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Data collection, methodological development and harmonization of transport statistics: Vehicle statistics

Electric vehicle charging: analysis of CO_2 emissions

Note by the secretariat

Summary

This document is presented as interim analysis conducted by the secretariats of the Working Party on Transport Statistics, the Working Party on Pollution and Energy, the For Future Inland Transport Systems (ForFITS) project, and the Working Party on Transport Trends and Economics. It explores real-time emissions associated with charging electric vehicles, and policy implications of this. It uses half-hourly carbon intensity of electricity generation data available for Great Britain as an example.

I. Background

1. There are currently around 7 million full battery electric vehicles (BEV) in the world[1], and their percentage of new registrations is expected to rise considerably in the future. Many countries have already set phase-out dates for the sale of new internal combustion engine vehicles, with others expected to follow suit. Some auto manufacturers have also announced a future end of sales of internal combustion engines, investing heavily in BEVs as the tool for zero tailpipe emission technology. While BEVs have zero tailpipe emissions when the vehicle is in operation, their charging uses electricity, resulting in a quantity of CO_2 emissions dependent on the source of the electricity. According to the Global Fuel Economy initiative (GFEI)[2], electric cars will have less overall in-use emissions when the carbon content of electricity is less than 800 grams CO_2 per kWh. The global average carbon intensity of electricity in 2018 was around 479 g CO_2/kWh and virtually every country is below 800g CO_2/kWh on average annually. Data on power generation CO_2 intensities are readily available for most countries of the world, but these usually only represent annual averages,

[1] IEA, 2021, Global EV outlook, https://www.iea.org/reports/global-ev-outlook-2021.
[2] GFEI Working Paper, 2021, https://www.globalfueleconomy.org/data-and-research/publications/gfei-working-paper-22.

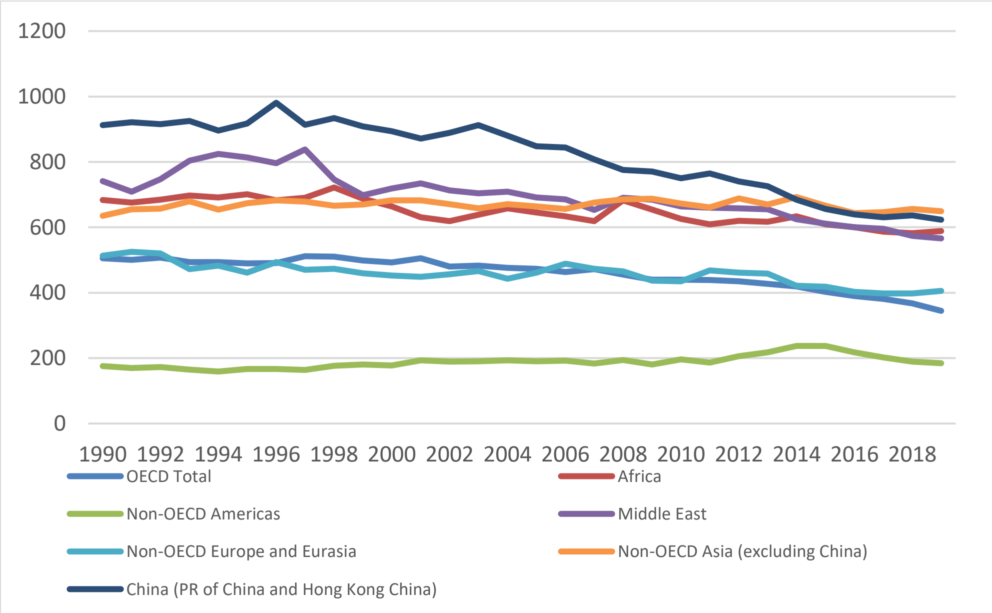
and may mask important differences over the course of the day, week, month or season. It is therefore possible that while average annual CO_2 intensities lend electric vehicles a CO_2 advantage, it could be even more pronounced if they are charged at the time when the power generation carbon intensity is the lowest, or conversely, they could offer a lower environmental benefit if vehicles are only charged when the power generation carbon intensity is highest. There are therefore strong policy implications for knowing real-time CO_2 generation rates, both to monitor, report and allocate CO_2 emissions from electricity to the appropriate end-use sector and also to encourage electric car users to charge their vehicles at the best times, when carbon content of electricity is lowest. This paper looks at the need to monitor EV emissions during the recharge, and the impact of the time resolution to calculate recharge emissions, and at the impact of recharging time on annual emissions.

II. Electricity mix and carbon content

2. According to IEA data, global greenhouse gas (GHG) emissions from fuel combustion were 34.2 Gt CO_2 equivalent in 2019. Direct CO_2 emissions from transport were 8.2Gt of this. In many countries that have reduced their CO_2 emissions in recent years, transport is the only significant sector where emissions have actually increased.

3. With growing successful efforts to decarbonise electricity, the average CO_2/kWh factor for the globe has changed from 537 g in 2000 to 479 g in 2018. By (IEA defined) regions, China has reduced its CO_2/kWh intensity the most (Figure 1). This change is due to more low-carbon and zero-carbon electricity sources being used, for example shifting from coal-fired generation to more gas-fired and renewable sources.

Figure 1
CO_2/kWh from electricity by (IEA-defined) regions



Source: IEA

4. Electricity is a secondary energy, produced from a primary source of energy; Each primary energy source has a different carbon intensity, and so the average carbon content of the electricity generated at any time depends on the generation mix. Recent years have witnessed the strong deployment of renewable electricity sources such as wind or solar that have a lower carbon intensity compared with other sources of electricity.

5. Most renewables power sources are intermittent, not able to provide a constant supply of electricity to the grid; Solar and wind energy for example can only provide electricity when there is sufficient sun and wind respectively. To accurately capture the emissions from any electric device, there is a need to be able to link the electricity use to the time the electricity

was generated; this occurs during the time of recharge of the vehicle, when it is plugged to the grid.

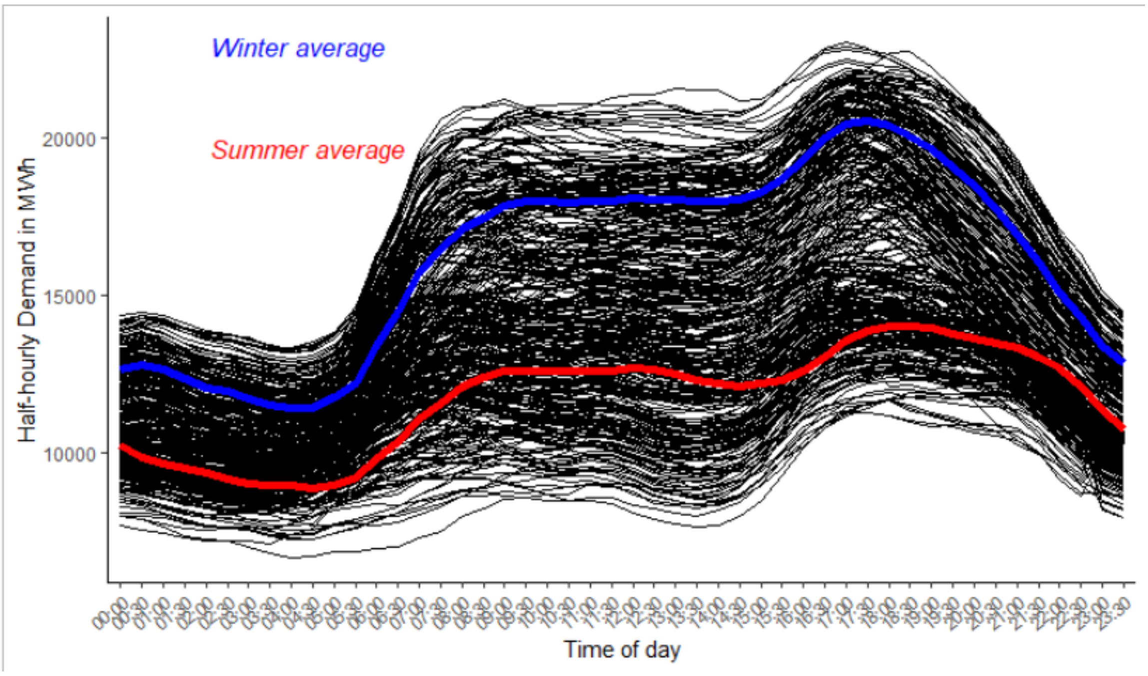
6. Adding many EVs to the fleet will increase electricity demand, but extra power generation capacity needs will depend on the capability of EVs to be recharged off-peak hours and/or when abundant intermittent low carbon electricity is generated, not requiring extra capacity; though the marginal power generation source to recharge EVs might come more carbon intensive sources, this paper only considers average instantaneous electricity mix as source of EV recharge.

III. Real-time CO_2 emissions from electricity: Case study for Great Britain

7. Most electricity grid operators, also referred to as distribution network operators (DNOs), are able to determine real-time electricity generation mix in their grid, and many of them share these data publicly. The best time series UNECE has identified is from Great Britain, for which UNECE has analyzed the potential CO_2 savings of recharging time and duration. Web sources such as electricitymap.org offer such data at a multinational level, but some of the data and methodology are proprietary. We therefore focus on Great Britain as a case study hereafter.

8. Before looking at the CO_2 intensity itself, it is worth considering the principal drivers of it. Variable renewables play a part in CO_2 intensity, as does user demand. Figure 2 shows the electricity demand for each day of 2020 for Great Britain, with the winter average and summer average plotted over it.

Figure 2
Great Britain daily electricity demand, 2020 and seasonal averages



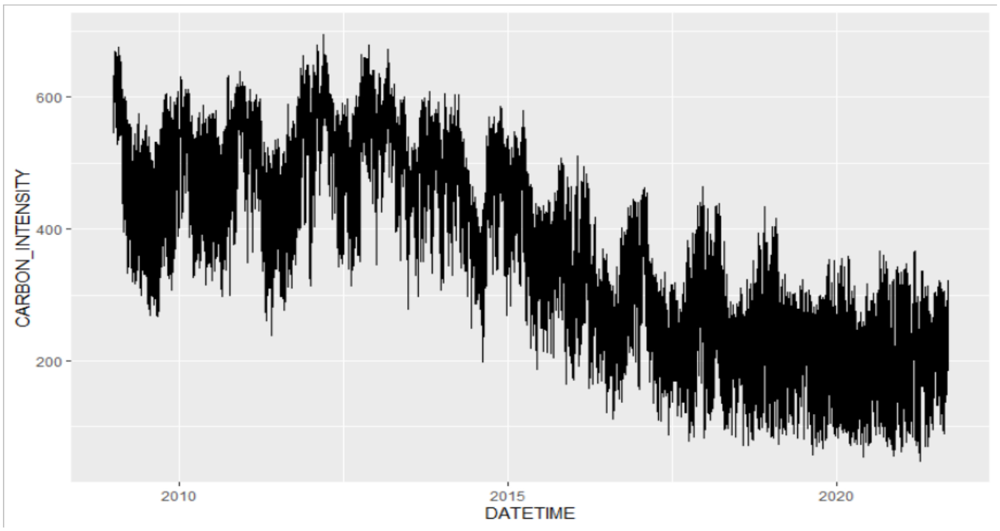
Source: National Grid

9. Throughout the year, demand steadily increases from nightly lows from 05:00 onwards, with a constant demand during the day from approximately 08:00 to 16.00, followed by an evening peak between 16:00 and 19:00. The Summer average is consistently lower than the Winter average throughout the day, reflecting the increased heating requirement in the Winter.

10. Taking the analysis further, Figure 3 shows the CO_2 intensity, on a half-hourly basis, of Great Britain's electricity grid going back to 1 January 2009. This shows the strong success that has been achieved in decarbonizing power generation. For example, in 2010 the mean

CO_2 per kWh was 498.3 grams/kWh, whereas in 2020 the figure fell by 61% to 192.3 grams/kWh.

Figure 3
Great Britain carbon intensity of electricity (grams per kWh) over time

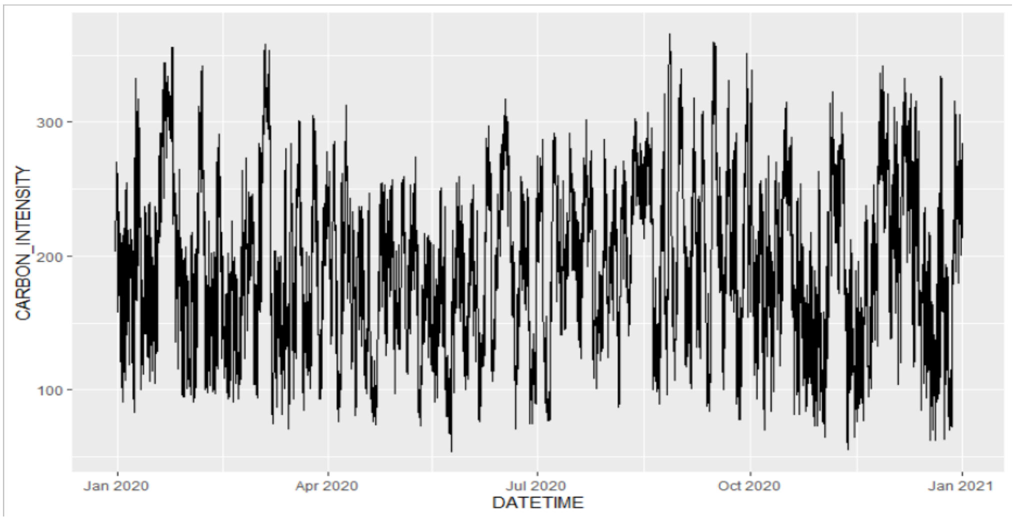


Source: National Grid

11. Similarly to what occurs for electricity demand, carbon intensity of the electricity has a strong seasonal component, with winter months average carbon intensity approximately 30% higher than summer months carbon intensity. Indeed, averaging over all the data, the average carbon intensity in June, July and August is 332.5, whereas in December, January and February it is 405.6. This trend nevertheless seems to soften during the latest years, perhaps because of a strong deployment of wind energy which has low seasonal effects.

12. Next, in order to mask any effects caused by the decrease in emissions factors over time, half-hourly analysis is only conducted on the year 2020. Figure 4 shows half-hourly intensities over the entire year. While erratic, this does show that even the worst peaks of CO_2 intensity in 2020 are lower than the mean intensity of 2010 (498 g per kWh).

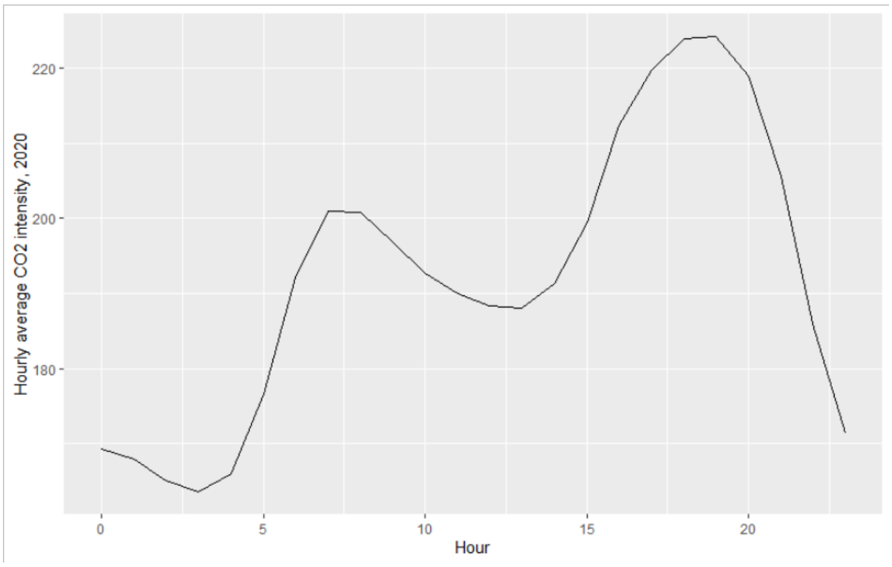
Figure 4
Great Britain CO_2 intensity of electricity (g per kWh) in 2020, half-hourly



Source: National Grid

13. Taking a yearly average on an hour-of-day basis, important differences depending on the time of day are evident (Figure 5).

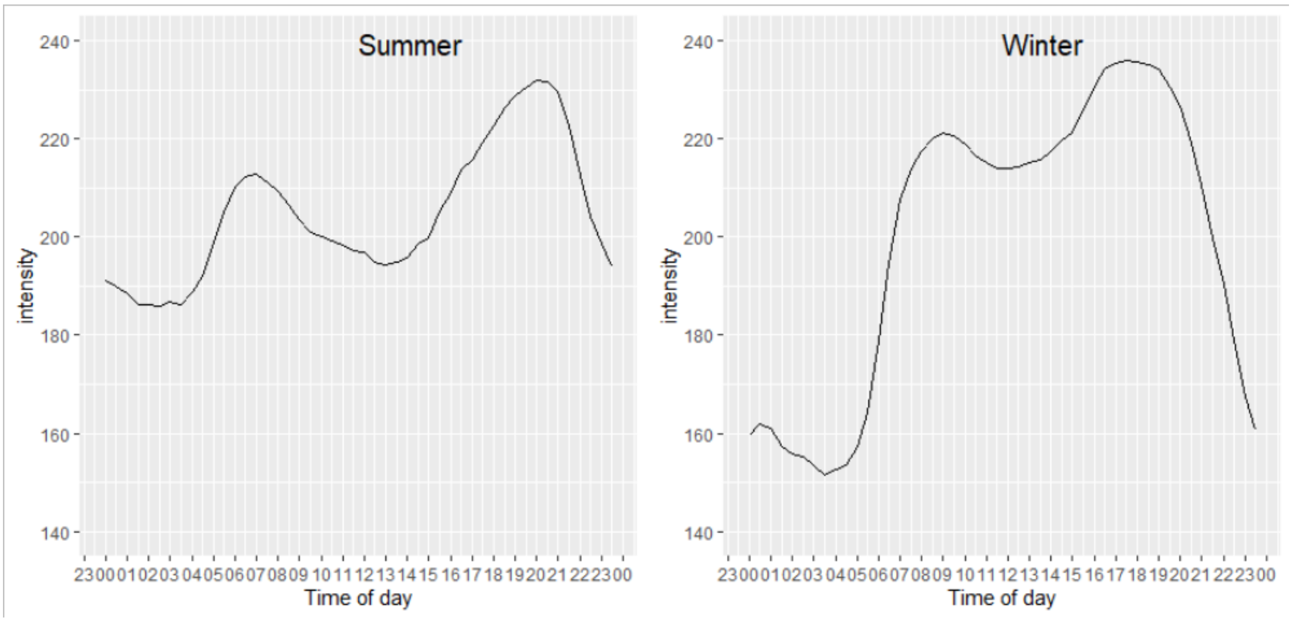
Figure 5
Great Britain CO_2 intensity of electricity (g per kWh) in 2020, hourly averages



Source: National Grid

14. This is explored further in Figure 6, breaking down hourly averages by Winter (defined as December-February) and Summer (June-August) for 2020. The highest carbon-intensive hour in winter is 18:00-19:00, which also corresponds with expected winter electricity demand peak (meaning that marginal electricity in the UK will be coming more from carbon intensive electricity sources such as natural gas or coal). Summer has a later peak after 20:00, and the trough of demand over night is much less pronounced.

Figure 5
Great Britain CO_2 intensity in 2020, daily trends in Summer and Winter



Source: National Grid

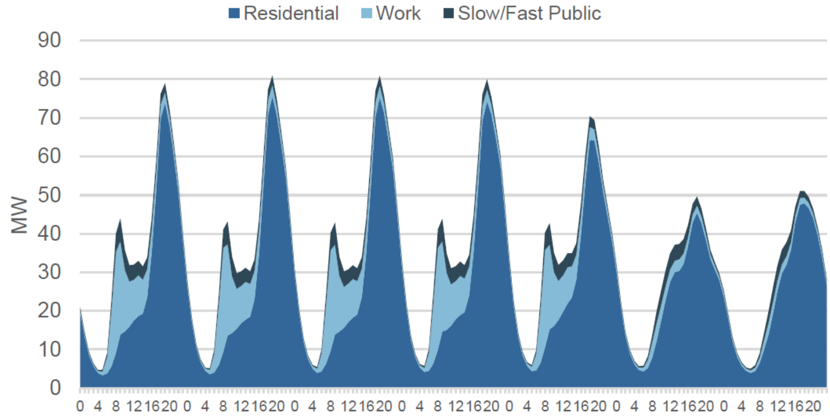
IV. Electric Vehicle recharging behaviour in Great Britain

15. According to a survey performed in 2017/2018 in Great Britain, charging peak demand from EVs occurs in the afternoon / early evening when EV owners plug in their vehicle at home coming back from work (Figure 7); as shown above, this coincides with the peak carbon intensity of electricity. So the potential to reduce peak demand and CO_2

emissions is high if EV recharging could occur at a time when the carbon intensity of electricity is lower, mostly during the night, and/or when renewable generation is high.

Figure 7

EV recharge weekly average demand profile in Great Britain



	Mon	Tue	Wed	Thu	Fri	Sat	Sun
GWh/day	0.90	0.93	0.94	0.96	0.91	0.71	0.70

Source: Element Energy[3]

16. The charging demand peak of EVs seems to thus be close to the overall electricity demand peak (comparing Figures 2 and 7), showing the need to deploy incentives and technologies to shift recharging times when overall demand is lower.

V. Emissions reporting and concluding remarks

17. Most studies looking at the well-to-wheel emission of electric vehicles (EVs) usually take the annual average carbon intensity to determine the carbon emissions of EVs. This analysis shows that, without any intervention, EVs may typically be charged when carbon intensity is at its highest, during evening peaks. The CO_2 emissions of EVs may therefore be underestimated, at least for electricity systems like in Great Britain where carbon intensity is higher during evening peaks, particularly during the Winter. This preliminary analysis shows that average EVs use electricity emitting 192 g per kWh of CO_2 for the 2020 average of Great Britain, but 364 g per kWh if charging at the worst hour of the year.

18. By charging EVs during low demand hours overnight, emissions can be significantly reduced. This document reflects preliminary analysis and further work will be carried out by the secretariat under the framework of the ForFITS tool, to provide further evidence about the need to closely monitor and accurately report on the real-time emissions of EVs, and to show potential benefits of implementing smart charging to incentivize charging during low CO_2 power generation times.

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[3] http://www.element-energy.co.uk/wordpress/wp-content/uploads/2019/04/20190329-NG-EV-CHARGING-BEHAVIOUR-STUDY-FINAL-REPORT-V1-EXTERNAL.pdf.