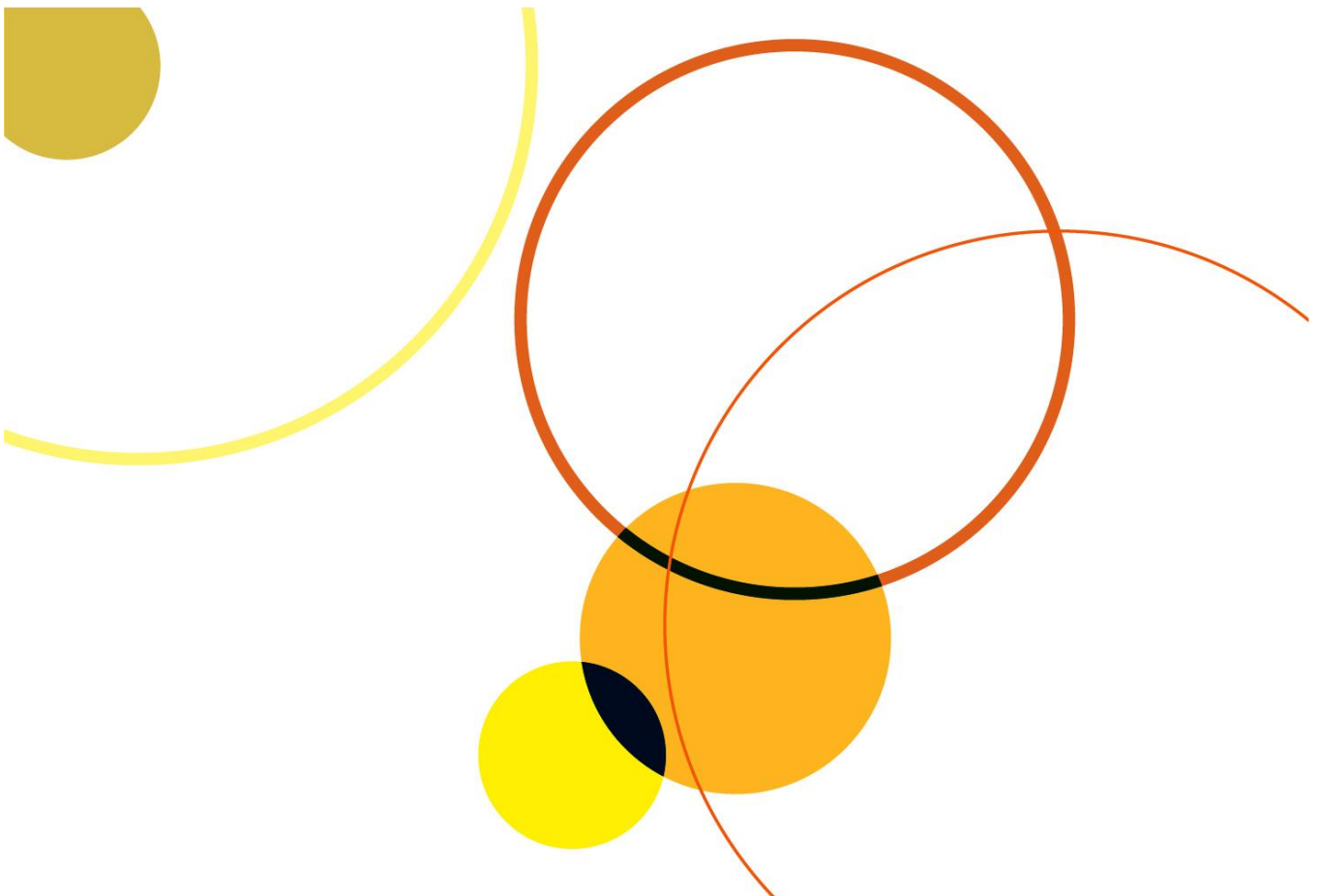


Accelerating the EV transition

Part 2: electricity system impacts

Report prepared for WWF

Final report
June 2018



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Glossary

Terms relating to electric vehicles	
Light duty vehicle (LDV)	A classification of road vehicles that includes cars, vans and sport-utility vehicles.
Electric Vehicles (EVs)	EVs (often referred to Battery Electric Vehicles – BEVs) refers to vehicles with an electric motor and battery. In this report we focus on LDV EVs – electric cars and vans.
Internal Combustion Engines (ICEs)	ICEs are conventional vehicles that produce power through the combustion of fossil fuels with air inside an engine.
Extended Range Electric Vehicles (E-REVs) and Plug-in Hybrid Vehicles (PHEVs)	E-REVs and PHEVs use an electric motor and battery but are supported by an internal combustion engine that may be used to recharge the vehicle’s battery. PHEVs use their electric and ICE motor interchangeably, whereas E-REVs only use the ICE motor when the electrical charge is exhausted.
Vehicle fleet	The total stock of vehicles in circulation at a particular point in time.
ICE phase out	The UK’s commitment to end the sale of all new conventional petrol and diesel cars and vans by 2040
Terms relating to charging patterns	
Standard charging	Scheduling charging of electric vehicles without regard to the existing utilisation of generation and network resources in the electricity system
Smart charging	Scheduling charging of electric vehicles to occur at times of low utilisation of generation and network resources in the electricity system
Vehicle to grid (V2G)	Allowing electric vehicles to provide electricity at times of high utilisation demand for generation and network resources



1 Introduction

In 2017 the UK Government's Air Quality Plan set out a commitment to end the sale of all new conventional petrol and diesel cars and vans by 2040, and "for almost every car and van on the road to be a zero emission vehicle by 2050" (Defra 2017). WWF has commissioned Vivid Economics to identify key impacts of moving from a 2040 to a 2030 phase out of conventional cars and vans. Part 1 covered selected impacts on the economy and the environment, such as jobs and value in the UK auto industry, as well as air pollution and carbon emissions (Vivid Economics 2018).

This report is Part 2, covering impacts on the electricity system and considering the potential value of repurposing used electric vehicle batteries for stationary storage.

In Part 1, we developed two phase out scenarios:

- The **2040 scenario** represents a 2040 end date for sales of new conventional and cars and vans. In this scenario, there is a fleet of 13 million EVs by 2030, up from around 137,000 today.
- The **2030 scenario** represents a 2030 end date for sales of new conventional and cars and vans. In this scenario, the fleet increases to 20 million EVs by 2030.

To estimate the value of smart charging and vehicle to grid (V2G) technologies in integrating electric vehicles into the electricity system, we carried out detailed electricity system modelling. In partnership with Imperial College, we estimated the composition and cost of the electricity system across the 2030 and 2040 scenarios, with variants in each case representing different charging profiles.

- Under standard charging, electric vehicles are charged at peak times, when there is high demand for electricity
- Under smart charging, electric vehicles are charged at off-peak times, such as overnight or during the day
- Under V2G, electric vehicles provide electricity to the grid at peak times.

We estimated the value of repurposing electric vehicle batteries for stationary storage as the cost saving from deploying repurposed batteries instead of new batteries. We estimated the quantity of repurposed batteries that might be repurposed in each scenario, and compared projections of repurposing costs with cost projections for new batteries.

The key findings of this work are:

- The 2030 scenario with smart charging is lower cost than the 2040 scenario with standard charging, and therefore cheaper for consumers.
- The charging profile is a more important factor than the number of electric vehicles in the cost of integrating electric vehicles into the electricity system. In other words, the smartness of the transition to electric vehicles will be the main factor determining how cost effective the transition is, not the speed of the transition.
- Smart charging and vehicle to grid are technically feasible, and a number of trials are currently underway in the UK.



- Smart charging could reduce the costs of charging electric vehicles by 42% in both 2030 and 2040 scenarios
- A combination of smart charging and V2G could reduce these costs by 49% in the 2040 scenario, and 46% in the 2030 scenario
- Running an electric vehicle could add around £175 per year to the vehicle owner's electricity bill under standard charging, and smart charging and/or V2G could similarly reduce this expenditure by 42-49%. This compares to an average of over £800 to run a new petrol or diesel car or van today.
- For repurposing to have a material value, innovations are needed to achieve a minimum lifetime and maximum repurposing cost. With such innovations, the total potential value of these batteries in the 2040 scenario could be around £250 million in 2040 and £1 billion in 2050. In the 2030 scenario, it could increase to around £400 million in 2040 and £1.3 billion in 2050.

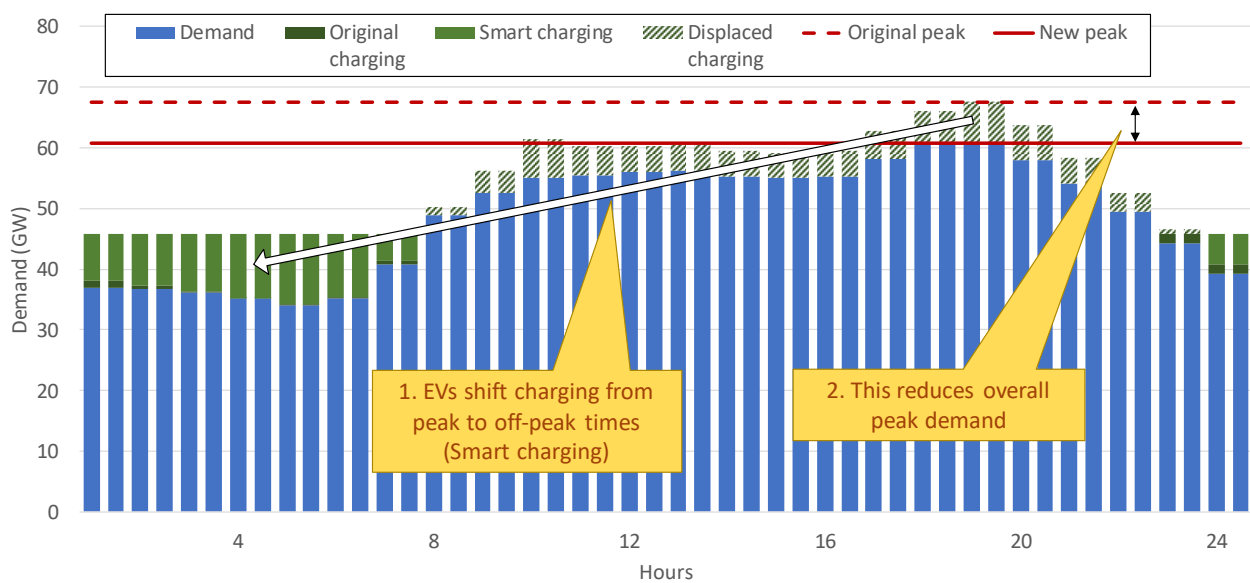


2 Impacts of electric vehicles on the electricity system

Electrification of light duty transport (cars and vans) could impose significant costs on the electricity system, if left unmanaged. New demand from electric vehicles could require new generation capacity, transmission infrastructure and distribution infrastructure, which would increase the cost of the electricity system. Under a standard charging profile, where charging is scheduled without regard to the availability of electricity system resources, the impact could be substantial. For example, National Grid found that peak demand from electric vehicles in 2050 could increase from 6 GW to 18 GW in a world where consumers plug in and start charging their vehicles at their convenience (National Grid, 2016).

Smart charging can reduce the impact on the electricity system of electrifying car and van transport. If charging is scheduled to occur at times of high availability of electricity system resources (“smart charging”), the impact will be significantly smaller. Figure 1 illustrates how smart charging can mitigate the impact of electric vehicle charging on peak demand, reducing the need for additional generation capacity and network reinforcements.

Figure 1. Use of smart charging to reduce the impact of electric vehicle charging on the electricity system



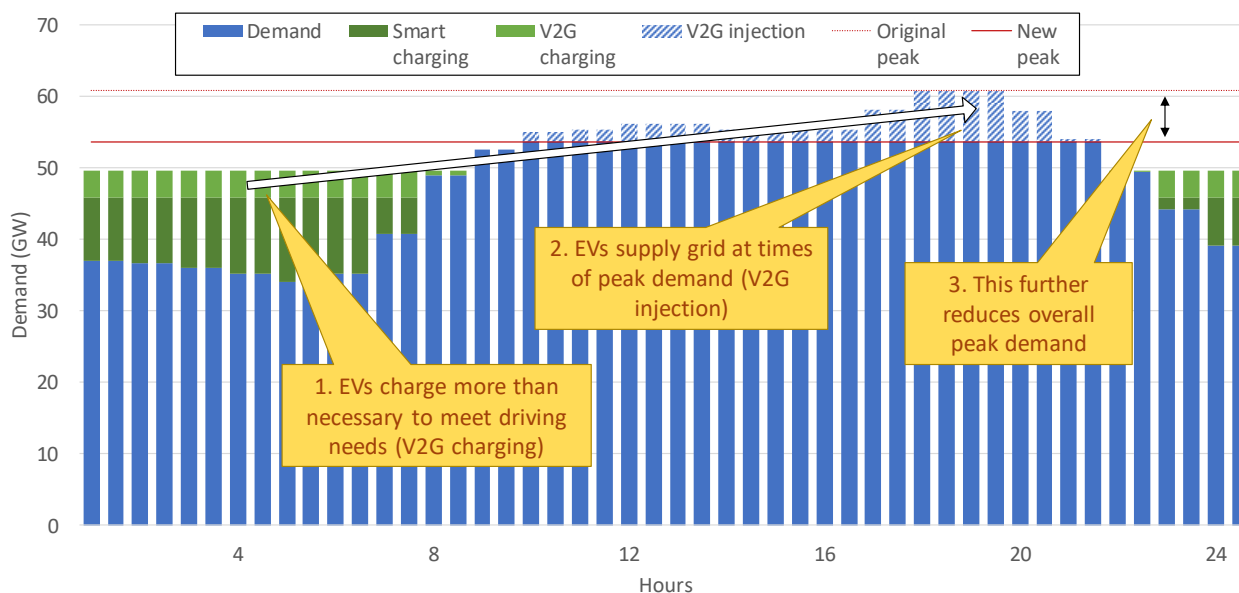
Source: Vivid Economics

Vehicle to grid (V2G) could provide additional system cost savings. If charging is managed in a way that allows vehicles to provide electricity at times of low availability of electricity system resources (“vehicle to grid”), integrating electric vehicles could reduce the total electricity system cost. Figure 2 illustrates how



vehicle to grid can further reduce peak demand, with electric vehicles potentially providing a **net benefit** to the electricity system.

Figure 2. Use of vehicle to grid to reduce peak electricity demand and deliver cost savings



Source: Vivid Economics

V2G is technically feasible, and a number of trials are currently underway. The future success of V2G technology will require Government and industry coordination (for example, in development of standards for V2G equipment and operation), and consumer acceptance. In order to explore and trial V2G technology and its commercial opportunities, Government has awarded almost £30 million in innovation funding for 21 V2G projects (Innovate UK, 2017). These projects include:

- SSE Services' Bus2Grid (a large scale, demonstration of Vehicle to Grid (V2G) technology in electric bus depots in London);
- Nissan's e4Future (a large-scale V2G demonstrator controlled by an aggregator platform stacking multiple services);
- OVO Energy's Sciurus (a large number of V2G charging units with participants who own/lease a Nissan LEAF EV, and a grid balancing platform to provide electrical support to grid operators during periods of peak energy demand)
- Octopus Energy's PowerLoop (a domestic V2G demonstrator project)
- Cisco's E-FLEX (a scale demonstration of a V2G market)
- Flexisolar's SMARTHUBS Demonstrator (A V2G trial comprising six sites and 150 V2G enabled EVs)
- AT Kearney's EV-elocity (An airport-based V2G demonstrator with 100 V2G enabled EVs).



3 Modelling and results

We have carried out detailed modelling to assess the impacts of integrating electric vehicles, for different levels of uptake and charging profiles. In partnership with Imperial College, we have developed two scenarios for electric vehicle deployment:

- The **2040 scenario** represents deployment of electric vehicles consistent with ending the sale of all new conventional petrol and diesel cars and vans by 2040; in this scenario, there are around 13 million electric cars and vans in 2030.
- The **2030 scenario** represents accelerated deployment of electric vehicles consistent with bringing the phase out date forward to 2030. In the 2030 scenario, there are around 20 million electric cars and vans in 2030.

For each scenario, we have developed a variant representing a different charging profile: standard charging, smart charging and vehicle to grid:

- In the standard charging variant, most owners charge their vehicle in the early evening (after the evening commute), which coincides with peak electricity demand.
- In the smart charging variant, we assume that 90% of drivers are willing to charge at off-peak times, such as overnight or during the day, and only 10% adopt standard charging.
- In the V2G variant, we assume that only 20% of drivers are willing to operate their vehicle in V2G mode at times of peak electricity demand. This is because peak electricity demand tends to coincide with standard charging demand.

We used Imperial College’s Whole-electricity System Investment Model (WeSIM) to model the scenarios. WeSIM calculates the pattern of investment in, and operation of, electricity system resources (generation, network, storage demand response and interconnection resources) which minimises the overall electricity system cost, given a set of constraints to ensure reliability (continuous balancing of generation and demand, reserve and adequacy constraints), carbon emissions, and accurately representing the characteristics of the electricity system (power flow limits, dynamic characteristics of generation plants, and operational constraints of storage and demand response).

The modelled scenarios include a 100 gCO₂/kWh carbon intensity and constraints on deployment of certain technologies. The modelled scenarios are based on finding the least-cost set of investment and operational decisions to meet demand given two key constraints. First, the carbon constraint is set at 100 gCO₂/kWh in 2030, in line with advice from the Committee on Climate Change; this level of grid intensity would result in emissions from electricity generation of under 20 gCO₂/km travelled, down from around 60 gCO₂/km today. Second, limits are placed on deployment of certain technologies. Nuclear is limited to 4.5GW in 2030, representing delivery of Hinkley Point C and continued operation of Sizewell B, the only existing nuclear plant not expected to decommission over the period to 2030. Carbon capture and storage and biomass are excluded from the scenario.

The modelled scenarios incorporate significant levels of flexible resources to accommodate low-carbon generation. A flexible electricity system is needed to make use of electricity generated from wind and solar. Flexibility can be provided by batteries, which can store renewable output for use at times of high demand; demand side response (DSR), which can shift demand to periods of high renewable output through



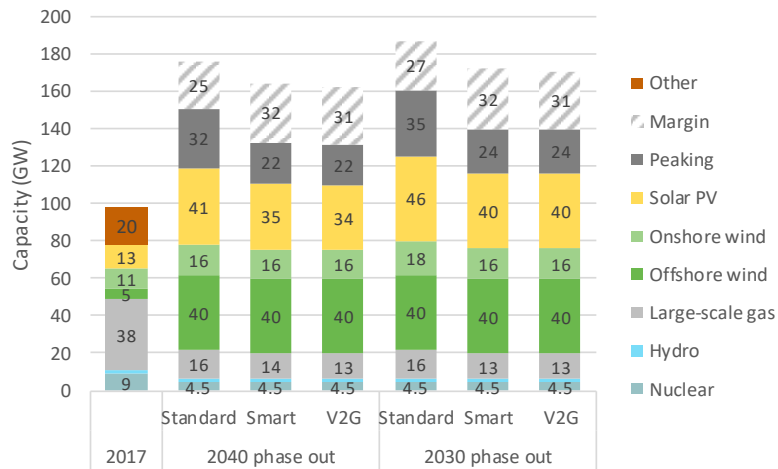
intelligent operation of industrial and commercial equipment, and smart appliances in homes; and interconnectors, which can import electricity from neighbouring markets if they have a relative surplus, or export it if they have a relative deficit. In the modelled scenarios, electricity system flexibility is provided by 20 GW of battery storage, 5 GW of demand side response and 18.5 GW of interconnectors.

To meet the carbon constraint, the modelled scenarios involve a dominant role for wind and solar, and a limited role for gas. Figures 3 and 4 describe the capacity and generation mix in the 2040 and 2030 scenarios, in the year 2030. While the capacity mix varies by scenario and charging profile, all scenarios in 2030 involve significant wind and solar capacity (56-58 GW wind and 34-46 GW solar), and limited large-scale gas (13-16 GW, down from around 38 GW in 2017). While levels of wind and solar capacity in 2030 are relatively high, they are within assessments of feasible potential and annual historical build rates. However, policy change (for example, new Contract for Difference auctions) will be needed to ensure the market can deliver them.

The capacity mix also includes peaking plant and security margin. Peaking plant are needed for a small number of hours when output from other generators is not sufficient to meet demand, and provide less than 1% of total generation. The security margin is made up of resources that are not expected to run during normal operation of the electricity system, but are needed to address extreme system stress events; these resources could consist of additional battery storage or DSR, or additional peaking generators.

Higher numbers of electric vehicles increase the amount of generation and generating capacity needed, while smart charging and V2G reduce it. Figure 3 shows the capacity mix in 2017 and in 2030, in the 2040 and 2030 scenarios under the different charging profiles. The 2030 scenario requires 1-2 GW more onshore wind, 5-6 GW more solar and 2-3 GW more peaking plant than the 2040 scenario, depending on the charging profile. However, smart charging reduces the total capacity needed by 11 GW in the 2040 scenario, and 15 GW in the 2030 scenario. V2G reduces total capacity by a further 2 GW in both scenarios. Figure 4 shows the generation mix. The 2030 scenario requires around 11 TWh more generation than the 2040 scenario.

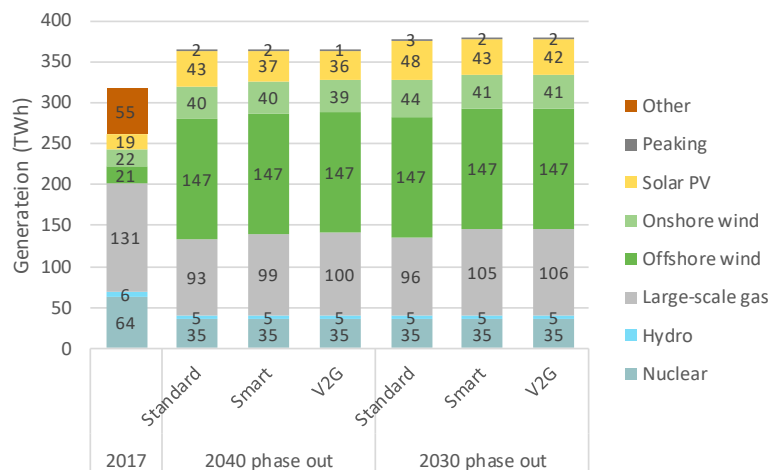
Figure 3. Capacity mix in 2017 and 2030 across modelled scenarios



Note: Other capacity includes coal and biomass. 2017 figures represent current installed capacity by technology, and include peaking plant and security margin. For 2030, peaking plant and security margin are represented as additional needs, and could be provided by a number of technologies.

Source: Vivid Economics analysis of Imperial College modelling

Figure 4. Generation mix in 2017, and in 2030 across modelled scenarios



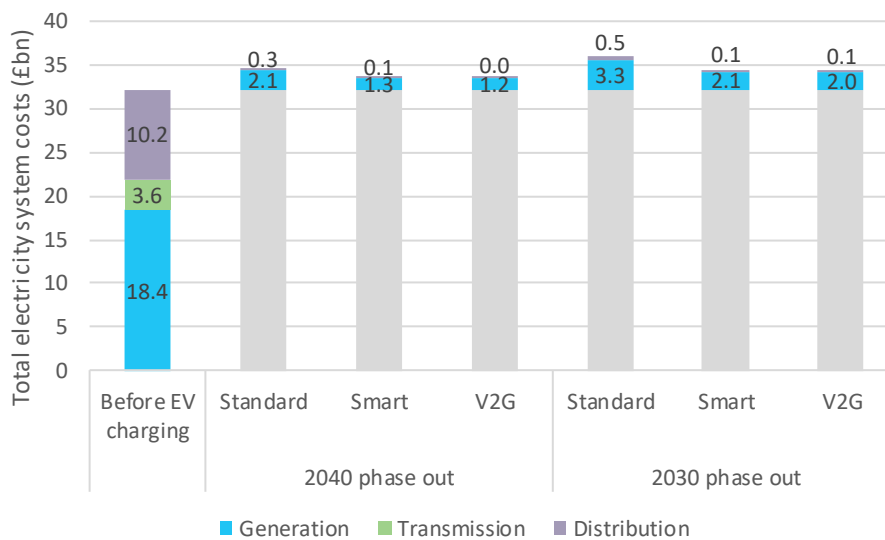
Note: Other generation includes coal and biomass

Source: Vivid Economics analysis of Imperial College modelling



The 2030 scenario with smart charging is cheaper than the 2040 scenario with standard charging. Figures 5 and 6 show the cost in 2030 of integrating electric vehicles in the 2040 and 2030 scenarios under a standard charging profile, and the cost saving achieved through smart charging and V2G (Figure 5 shows total electricity system costs, while Figure 6 shows the change in costs). With standard charging, the cost of integrating electric cars and vans is £2.5 billion per year in the 2040 scenario (with 13 million electric vehicles), or £3.9 billion per year in the 2030 scenario (with 20 million electric vehicles)¹. Smart charging could reduce these costs by around £1.1 billion (a 42% reduction) in the 2040 scenario, or around £1.6 billion (also a 42% reduction) the 2030 scenario; while a combination of smart charging and V2G could reduce these costs by around £1.2 billion (a 49% reduction) in the 2040 scenario, or £1.8 billion (a 46% reduction) the 2030 scenario. As a result, the total cost of integrating electric vehicles with smart charging in the 2030 scenario is only £2.2 billion per year – a £0.3 billion saving relative to the £2.5 billion per year cost in the 2040 scenario with standard charging. With V2G the cost falls further to £2.1 billion, a £0.4 billion saving relative to the 2040 scenario with standard charging.

Figure 5. **The 2030 scenario with smart charging is cheaper than the 2040 scenario with standard charging (1)**



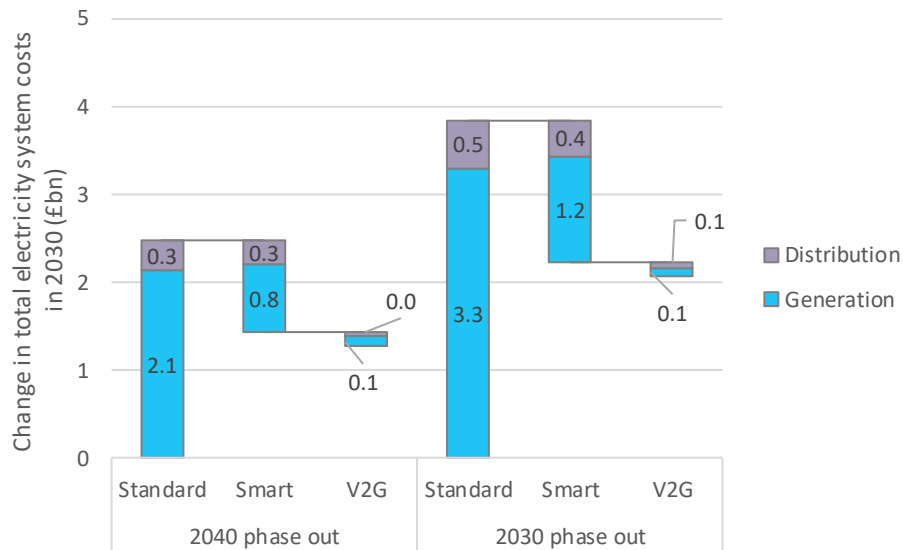
Note: Transmission and distribution costs before EV charging based on Committee on Climate Change (2017). Other costs based on Imperial College modelling.

Source: Vivid Economics analysis of Imperial College and Committee on Climate Change modelling

¹ Figures may not sum due to rounding



Figure 6. The 2030 scenario with smart charging is cheaper than the 2040 scenario with standard charging (2)



Source: Vivid Economics analysis of Imperial College modelling

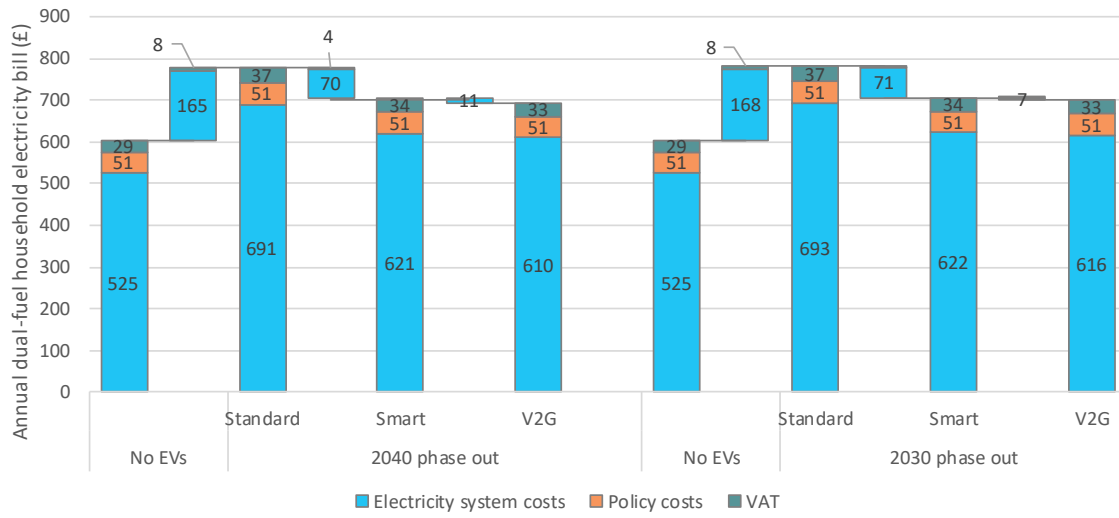
Running an electric vehicle could add around £175 per year to the owner’s electricity bill under standard charging, but smart charging and/or V2G could reduce this by 42-49%. The Committee on Climate Change estimates that the electricity bill for an average dual-fuel household in 2030 could be around £600². This estimate does not include the additional cost of operating an electric vehicle on the bill. Figure 7 shows the cost of operating an electric vehicle and its impact on the electricity bill in 2030 in the 2040 and 2030 scenarios. Under standard charging, operating an electric vehicle could add around £175 to the bill in the 2040 scenario, compared to an average of over £800 to run a new petrol or diesel car or van today³. Smart charging and V2G could deliver savings of around £75 or £85, respectively, resulting in a total bill increase of around £100 in the case of smart charging, and £90 in the case of V2G. The phase out date makes very little difference to electricity costs: overall costs are around 1% higher in the 2030 scenario but again, a 2030 phase-out with smart charging and V2G works out cheaper for consumers than a 2040 phase-out without these – by around £80 (10%).

² Committee on Climate Change (2017): Energy Prices and Bills Report 2017

³ Based on average new car fuel consumption of 5.4 litres per 100km, fuel prices of 117 pence per litre, and average travel of 13,000 km per year. Source: DfT (2017): Transport Statistics Great Britain



Figure 7. Cost of operating an electric vehicle on the average electricity bill in 2030



Note: Costs are estimated for the average household, assumed to be on a time of use tariff in 2030

Source: Vivid Economics analysis of Imperial College modelling



4 Potential value of repurposing electric vehicle batteries

The shift to electric cars and vans creates the prospect of a large volume of batteries available to be repurposed as stationary storage in the electricity system as the vehicles are retired. In the 2030 scenario, there are 20 million electric cars and vans on the road by 2030; in the 2040 scenario, there are 13 million by this date. This represents a total volume of battery storage of around 120 GW⁴. Batteries will be highly valued in a future low-carbon electricity system, as they can store electricity at times of high output from variable renewables and low demand, and inject electricity back into the grid at times of high demand and low output. Possible applications include small-scale battery storage in homes and workplaces, for example, to store excess solar PV generation, or the deployment of large-scale battery storage on the transmission or distribution networks.

Auto manufacturers are already pursuing initiatives to repurpose electric vehicle batteries. For example, in 2017 Powervault and Renault announced a trial initiative to re-use electric vehicle batteries in home energy storage units (Powervault, 2017). In 2018, Nissan announced an initiative to install new streetlights that will be powered by a combination of solar panels and used batteries from the Nissan LEAF electric car.

This section estimates the value of these repurposed batteries. Specifically, we estimate the value of repurposed batteries as the cost saving from deploying repurposed batteries instead of new batteries. Our estimates assume that 50% of electric vehicle batteries can be repurposed and used productively in the electricity system.

The potential volumes of repurposed batteries will depend on the quality of the batteries at the end of the vehicle lifetime. Batteries degrade through use (cycle life), and over time (calendar life). Due to this degradation, the suitability of batteries for repurposing is highly uncertain; available evidence on the factors affecting suitability is summarised in Box 1. The prospect of a second life appears feasible from the perspective of cycle lives, and V2G is unlikely to result in significant battery degradation. However, long calendar lives have not yet been demonstrated.

Box 1 – Evidence on the suitability of batteries for repurposing is highly uncertain

Batteries degrade through use, and over time. The life of a battery is determined by interactions between a number of factors, including the number of times it is charged or discharged; the rate at which charging or discharging occurs; the depth to which it is discharged; temperature at which it is maintained both during operation and between uses; and its age. As the determinants of battery life are complex, two simplifying metrics are typically used to describe battery life: cycle life, and calendar life:

- Cycle life is the number of charge/discharge cycles a battery may go through before its usable capacity decreases to 80% of its original capacity.

⁴ Electricity system batteries are typically expressed in terms of rate of charge or discharge, measured in gigawatts (GW), while electric vehicle batteries are typically expressed in terms of volume of storage, measured in gigawatt-hours (GWh). A battery's volume divided by its capacity gives its duration; to measure a given volume of batteries in GW we express this in terms of GW of four-hour batteries.



- Calendar life is the number of years a battery may be used before its usable capacity decreases to 80% of its original capacity, regardless of how that battery is used.

There is a strong body of evidence that by 2030, the cycle life of EV batteries will be more than sufficient to meet the needs of operating an electric vehicle throughout its lifetime, and to permit subsequent use in a “second life”:

- Academic and industry experts estimated a range of lithium ion battery cycle life of 1,500 to 15,000 cycles in 2020, increasing to 2,000 to 30,000 cycles in 2030⁵. This is more than sufficient for the 800 cycles an electric car in the UK might use over its lifetime.
- This is consistent with cycle lives observed in some EV batteries today. For example, a study on Tesla Model S batteries in the Netherlands indicated that on average the batteries have 91% of their original charge remaining after 270,000 km of driving, and that 820,000 km of driving would be needed to reduce battery capacity to 80% of their original capacity⁶. This implies a cycle life of around 3,500 cycles.
- Analysis of the modelling results summarised in Section 3 suggests that V2G could increase the number of cycles by less than 10%, adding under 80 cycles to an expected 800 cycles.
- Analysis of the modelling results also suggests that a stationary storage battery in 2030 might go through 160 cycles per year in 2030. If a repurposed battery lasts 10 years this implies an additional 1,600 cycles, or 2,400 in total.

However, there is less evidence that its calendar life could be long enough to permit subsequent use in a “second life”. Current warranties and estimates suggest calendar lives as long as the vehicle, but the research does not guarantee successful operation beyond that:

- Nissan provides an 8 year warranty on the LEAF’s battery
- Element Energy (2012) estimated that “based on the expected improvements in thermal control and management, it is reasonable to assume that future cells will achieve a 12 year lifetime (temperate climates) from 2020.”⁷
- The United States Advanced Battery Consortium (USABC) has a goal for a calendar life of 15 years for batteries commercialised in 2020⁸.

While the prospect of a second life appears feasible from the perspective of cycle lives, long calendar lives have not been demonstrated. Further research is needed to develop reliable estimates of future calendar lives.

⁵ Few et al. (2018): Prospective improvements in cost and cycle life of off-grid lithium-ion battery packs: An analysis informed by expert elicitations

⁶ Steinbuch (2017): Tesla Model S battery degradation data; available at <https://steinbuch.wordpress.com/2015/01/24/tesla-model-s-battery-degradation-data/>

⁷ Element Energy (2012): Cost and performance of EV batteries

⁸ United States Advanced Battery Consortium (no date provided): EV battery goals; available at: http://www.uscar.org/commands/files_download.php?files_id=364



The costs of repurposing electric vehicle batteries are currently uncertain. However, some estimates are available. For example, Casals et al. estimated the costs of repurposing electric vehicle batteries using two different approaches⁹:

- The direct re-use approach. This approach involves minimal intervention, and comprises disassembling the battery, testing the modules or cells, and replacing defective components before reassembly. The disadvantage of this approach is that batteries that are optimised for electric vehicle applications could suffer a performance disadvantage for the range of stationary storage applications to which they might be put. Casals et al. estimated that repurposing a battery with this process could cost around €87 (£75) per kWh.
- The module re-work approach. This approach involves reconfiguring the battery for the new stationary storage application (for example, intra-day balancing, or fast frequency response), as well as upgrading its refrigeration system and electronics to enhance its performance. Casals et al. estimated that repurposing a battery with this process could cost around €240 (£200) per kWh.

Repurposed electric vehicle batteries will need to compete with new, dedicated stationary storage batteries, whose cost is projected to decrease significantly. Cost projections from the International Renewable Energy Agency (IRENA) suggest that lithium nickel manganese cobalt oxide (NMC), the battery chemistry currently used in the Nissan LEAF, could decrease in cost from around \$450 (£333) per kWh today to \$145 (£107) per kWh in 2030¹⁰.

For repurposing to have a material value, innovations are needed to achieve a minimum lifetime and maximum repurposing cost. First, batteries would need to last around 10 years beyond the 13-year lifetime of a car or van, i.e. around 23 years overall. Second, battery repurposing costs would need to be at least 25% lower than the cost of a new battery.

Given these innovations, the total potential value of these batteries could be around £250 million in 2040 and £1 billion in 2050, in the 2040 scenario:

- **The more electric cars and vans are purchased, the more batteries can be recovered when these vehicles retire.** Assuming a ten year life for repurposed batteries, the volume of repurposed batteries in a given year is determined by the number of cars and vans that have retired over the previous ten years. For example, the repurposed batteries in 2030 will consist of batteries recovered from cars and vans that retired in the years 2020-2029. Batteries from older vehicles would be more than ten years old, and unsuitable for continued use. In the 2040 scenario, under 200,000 EVs would retire and allow recovery of their battery for use in 2030; this number would rise to around 7 million EVs for 2040, and 24 million EVs for 2050.
- **Initial volumes of repurposed batteries are low, but these will increase significantly over time.** By 2030, only 0.3 GW of second life battery capacity could potentially be available in the 2040 scenario, due to the low numbers of electric cars and vans retiring in the previous ten years.

⁹ Casals et al. (2014): A cost analysis of electric vehicle batteries second life businesses

¹⁰ International Renewable Energy Agency (2017): Electricity storage and renewables: costs and markets to 2030



However, by 2040, 18 GW of second life battery capacity could potentially be available, rising to 66 GW in 2050.

- **We value these batteries at the cost saving they offer relative to purchasing new batteries.** The total potential value of these batteries could be around £250 million in 2040 and £1 billion in 2050, in the 2040 scenario. By 2050, this value is around 3% of the total cost of the electricity system, and could reduce total electricity prices and consumer bills by a similar proportion.
- **It is possible that such large volumes are more than the electricity system needs.** For example, if either (1) alternative resources such as demand response and interconnection prove highly feasible and cost-effective in delivering a flexible, low-carbon electricity system; or (2) advances in battery recycling offer a cost-effective alternative to repurposing used batteries, then the value of repurposed batteries could be lower.

In the 2030 scenario, volumes of repurposed batteries, and the value of these batteries, are higher than in the 2040 scenario:

- **This finding is due to the higher number of electric vehicles in the 2030 scenario.** In the 2030 scenario, under 200,000 EVs would retire and allow recovery of their battery for use in 2030; this number would rise to around 11 million EVs for 2040, and 33 million EVs for 2050.
- **Volumes of repurposed batteries are higher than in the 2040 scenario.** By 2030, only 0.3 GW of second life battery capacity could potentially be available, rising to 27 GW in 2040, and 90 GW in 2050.
- **The total potential value of these batteries is therefore also higher.** This value could be £400 million in 2040 and £1.3 billion in 2050. By 2050, this value is around 4% of the total cost of the electricity system, and could reduce total electricity prices and consumer bills by a similar proportion.
- **Even if the UK electricity system does not need such large volumes of batteries, there may be opportunities for export in addition to UK deployment.** Given the UK would be a market leader in EVs in the 2030 scenario, it is possible that surplus repurposed batteries could be exported to countries with less mature EV fleets and a relatively high demand for batteries.

5 Conclusions

We have carried out detailed modelling to assess the impacts of integrating electric vehicles, for different levels of uptake and charging profiles. In partnership with Imperial College, we have developed two scenarios for electric vehicle deployment:

- The **2040 scenario** represents deployment of electric vehicles consistent with ending the sale of all new conventional petrol and diesel cars and vans by 2040; in this scenario, there are around 13 million electric cars and vans in 2030.
- The **2030 scenario** represents accelerated deployment of electric vehicles consistent with bringing the phase out date forward to 2030. In the 2030 scenario, there are around 20 million electric cars and vans in 2030.

For each scenario, we have developed a variant representing a different charging profile: standard charging, smart charging and vehicle to grid:

- In the standard charging variant, most owners charge their vehicle in the early evening (after the evening commute), which coincides with peak electricity demand.
- In the smart charging variant, 90% of vehicle owners charge at off-peak times, such as overnight or during the day, and only 10% adopt standard charging.
- In the V2G variant, 20% of vehicle owners adopt V2G in addition to smart charging, and provide electricity to the grid during the evening peak.

The key findings of this work are:

- The 2030 scenario with smart charging is lower cost than the 2040 scenario with standard charging, and therefore cheaper for consumers.
- The charging profile is a more important factor than the number of electric vehicles in the cost of integrating electric vehicles into the electricity system. In other words, the smartness of the transition to electric vehicles will be the main factor determining how cost effective the transition is, not the speed of the transition.
- Smart charging and vehicle to grid are technically feasible, and a number of trials are currently underway in the UK.
- Smart charging could reduce the costs of charging electric vehicles by 42% in both 2030 and 2040 scenarios
- A combination of smart charging and V2G could reduce these costs by 49% in the 2040 scenario, and 46% in the 2030 scenario
- Running an electric vehicle could add around £175 per year to the vehicle owner's electricity bill under standard charging, and smart charging and/or V2G could similarly reduce this expenditure by 42-49%. This compares to an average of over £800 to run a new petrol or diesel car or van today.
- For repurposing to have a material value, innovations are needed to achieve a minimum lifetime and maximum repurposing cost. With such innovations, the total potential value of these batteries in the 2040 scenario could be around £250 million in 2040 and £1 billion in 2050. In the 2030 scenario, it could increase to around £400 million in 2040 and £1.3 billion in 2050.



Two main policy implications emerge from these findings:

- **First, integrating electric vehicles into the electricity system is manageable even under a 2030 phase out date for conventional cars and vans, as long as the opportunities from smart charging and V2G are realised.**
- **Second, a 2030 phase out would increase the availability of batteries for reuse as energy storage, but further work is needed to develop a better understanding of battery lifetimes, repurposing costs, and the relative costs and benefits of battery storage and alternative flexible resources in the electricity system.**

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Company Profile

Vivid Economics is a leading strategic economics consultancy with global reach. We strive to create lasting value for our clients, both in government and the private sector, and for society at large.

We are a premier consultant in the policy-commerce interface and resource- and environment-intensive sectors, where we advise on the most critical and complex policy and commercial questions facing clients around the world. The success we bring to our clients reflects a strong partnership culture, solid foundation of skills and analytical assets, and close cooperation with a large network of contacts across key organisations.

