The smart route to electric vehicles
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I am interested in the electrification of the economy, how cities can use electrification to tackle climate change and local pollution. The electricity sector is a complex market, and bringing in heat and transport into that will change it wildly. This is why I got interested in smart charging and smart metering. We have the technology available to make electric transport in particular a real benefit to the electricity system, but it’s not just a techno fix, it requires new business models and consumer behaviours together.

I have been researching clean energy futures at the University of Leeds since 2013. My work has been used by the International Energy Agency, UK Government, and global consultancies. In 2016 I was awarded an Engineering and Physical Sciences Research Council fellowship investigating the deep decarbonisation of cities. This research has explored how utilities, cities, car manufacturers and others can come together to not only electrify the transport system, but change the way we think about energy and travel altogether.

Dr Stephen Hall
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Modernising our energy system lies at the heart of the Government’s Industrial Strategy and Clean Growth Grand Challenge.

A smart energy system will deliver cheaper and cleaner energy for consumers, create high value jobs and help us meet our climate change commitments.

Our action plan outlines that a smarter, more flexible energy system could bring benefits to consumers, the energy industry and wider economy worth up to £40 billion over the next few decades.

Smart meters are a key enabler to achieving these benefits and have the potential to entirely change the way we interact with our energy system. They can unlock tariffs that reward consumers that use energy at off-peak times. Combined with smart charging, they will enable electric vehicle owners to charge their cars during cheaper periods.

This research draws together all the evidence that points to this smart future, and the positive effect this will have for consumers and the nation as a whole.

It highlights the importance of the Clean Growth Grand Challenge, the smart meter rollout, and the work that BEIS is doing to deliver a smarter energy system.

We are working towards a cleaner energy future that works better for consumers, putting them back in control of their household energy. To make this a reality we need to embrace the technology needed to get us there which is why we are committed to all homes and businesses being offered a smart meter by the end of 2020.

It’s changes like this which will benefit all energy consumers and Great Britain as Government and industry work to positively change the way we live for the better.

**The Rt Hon Claire Perry MP**
Minister of State for Energy and Clean Growth
Department for Business, Energy and Industrial Strategy
Introduction

As an environmentalist it is difficult to admit, but I like cars... For a long time enjoying driving was completely incompatible with being a sustainability academic. However, I believe this has now changed because of two technologies; electric cars and smart meters. In this report I will explore how these two technologies together enable an 'incredible prize'; affordable, green driving which accelerates the UK’s transition to a sustainable economy.

However, the environmental benefits of driving electric are not a given. The explosion of electric vehicles (EVs) could increase electricity demand by up to 15% over the next 30 years1. Making sure this electricity is as clean as possible is where smart metering comes in.

EVs mean a big shift in energy demand, from liquid fossil fuels to mainly grid electricity. This affects everything, from how much new infrastructure is needed, to the price of power and the environmental impact of car charging. Smart metering can go a long way to solving these problems by affecting when energy is used, as well as how much is needed.

Let’s start with some numbers. Sales of EVs have increased at such a rate that tens of thousands are now registered each month in the UK2. While this is still a small percentage of new registrations, longer range models capable of 200+ miles on a single charge, are expected to come on sale throughout 2018-193. For most of us this means one overnight charge would last for three weeks of driving4. With plug in car prices set to reduce5 we can expect to drive further and pay less for electric mobility in the very near future.

What is an electric vehicle?

There are four main types:
• battery electric vehicles (BEVs)
• plug in hybrid electric vehicles (PHEVs)
• range extended electric vehicles
• hydrogen fuel cell vehicles

I focus on BEVs, PHEVs and Range Extenders because they all need to plug in to charge the battery and therefore affect the electricity system. BEVs are 100% battery powered and are often called ‘zero emission’ vehicles as they have no exhaust fumes. PHEVs are still low emission because they use electric drive for low speed, short range journeys. PHEVs have a much smaller battery than BEVs and use the conventional internal combustion engine for longer range or higher speed trips. Range extenders still use 100% electric drive but use an on board internal combustion engine as an electricity generator to achieve longer distances. Each has a substantial market share but petrol PHEVs were the most popular in 2017 to date. For more detail see goultralow.com/choosing6.

2 SMMT, Vehicle sales data reports. https://www.smmt.co.uk/vehicle-data/
5 http://www.advantagelithium.com/_resources/pdf/UBS-Article.pdf
6 https://www.smmt.co.uk/vehicle-data/evs-and-afvs-registrations/
These trends point to a growing market share for EVs and a huge change in energy vectors from petrochemicals to electricity. This is good news for our climate change efforts, because EVs already emit approximately 60% less greenhouse gas (GHG) than a conventional diesel car over their lifecycle. How much GHGs are saved depends on how clean the electricity is that goes into the vehicle. In the UK we have reduced the emissions intensity of electricity by nearly 50% in four years. This is a huge achievement, and with new capacity in offshore wind due throughout the 2020s, that emissions intensity will reduce even further.

At high levels of fleet replacement, EVs also have significant effects on air pollution. This is why the UK government is using electric car promotion to reduce the 40,000 extra deaths cause by poor air quality every year. So electric cars could mean cleaner air and a more stable climate. Excellent news for environmentalist drivers.

None of the benefits of EVs can be taken for granted though. In order for EVs to be ‘incredible’ I want to set four conditions, they need to be:

- cheap to charge
- full of green energy
- fair to other consumers
- support the UK economy

The rest of this report explores how smart metering could satisfy these four conditions; they can do so by keeping it cheap, keeping it green, making it fair, and making it productive.

What is a smart meter?

Smart meters are the new type of gas and electricity meter that automatically send meter readings to energy suppliers. They ensure accurate energy bills and the portable in-home display (IHD) provides consumers in near real time with energy cost information in pounds and pence. Smart meters are being offered to all households and small businesses across Wales, Scotland and England. The new meters are being installed by energy suppliers at no upfront cost.

“In the near future, for most consumers, one charge will last three weeks.”

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For most people the biggest decision they make about energy is which supplier to choose. Switching energy suppliers can give householders and business better deals on both gas and electricity. Consumers can also opt for green energy tariffs, where the power used is matched with renewable generation. While some of us switch supplier regularly, most people, about 56%, are what are known as ‘sticky’ customers¹, they have never switched or did not even know they could. Smart metering will make switching easier for consumers and more importantly will allow energy suppliers to offer more exciting tariffs.

New tariffs will offer customers with smart meters and EVs better ways of managing their energy use. These new deals do two things. Firstly, the smart meter measures both how much consumers use and when they use it. Traditional meters only measure how much is used, and since the wholesale price of electricity varies from hour to hour, it is up to energy suppliers to estimate what your ‘demand curve’ looks like through the day, and bill you accordingly. This is fine if you match their estimate, but if you use lots of energy during peak times, when prices are high, you are likely underpaying, and if you use most of your energy when system demand is low, then you are probably overpaying.

This matters if you are driving an electric vehicle, because if you plug it in to charge from 60% to 100% at 5:30pm every night, and so does everyone else, ‘peak load’ in the system gets higher, and prices would go up for everyone.

Figure 1 demonstrates the impact of a high penetration of EVs on the average daily peak by 2035. In this case, drivers plug in when they return home and increase peak demand on the system hugely, this would mean building new power stations just to cover EV charging and impacting everyone’s electricity bill.

The opposite is also true, if charging is managed to start after the peak, perhaps 11pm as in Figure 2, then the power used could come much cheaper, and avoid expensive peaks.

Most of this is already possible as EVs can be programmed to start and stop charging by their owners. However if no smart meter is installed, you would still pay the average price, and not the cheaper rate you could get by charging at night.

With a smart meter installed, energy suppliers can reward drivers for charging during low price periods and the savings can be passed onto their individual bills. This is exactly what the utility company OVO is doing (see the Ovo case study).

It is not just EVs that can be used in this way. Smart meters and in-home management systems can communicate with devices such as fridges and freezers, washing machines and dryers, to move consumption away from short periods of very expensive power.

What does an electric vehicle cost to run?
For those unfamiliar with electric car charging, the average petrol or diesel car costs around 12p per mile to fuel, where electric drive costs approximately 3p per mile\textsuperscript{12}. For most homes a charge point will need installing because it is not recommended to use a domestic socket. These units cost around £280-300 with the available government grants applied for a basic version\textsuperscript{13}, however to benefit from faster or smarter charging more expensive models are available. Most important though is the short term cost of ownership for the vehicle, with taxes, grants, fuel costs, insurance etc all considered. New research shows that buying a new pure electric car over a four year period is cheaper than conventional diesel or petrol alternatives\textsuperscript{14}. 

Figure 1
Unmanaged charging: the impact of a high penetration of EVs on the average daily peak by 2035\textsuperscript{15}

![Graph showing unmanaged charging impact]

Figure 2
Managed charging: the reduced impact of high EV penetration on the average daily peak by 2035\textsuperscript{16}

![Graph showing managed charging impact]

\textsuperscript{12} Depending on how one drives. See: https://www.goultraitel.com/how-do-you-charge-an-electric-car/home-charging-calculator/
\textsuperscript{13} https://www.gov.uk/government/publications/electric-vehicle-homecharge-scheme-authorised-installers
\textsuperscript{14} https://doi.org/10.1016/j.apenergy.2017.10.089
\textsuperscript{15} Aurora Energy Research, The e-mobility revolution: impact of electric vehicles on the GB power system and emerging utility business models https://www.auroraer.com/insight/e-mobility-revolution-impact-of-electric-vehicles-on-the-gb-power-system/
\textsuperscript{16} ibid
21st century tariffs for a 21st century system

The energy supplier OVO recently launched a new smart meter enabled electricity tariff called EV Everywhere. This tariff ticks the low carbon box by matching consumer demand to 100% green energy, and rewards consumers for charging off peak. It can do this using the smart meter in a dual price mode, like a digital version of an economy seven meter. This tariff also gains drivers free membership of the UK’s largest public charging network POLAR Plus.

By installing a smart meter and a smart charge point, consumers will in future be able to earn money by offering grid service. A new partnership with EV manufacturer Nissan aims to offer OVO consumers vehicle to grid tariffs in the near future. Tom Pakenham, Head of EVs at Ovo said:

“Here at OVO […], we are excited about the development of innovative technology such as smart charging infrastructure, and even the potential to discharge excess energy in cars during peak periods to help the grid to manage peak demand. Doing so offers a whole host of benefits; from helping reduce reliance on fossil fuel power stations to provide backup power during peak periods…”

With new tariffs such as these entering the market from a number of suppliers, the switching decision of an EV driver with a smart meter could deliver substantial system benefits. Dr Chris Horne, Head of Origination at E.ON explains how smart meters and electric vehicles together will have far reaching benefits for utilities and their consumers:

“Smart meters are integral to the development of electric vehicle tariffs; helping to manage the energy demand from the growing number of vehicles on our roads and allowing consumers to get the most from the sustainable technologies in their homes such as solar panels and battery storage. The next big challenge is going to be how we begin to use electric vehicles both to help power our homes and support the wider grid system. That is when we will begin to see that this is a complete change in the way we think about energy, motoring and vehicles.”

17 https://www.ovoenergy.com/ev-everywhere
18 https://polar-network.com/
As energy utilities offer more diverse tariffs, consumers and their energy company will learn together how to get the most out of the smart energy technologies being offered in the 21st century energy market.

“Our existing power stations are closing down and their replacements will be radically different as we decarbonise supply to reduce emissions. This represents an enormous challenge, but it also leaves the UK uniquely placed to benefit from three exciting innovations set to transform the global electricity market – interconnection, storage and demand flexibility.”
Keeping it green

So smart meters with time of use tariffs could give EV drivers cheap charging. But what about those of us who want charging to be cheap and green? By ‘green’ I mean low-carbon. I already have a ‘green’ energy tariff at home, but this just matches my annual profiled demand with renewable generation somewhere on the system.

Green energy tariffs are good for developing the renewables sector, but I am still using the same dirty electrons as my neighbour. I want my electric charge from as much sun, wind, wave and other clean sources as possible.

The good news is that for the moment cheap and green charging are often the same thing. With a smart metered time of use tariff you will save money by charging after 10pm when demand is low. Low demand often means low-carbon, composed of baseload nuclear, some biomass and whichever of the wind, sun, or both are blowing or shining strongly. Clearly though, one can expect very little solar generation after 10pm. Indeed the lowest carbon periods may be sunny, windy weekends.

It is not always the case that low-carbon energy and low price periods will combine. The electricity wholesale price is a complex beast, and forecasting is beyond the vast majority of us. We need our energy supplier to give us simple, clear messages about when to set our electric cars to charge cheaply and cleanly. Unless of course, we can automate the whole process.

Most EV manufacturers have a related app that interfaces with the vehicle and can schedule charging. At the same time there are other apps such as JuiceNet Green which predict when electricity will be greenest. With smart meters installed there is no technical barrier to using a smart phone app to set your individual preference for convenience, price, or planet.

The more green energy drivers choose, the better the market for renewables developers who can be sure of selling their output. Electric car drivers with smart meters could become a major force for further expansion of our low-carbon generation fleet.

19 http://electricinsights.co.uk
20 Staffell, I, Scurlock, J. (2017), Electric Insights Quarterly, April to June 2017, Drax
This is just the beginning of what smart meters enable EV drivers to do. That expensive peak shown in Figure 1 will still exist with smart charging, it is just other home appliances will be making it. Most drivers will arrive home with substantial charge still left in the car. What if the battery could then use the cheap power stored the night before, to power the home over the peak period. This would further reduce energy bills and let drivers avoid dirty peak power. Recent research shows this is both possible and good for the vehicle battery. Most studies on the economics of using vehicle batteries for home or grid management have assumed it affects the value of the battery in the same way as putting more miles on a normal car. This new research finds the opposite, and suggests you could be doing your battery good by using it more often.

In the future, smart metered customers with EVs could lower the emissions intensity of the whole system at the same time as saving money by avoiding system peak prices with vehicle to home technology.

We can even go one step further and aggregate vehicle batteries to provide useful services to the whole electricity system. Vehicle batteries are well placed to offer power quality services such as frequency regulation and load balancing, and get paid for doing so. Smart meters are critical here, because they can track ‘proof of delivery’ and make sure payments are distributed fairly. With UK trials underway, it will not be long before commercial offerings are being tested.

With the ability to vary the cost, environmental impact, and services an EV provides, the opportunities for drivers to support a low carbon future for the UK are just beginning.

22 Uddin, et al. 2017. On the possibility of extending the lifetime of lithium-ion batteries through optimal V2G facilitated by an integrated vehicle and smart-grid system. Energy.
23 https://www.ovoenergy.com/guides/electric-cars/vehicle-to-grid-technology.html
25 http://www.ncl.ac.uk/press/news/2017/01/v2g/
Making it fair

With all the potential for new tariffs, it is easy to lose sight of other challenges EVs pose. One is the impact on the grid. The ‘grid’ in this case is the low voltage distribution network. The vast majority of cables, pylons, and substations that we see in our towns and cities. We all pay an average charge for using this network. The fairness problem comes up if several houses in a street buy EVs and the capacity of the grid is exceeded. In that case we all end up paying for those upgrades, even if we never go near an EV. If we want more and more EVs on the roads we have to solve this problem if we want to keep the lights on.

There are 14 distribution networks in the UK run by six different groups of Distribution Network Operators (DNOs). These companies are responsible for the day to day maintenance of this critical infrastructure. As the electric vehicle market started to grow these companies ran a number of trials to explore how the network could be affected. One major trial was the ‘My Electric Avenue’ project. This trial found that when electric vehicle penetration in a local area reaches 40% and above, up to one third of the UK’s distribution network, 312,000 circuits, would require some form of intervention.

The trial installed communications technology in charge points and on the network to automatically switch charging off for 15 minutes to protect the grid. The DNO worked closely with trial participants to communicate the need for this interruption of service. This technology has been developed since, and the Electric Nation project (case study below) goes further in showing that no DNOs can work with EV drivers to protect networks, avoiding expensive and inconvenient upgrades.

Electric Nation case study

The Electric Nation trial led by DNO Western Power Distribution is recruiting over 700 EV drivers to learn about charging behaviours, network impacts, and smart charging performance. Recent charging trials have shown that by the time 40% of cars are electric, we could need £2.2bn of system upgrades. Smart charging could almost eliminate the need for this spending. Previous trials have worked with one type of car, but the Electric Nation project will recruit diverse drivers and vehicles to understand how smart charging can protect the network in real use cases. Project manager Mark Dale explains:

“this is the largest trial of smart EV charging in the country and it shows that we can manage the physical stress on the grid with some fairly inexpensive kit”

The trial will fit communications enabled chargepoints that can communicate with the customer’s home broadband network and the local grid. It is also developing a network assessment tool, that will enable the network operator to see where problems could arise and test out the smart charge equipment to see how they can be managed remotely. Currently this needs to work with extra telecoms kit in the home and on the network, but in future this could be bundled into the smart meter infrastructure:

“we need all the appliances to be able to talk to each other, we currently use broadband routers and consumers internet connection but in future we could manage charging directly through the smart meter and in home devices, there’s no technical barrier to that, but it does require network operators being allowed access and control”

26 http://myelectricavenue.info/
28 http://www.electricnation.org.uk/
29 http://www.westernpower.co.uk/
Both the My Electric Avenue and Electric Nation projects show how partnering with EV drivers can manage the public network without the need for re-enforcement even at high levels of EV penetration up to 70%.

There are some future challenges. With all of the new tariffs designed to ramp charging up and down, and even sell electricity back into the market, there is a disconnect between what is good for energy markets, in terms of cheap, green, or convenient, and what is needed to protect the grid.

The needs of markets don’t always match the needs of infrastructure. At the moment simply staggering charging start times and operating simple off-peak tariffs may help protect local grids. However, with increasingly sophisticated tariffs the needs of suppliers and the network operators might not always align. This is where smart metering can help.

The smarter the metering infrastructure the more able it is to accommodate the needs of third parties. Through close engagement with bodies like the smart grid forum31, and the Smart Energy Code Company32 energy suppliers, network managers, regulators, and manufacturers can explore how smart EV charging impacts the wider system and find new business models and regulatory structures to enable efficient network management. This would mean controlling EV charging for grid protection as well as for a cleaner, greener market. This would require sharing smart meter data with networks as well as suppliers.

Another element of fairness is communication to all consumers with any kind of smart enabled appliance about why, how and for whom different interventions are being made. At the time of writing the Automated and Electric Vehicles Bill33 is going through parliament and the issues of fairness, data security, and communication with consumers are high on the agenda34.

As homes get smarter and smart meters become the norm, we can see a future where on a single interface, consumers can acquire cheap, green power, and also agree for their charging levels to be managed to protect the local grid.

31 https://uksmartgrid.org/
32 https://www.smartenergycodecompany.co.uk/
33 https://services.parliament.uk/bills/2017-19/automatedandelectricvehicles.html
34 https://publications.parliament.uk/pa/cm201719/cmpublic/Automated/PBCT12_Combined_1-4_31_10_2017.pdf
Making it productive

The final condition I want to set is making sure we maximise the wider economic benefits of integrating EVs into the smart metering and smart appliance revolution. For this we need home grown companies that can manage everything from software interfaces, to professional and experienced installers in people’s homes.

Estimates of the size of the smart home/energy flexibility market vary hugely\(^{(35)}\), largely because we do not know what the energy system will look like in the future. Similarly we can expect exponential growth in EV sales, but how many and by when is unclear. Recent research suggests that by 2030 up to 1.8m new charge points will need installing per year, as demand for new EVs and home charging peaks. Add to the charge point opportunities for domestic microgeneration to be linked to vehicle charging, and there is a substantial smart home retrofit market to access.

The opportunities for local businesses to benefit from this transition are demonstrated by the success of The Phoenix Works Explored in The Phoenix Works case study. The customer offers that are enabled by smart metering, mean local businesses like The Phoenix Works can grow to service both regional and national markets, affording UK businesses new growth opportunities.

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There are good reasons for using local companies with local knowledge to install, programme, and maintain the smart home/EV interface. There is good evidence\textsuperscript{36,37} to suggest that locally rooted installers and supply chains lead to much better outcomes for home energy retrofit, in terms of technical performance, sector learning, and householder behaviours.

A strong local supplier base for smart home and vehicle charging equipment, leads to both regional job growth, and improvements in the use of such technologies.


\textsuperscript{37} Wade, F., Shipworth, M. and Hitchings, R. (2016), Influencing the central heating technologies installed in homes: The role of social capital in supply chain networks. Energy Policy, 95, pp.52-60
So can the smart meters and EVs together capture that incredible prize: affordable, green driving which accelerates the UKs transition to a sustainable economy?

It is clear smart meters allow new tariffs to reward drivers for charging off peak with cheaper power. It is also clear that that electric vehicle charging will soon be able to track either the cheapest or greenest electricity on the system. With new vehicle to grid tariffs also in development, the following scenario will soon be possible.

My smart meter is installed, I buy an electric car, and get a smart charger installed by a local company and access some government help with the cost. I then find the most exciting energy tariff I can. I download an app and set it to ‘maximum renewables’. I plug the car in every night but it only charges when clean energy is high on the system, lots of North Sea wind during the night for example.

I then drive around the next day with zero exhaust fumes, and return home at 5:30, plug the car in and it powers the house to avoid the peak. There is a football match on, meaning National Grid needs a little help to make the system balance, and the car can do that too. Maybe later on the DNO has to turn my charge down a bit, but I don’t notice. I check my in home display (IHD) and energy bill online and because my smart meter can log all this data, I know I have spent a grand total of £12 for all my transport power. I have supported renewable energy companies, and protected my local grid.

Now I don’t know about you, but that sounds pretty incredible to me, and I might just feel less guilty about being a car loving environmentalist.
To find out more about smart meters please visit smartenergyGB.org