School of the Built
Environment

University of
Reading

EV CARBON EMISSIONS – THE IMPLICATIONS OF 'TIME OF CHARGE'

As electric vehicles (EVs) displace carbon emissions from our roads to our power grid, the time that we charge these cars will have a growing influence on the carbon saved

VARIABILITY IN POWER SYSTEMS

At the University of Reading our research into energy variability is revealing opportunities to increase the true carbon saving from vehicle electrification.

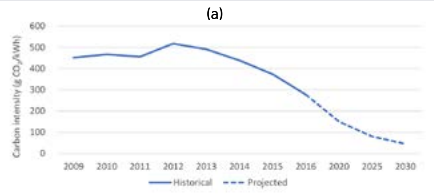
Modern power systems have evolved to continuously balance changes in electricity demand that arise from weather and behavioural influences. University of Reading researchers have been at the forefront of understanding emerging 'supply side' variability as we increase the levels of weather dependent renewables, especially wind and solar generation. Robustly characterising this variability built a platform for more recent work considering energy system impacts and exploring measures that will help to manage this variability. The potential rise of electric vehicles is of significant interest, given the potential to shift charging times in a way that is beneficial for the grid.

Exploring carbon emissions is a core strand to this work. Many current changes (including investment in renewables and the development of electric vehicles) are motivated by a desire to reduce society's carbon emissions. In practice, the emissions from our power grid vary from minute to minute, depending on the generation type operating in each moment. There is a growing awareness of the 'time varying' nature of these emissions and it can be anticipated that future government policy and commercial investment will begin to factor this in. This could prove a significant aspect for EV charging. With the prospect of managed charging already imminent, there is an opportunity to consider the carbon benefits of alternative charging strategies.

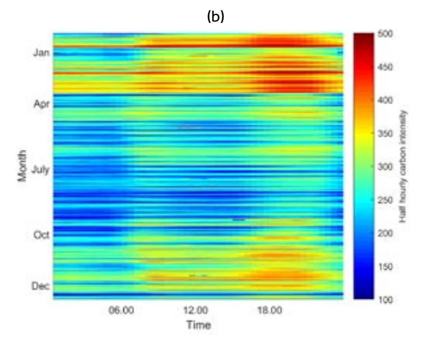
How grid carbon emissions vary

In carbon terms, not every power station is built equal. Coal fired power stations are responsible for the highest per unit emissions (> 900gCO_2e/kWh. See Box 1), with gas generation rather better (as low as 360 gCO_2e/kWh for efficient gas plant), whilst nuclear and renewables have very low carbon emissions. These last two are commonly deemed zero carbon in operation, but do still result in some carbon emissions from their initial construction. As a result, instantaneous carbon emissions change as weather sensitive renewables vary in output and other power stations are turned up, down, on or off to balance electricity demand. Average grid emissions have fallen dramatically over recent years, but large variations are still seen from hour to hour.

Fig 1.



(a) Trends in annual average UK grid carbon intensity.



(b) Half hourly UK grid carbon intensity across 2016.

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Box 1. Calculating grid carbon intensity

Calculating carbon intensity combines electricity generation data by fuel type[2] with a 'carbon factor' – estimating the emissions that arise from an average power station to produce this. Carbon factors are highly uncertain[3] as they must allow for power station efficiency which varies from one station to the next and continuously with operating level. Values quoted in text are indicative figures only. Calculated results draw factors from a recently published academic study [4].

Box 2. DriveElectric's Crowd Charge Project

Through an Innovate UK funded Knowledge Transfer Partnership, the University of Reading are supporting Drive Electric (an EV leasing and smart charging services company) to develop a business model that will bring smart EV charging to market. DriveElectric have built a presence in this area through participation in SSE Networks' My Electric Avenue and WPD's active Electric Nation projects (see Box 3.)

driveelectric

Vehicle carbon intensity

Electric vehicles are sometimes seen as zero carbon, reflecting the absence of 'tailpipe' (or 'point of use') emissions. This is reflected in current vehicle testing and a range of vehicle marketing and policy related incentives. However, it is widely recognised that vehicles should be deemed responsible for the emissions that come from generating the electricity drawn when charging. It is anticipated that this logic will increasingly be reflected in environmental assessments (especially carbon footprinting) and related legislation / incentive schemes.

By combining average vehicle efficiency figures with data on grid carbon intensity, it is possible to reach a first estimate of the 'fuel based' emissions that should be attributed to driving these vehicles (see Fig 2). In recent years, not all EVs would have been demonstrably better than efficient diesel or petrol cars. Current changes in grid carbon intensity are dramatically improving the case for EVs and this trend is set to continue as the power grid decarbonises further.

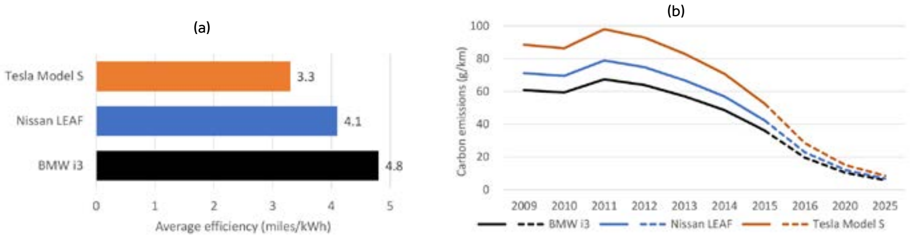

Fig 2. (a) Typical vehicle efficiency figures and (b) the implied annual average carbon emissions. (Efficiency figures for three popular models from[1])

User behaviour and impact on energy demand

In practice, particular patterns are seen from vehicle charging. Full electric vehicles cannot (currently) be charged while driving. Drivers' individual circumstances will influence whether charging will tend to occur at home, at a workplace or at a public charging point and this constrains when power is drawn from the grid.

Early experience with EV charging is showing something of a worst-case scenario for the power system. Many drivers connect their cars when arriving home from work and set them to charge immediately. This adds significant demand to the grid at the time which is most challenging. Fig 3 shows an average pattern of charging, collected from DriveElectric's Crowd Charge smart charging system (see Box 2). This reflects 77 domestically charged, fully electric cars for a period of three months (June to August 2017), without charge control. The charging pattern has been corrected to provide the total electricity needed to drive the example cars 10,000 miles in a year, overlaid on a typical domestic electricity demand profile (Elexon class 1).

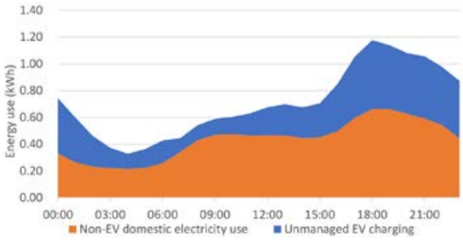

Fig 3. Domestic energy use by time of day, with additional demand from charging an EV.

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[1] Vehicle Certification Agency. UK Car Fuel Data - August report. 2017. http://carfueldata.direct.gov.uk/

[2] Elexon. Elexon data portal. 2016. www.elexonportal.co.uk

[3] Parliamentary Office of Science and Technology. Postnote 383: Carbon footprint of electricity generation. 2011.

[4] Measuring the progress and impacts of decarbonising British electricity. Staffell, Iain. 2017, Energy Policy.

Box 3. Industry innovation

The energy industry has been conducting a wide range of research projects to assess the impacts of potential EV growth. Of these, two have been referenced in this sheet, which have either involved University of Reading researchers or our project partners. Further information on the studies conducted by the distribution network companies Scottish and Southern Energy Networks and Western Power Distribution can be found at:

www.myelectricavenue.info
www.electricnation.org.uk

Time varying carbon emissions

A more sophisticated approach to considering EV carbon emissions, is to take the actual time that vehicles charge and then apply grid carbon intensity figures which reflect the power generation operating at each moment. Figure 4 (b) combines the charging profile shown (a), with the carbon intensity data presented in Fig 1(b). A sizable share of the charging occurs in the early evening, coinciding with a period when grid carbon intensity is at its highest. This is already balanced somewhat by extensive overnight charging, but there is a clear opportunity for improvement.

There is widespread concern that, should the unmanaged profile become widely established, then this could put considerable strain on our low voltage Distribution Networks. The result would be a need for expensive upgrades to support this, particularly with peak demand in the early evening. These concerns have been examined in a number of studies conducted by the Distribution Network Operators, including SSEN's 'My Electric Avenue' project and WPD's current 'Electric Nation' trial (see Box 3.)

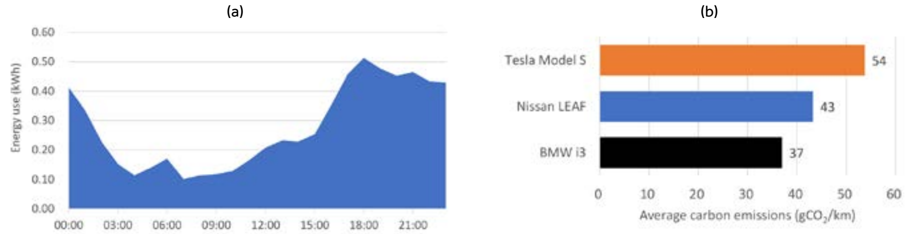

Fig 4 (a) Pattern of uncontrolled charging demand and (b) resultant average vehicle carbon emissions.

Controlled charging

The network challenges could be significantly mitigated by implementing controlled charging of EVs to avoid times when the power grid is at greatest strain. There are a range of incentives and mechanisms that could be introduced to achieve this, though considerable uncertainty as to which mechanisms will become widely adopted.

Here we have simulated a controlled charging profile that seeks to shift charging into low demand periods afforded by the current domestic power consumption profile. In our profile, control efforts are prioritised between the hours of 4pm and 8am when cars are most likely to be connected. Analysis reveals a modest, but worthwhile carbon saving of some 5 - 7% of the charging related carbon emissions. This is an early result and we will be assessing alternative charging strategies, including the potential for carbon optimised charging and a solar oriented regime. Fig 1(b) implies that shifting charging between days could have a higher impact. The potential for saving is also set to grow as renewable generation continues to rise.

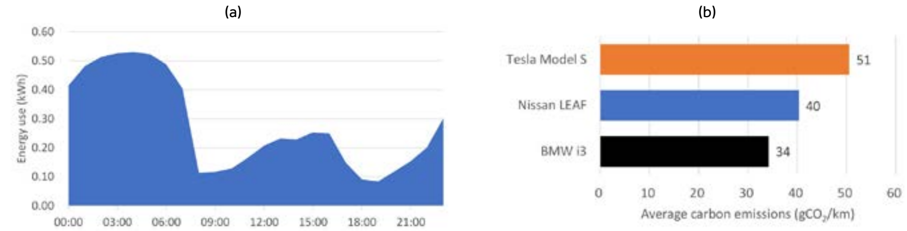

Fig 5 (a) Pattern of controlled charging demand and (b) resultant average vehicle carbon emissions.

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Marginal carbon emissions

The approach used above assesses the carbon emissions from grid operation in any half hour and allocates this evenly across all electricity demand. Some commentators, though, argue that this is not a fair reflection of the marginal impact of new demand. A similar argument applies when considering the carbon saving of new, variable low carbon generation such as solar. The question here comes from asking which power generation actually adjusts its output when new demand is added. This is highly relevant when considering vehicle electrification, which effectively reduces energy demand from oil derived fuels while increasing electricity demand. With recent closures in coal fired generation, it is a reasonable generalisation to assume that marginal generating plant is usually gas fired at any time of day. From this viewpoint, the time of use saving from controlled car charging would be negligible. It would only be at times of high electricity demand when remaining coal plant is called, or, in the most extreme cases, oil fired generation, that appreciable differences in marginal carbon intensity would be seen.

By contrast, rapid growth in renewable generation raises the prospect where time adjusted energy demand would appropriately be attributed a higher carbon saving. High, instantaneous levels of renewables can sometimes cause system problems, either (i) because local cables in the energy grid have insufficient capacity to move the electricity, or (ii) at very high levels, when the System Operator is concerned about stability. In either case it can be necessary to turn off ('constrain' / 'curtail') free, low carbon, energy. Shifting the charging of EVs to such times would bring about a considerable carbon saving.

RESEARCH BASE

This thought piece has been compiled by Anthony Simpson, Vicky Papaioannou and Dr Phil Coker. Anthony Simpson is currently working with Drive Electric on their Crowd Charge initiative (see Box 2.) Vicky Papaioannou is investigating the uncertainties inherent in using electricity carbon intensity data, sponsored by the National Physical Laboratory and the Engineering and Physical Sciences Research Council. Research work across this area is led by Dr Phil Coker and Dr Ben Potter. The TSBE Centre within the School of the Built Environment offers a dedicated contact point to help connect industry partners with our leading experts.

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