – a total of £4.50.

Repeated over a whole year (assuming commuting just four days a week and minus five and a half weeks of holiday in which her car is unavailable for V2G activity) her Nissan Leaf would provide her house with 0.56MWh of electricity, saving her over £190, and send 2.04MWh back to the grid, earning her over £650 – a total of £850.¹³

This example is a conservative one, as the 40kWh battery in the entry level Nissan Leaf is quite small. The larger batteries available in many EVs – some, such as the BMW iX 50¹⁴ and the Polestar 3¹⁵, exceed 100kWh - would easily allow their owners to discharge electricity back to the grid for longer, and generate greater savings. This is demonstrated by repeating the above scenario, but with a Nissan Leaf e+ with a larger, 62kWh battery capable of comfortably discharging electricity back to the house and grid for 3 hours a night, rather than two. In this scenario, the driver's car would discharge 21kWh. Assuming 4 kWh is used to power the house, the remaining 17kWh would go back to the grid. The car would be left with 23kWh in charge – or 82 miles in range – before being recharged again over night. For those three hours the driver would save £1.40 to power her house from her car, and earn her £5.40 in selling electricity back to the grid – a total of £6.80 a day. Over a whole year, her total savings would be over £1,260.

¹³ Figures don't sum due to rounding to nearest £10.

¹⁴ <https://ev-database.org/uk/car/1473/BMW-iX-xDrive-50>

¹⁵ <https://www.polestar.com/uk/polestar-3/specifications/>

THE ZEV MANDATE

The rate at which V2G capable EVs arrive on the UK's roads in the years ahead, and be available to balance the grid and generate savings for their owners and other energy bill payers, will be determined by a number of factors. The extent to which car manufacturers embrace the technology, and decide to include it in the vehicles they produce, will be key. So too will Government policy, most notably its imminent introduction of a Zero Emissions Vehicle Mandate, or ZEV mandate.

The ZEV mandate is a requirement for manufacturers to ensure that an increasing proportion of the vehicles that they sell in the UK are electric. The introduction of such a mandate was committed to by the Government in its 2021 Net Zero Strategy and is scheduled for introduction in 2024. It is one of the mechanisms by which the government will achieve its phase-out of sales of new conventional petrol and diesel cars and vans from 2030, only allowing the sale of zero emission vehicles from 2035.

The government is currently proposing a target of 22% of a car manufacturer's sales to be electric in 2024, rising incrementally each year (e.g. 38% in 2027, 80% in 2030) until 2035 when 100% of car sales will be fully electric¹⁶. The EV market in the UK is already on course to achieve these goals. Stronger proposals track the 'high' scenario for projected EV sales out to 2035 from the car industry body the Society of Motor Manufacturers and Traders (SMMT) (e.g. 34% in 2024, 60% in 2027, 80% in 2030, and 100% in 2035)¹⁷.

¹⁶ <https://www.gov.uk/government/consultations/policy-design-features-for-the-car-and-van-zero-emission-vehicle-zev-mandate>

¹⁷ <https://www.transportenvironment.org/wp-content/uploads/2022/06/TE-response-to-ZEV-Mandate-consultation-1.pdf> & <https://www.smmt.co.uk/wp-content/uploads/sites/2/SMMT-new-car-market-and-parc-outlook-to-2035-by-powertrain-type-11-06-21.pdf>

V2G AND THE ZEV MANDATE

If the Government were not to introduce a ZEV mandate, and the uptake of electric vehicles was to follow current trends, we could expect around 15.4 million EVs on the road by mid-2035. If the Government introduces a ZEV mandate using its proposed targets, this figure rises to 16.7 million. If the Government introduces a higher mandate, the figure rises to 18.8 million.

Alongside these figures, we can set out some scenarios for how quickly V2G technology will be applied to the EVs of the future:

- **Slow V2G:** New EVs with V2G rises by 2.5% per year from 2026, reaching 12.5% by 2030
- **Mid V2G:** Rises by 10% per year from 2026, reaching 50% by 2030
- **Rapid V2G:** Rises by 20% per year from 2026, reaching 100% by 2030

Combining these ZEV mandate projections, and our V2G roll-out scenarios, we can generate forecasts for the total number of V2G EVs that will be available in the UK in the years ahead.¹⁸ We can also apply the analysis used in our Nissan Leaf case study to understand the cumulative savings that would be generated by the owners of these additional vehicles. This analysis takes into account projections for the price of electricity in the UK in the years ahead, and the contribution of wind power that reduces the need for V2G to operate at maximum levels.¹⁹

Scenario one – ZEV mandate with proposed targets, and slow V2G

In this scenario, the UK would have 2.3 million V2G EVs on the road by 2035. If two-thirds of drivers made their vehicles available to discharge energy back to the grid for two hours a night, the total savings accumulated by 2035 would be £1.1bn. Were drivers able to make their vehicles available for three hours a night, these savings rise to £1.9bn.

¹⁸ Savings in each year are calculated based on the number of V2G-enabled EVs forecast to be on the road as of the middle of each year (to give the savings for the average size of the V2G fleet that year), multiplied by two-thirds to account for the fact that not all EV drivers would participate in V2G on each of the days in the example.

¹⁹ V2G would tend to operate at lower levels when wind output was higher, i.e. when power prices were already cheaper. Some individual EVs might earn the maximum in the scenario, but average earnings and the overall V2G output across all EVs would likely be reduced by the load factor of the UK's wind power fleet (taken to be 50% i.e. a mixture of onshore and offshore wind, but increasingly weighted towards offshore wind at over 60%).

Scenario two – ZEV mandate with proposed targets, and mid V2G

In this scenario, the UK would have 9 million V2G EVs on the road by mid-2035. If two-thirds of drivers made their vehicles available to discharge energy back to the grid for two hours a night, the total savings accumulated by 2035 would be £4.2bn. Were drivers able to make their vehicles available for three hours a night, these savings rise to £6.3bn.

Scenario three – ZEV mandate with ambitious targets, and high V2G

In this scenario, the UK would have 13.5 million V2G EVs on the road by mid-2035. If two-thirds of drivers made their vehicles available to discharge energy back to the grid for two hours a night, the total savings accumulated by 2035 would be £7.6bn. Were drivers able to make their vehicles available for three hours a night, these savings rise to £11.3bn.

The cumulative savings available to the UK's drivers under any scenario are significant, but vary considerably depending on the level of ambition in the ZEV Mandate and the speed of V2G uptake – the difference between earnings in Scenario One and Scenario Three being £6.5bn if EVs provide V2G for two hours most days, and £9.4bn if it's three hours.

WIDER IMPACTS ON ENERGY BILLS

Using electric vehicles to balance the grid will be considerably cheaper than the current practice of paying high prices to fire up extra gas-fired power stations at short notice. This could result in cheaper prices for all of the UK's electricity consumers, irrespective of whether or not they drive a V2G EV.

Such use of V2G at peak times could bring considerable cost savings for electricity customers. Typically, 'baseload' prices, which apply to power sold overnight, are around 10–20% cheaper than peak prices. EVs would largely be charged at night at the lower rate and then partially discharged at peak time, effectively shifting cheap electricity to the peak time, and reducing the need for more expensive gas power plants.

Due to the complex nature of wholesale and balancing markets, it is difficult, at this stage, to quantify the exact savings that could be on offer. A trial carried out by Octopus EV identified savings in balancing costs from V2G, and estimated that these could amount to £62million per year if 1million V2G EVs were in operation – at lower prices from before the gas crisis.²⁰

Alongside wholesale and balancing markets, the industry is continuing to develop markets for flexibility and grid services (e.g. frequency response), opening up more opportunities for V2G. Ofgem notes that flexibility could save electricity consumers £3.2–4.7bn a year by 2030, of which 25-40% would be through cheaper generation being available to balance the system ('reserve services')²¹ – of which V2G could be a major part.

One way of expressing the scale of V2G's potential in balancing the grid is to look at the number of fossil fuel power stations that would not have to be fired up at times of high demand were V2G rolled out at scale.

²⁰ <https://octopus.energy/press/octopus-energy-and-national-grid-eso-demonstrate-future-role-for-electric-vehicles-in-first-for-great-britain/>

²¹ <https://www.ofgem.gov.uk/sites/default/files/2023-03/Ofgem%20Call%20for%20Input%20on%20the%20Future%20of%20Distributed%20Flexibility2023.pdf>

For winter 2022/23, National Grid signed contracts with coal power plants for a total of 2.4GW of capacity, to have them on standby in case of tight margins caused by gas shortages or outages at French nuclear plants.²² The cost is estimated to be up to £395million.²³ Whilst coal plants were asked to warm up on a few occasions, only once was any of this extra coal power actually used, with up to 800MW being connected to the grid for a few hours on 7th March.²⁴

EVs feeding into the grid at peak time could have directly replaced these coal plants had V2G been available. The 800MW of coal capacity used briefly this winter could be displaced V2G ahead of winter 2026/27 under the scenario of an ambitious ZEV mandate and rapid V2G uptake (in the meantime gas will fill the gap after coal plants close). But V2G would not be available to fully replace this coal generation for another two years (i.e. ahead of winter 2028/29) under the scenario of the Government's proposed ZEV mandate and low V2G uptake.

As V2G capacity grows, it would also reduce our dependence on gas power plants at peak times. This is important because, at present, peak demand is quite often met using one of the UK's older, less efficient gas power plants. The less efficient the gas power plant, the more gas it uses to produce each unit of electricity, increasing our gas imports and driving wholesale prices higher by setting high 'marginal prices' for themselves and other generators.

The least efficient gas power plants, called open cycle gas turbines (OCGTs) provided almost 1GW of power on some occasions this winter.²⁵ Adding this to the 800MW of coal that was briefly used gives 1.8GW of expensive peaking power plants. Under the third scenario (higher uptake of EVs and V2G), this level of power would be available instead from V2G sources ahead of winter 2027/28, allowing the least efficient gas plants to be mothballed.

This logic extends to the more modern 'closed cycle gas turbines' (CCGTs), which are not all created equal, but rather a 'continuum' of efficiency. Displacing the least efficient (more expensive) CCGTs with V2G would reduce the UK's gas imports and bring down peak wholesale prices that feed through into customers' bills.

²² <https://www.nationalgrideso.com/news/national-grid-eso-confirms-early-detail-winter-coal-contracts>

²³ <https://www.current-news.co.uk/cost-of-winter-contingency-coal-units-could-hit-395-million-clarifies-national-grid-eso/>

²⁴ <https://www.reuters.com/world/uk/uks-national-grid-expects-tight-power-supply-tuesday-evening-2023-03-07/>

²⁵ Generation data is sourced from the Balancing Mechanism Reporting System (BMRS), published by Elexon: <https://www.bmreports.com/bmrs/?a=generation/fueltype/current>

This winter, the UK used over 20GW of CCGTs at a few times of peak demand – or about 20 gas power plants at typically 1GW each. The power generated by 20 gas power plants at times of peak demand could be replaced by V2G ahead of winter 2030/31, under the third scenario with its faster uptake. Having the ability to avoid using gas power stations at peak time would be particularly important if another gas crisis occurred and supplies were constrained.

METHODOLOGY

The simple example of daily EV charging and V2G discharging that is outlined in the report is based on the average round-trip car commute of 20 miles per day, as per various sources, e.g. data tables NTS0409 and NTSQ01006 (DfT), and an SME survey. This distance accounts for around two-thirds of car commutes. It assumes that this occurs on four weekdays each week, minus 5.6 weeks of annual holiday.

Examples for an individual EV were produced using model-specific data from the EV Database. The examples were tested in the most extreme case of a winter's evening, using the 'cold weather' efficiency values, and annual energy values used the 'average' efficiency values.

Overall car sales forecasts are from SMMT estimates. EV sales forecasts are based on Government ZEC Mandate proposal, and the SMMT's high EV sales scenario (SMMT, 2021), which give rising percentages of EV sales year-on-year, reaching 100% of new car sales by 2035. V2G uptake is modelled as a percentage of new EV sales, starting at 2.5% currently, and then rising from 2024 by 2.5%, 10% and 20% per year. Number of V2G-enabled EVs in any given year is the value at the mid-point of that year.

The V2G analysis then included only two-thirds of V2G-enabled EVs that would be on the road in any one year. This was chosen to be slightly below the level of 70% of households in England with a vehicle that have access to private, off-street parking and so could easily engage with V2G. This will include a mix of cars used for commuting (for which two-thirds of round-trip car commutes are no more than the average of 20 miles per day). and cars used for other purposes (e.g. school run, errands, etc) usually undertake shorter daily distances, and so could also engage in the daily pattern outlined. In reality, larger battery capacities mean that households have even more scope to engage with V2G than is suggested in the conservative examples in this report.