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Keeping the Car Clean: ‘Smart’ EV Charging to Support Renewables

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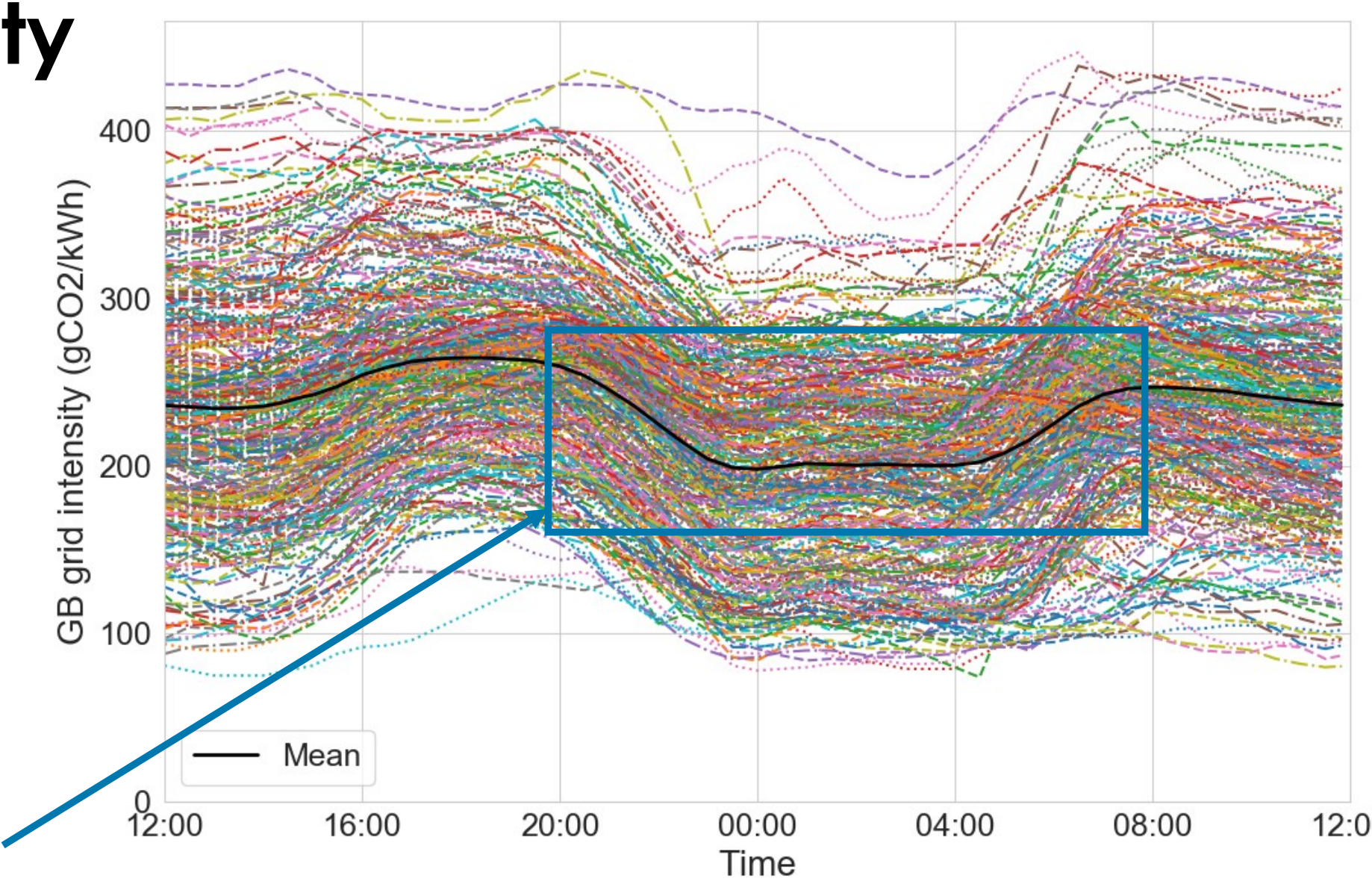
Motivation

- Transport is the biggest CO_2 emitter in the UK (**~1/3 of emissions**) – the vast majority from road transport [1]
- Electric vehicles (EVs) are cited as key to going ‘net zero’ [2], and we could be getting **35 million of them by 2040** [3]
- Private cars spend **96% of their time parked** on average [4], so EV charging is likely to be *flexible*
- The *carbon intensity* (CO_2 per unit of energy) of the grid varies – and is predicted to vary more with increasing renewables
- Intermittent renewable generators (such as wind farms) are curtailed when their output exceeds local demand and transmission capacity
- Can we get EVs to **charge when grid carbon intensity is low, or when renewable energy output is high?**
- Can EVs provide demand when needed to **absorb excess renewable electricity that would otherwise be curtailed?**

GB Grid Carbon Intensity

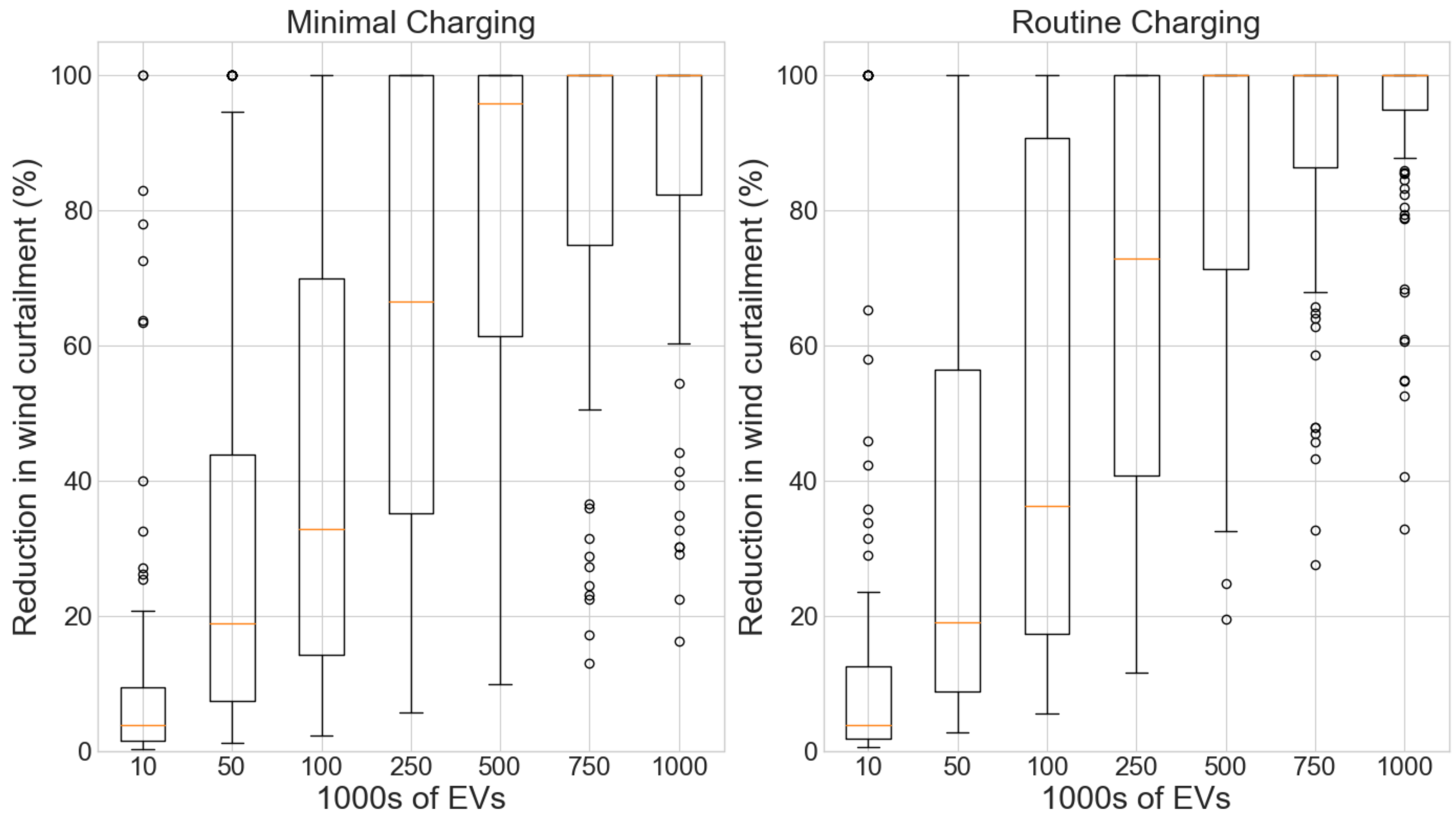
- National Grid’s Carbon Intensity API [6] used to generate grid intensity (gCO_2/kWh) time series for the period 1 June 2018 – 31 May 2019



Intensity tends to be lowest overnight – when most EVs are plugged in

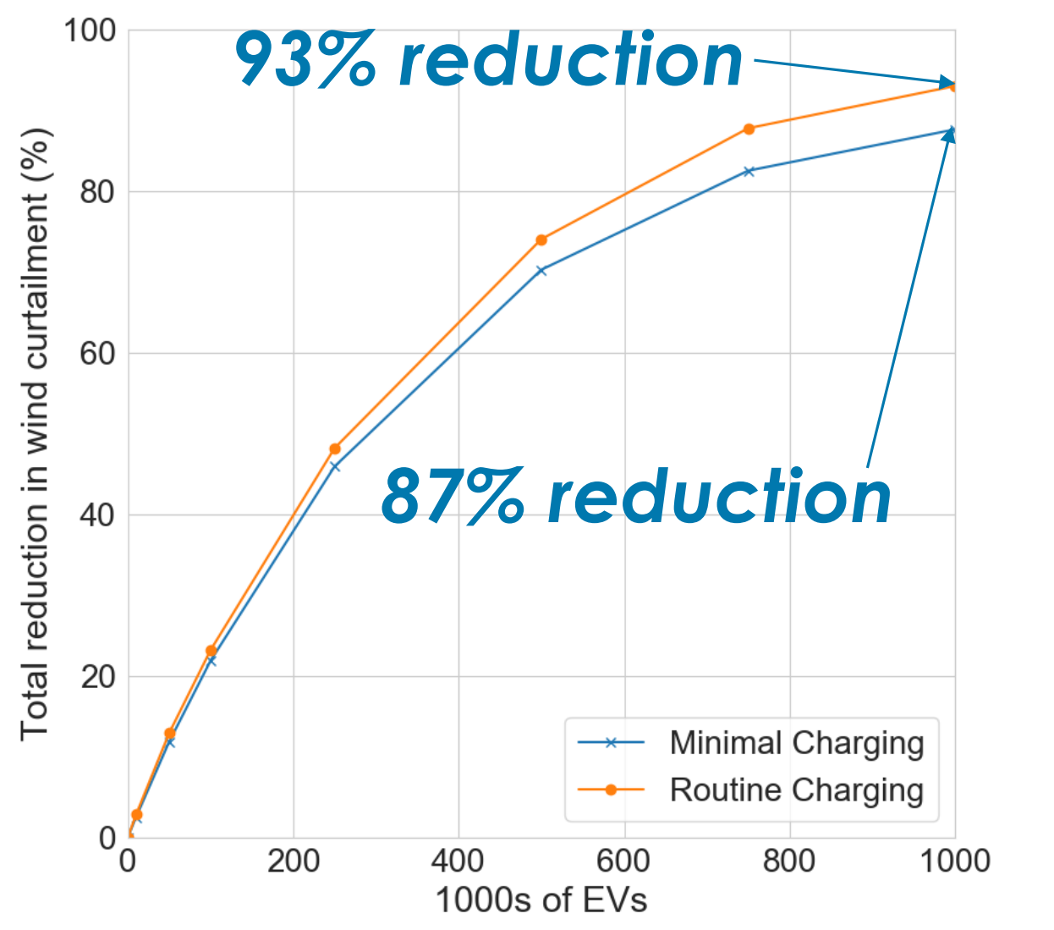
Daily GB grid carbon intensity, 1 June 2018 – 31 May 2019

Results – Absorption of Wind Curtailment



Box plots showing percentage reduction in wind curtailment at Whitelee windfarm on 112 days with curtailment from smart charging of EV fleets of various sizes

- Reduction in curtailment increases with EV fleet size
- Rate of increase is diminishing due to days with curtailment in the middle of the day (when fewer EVs are plugged in)
- Routine charging offers greater reduction due to flexibility, though numbers are not vastly different due to constant transport energy requirement



93% reduction

87% reduction

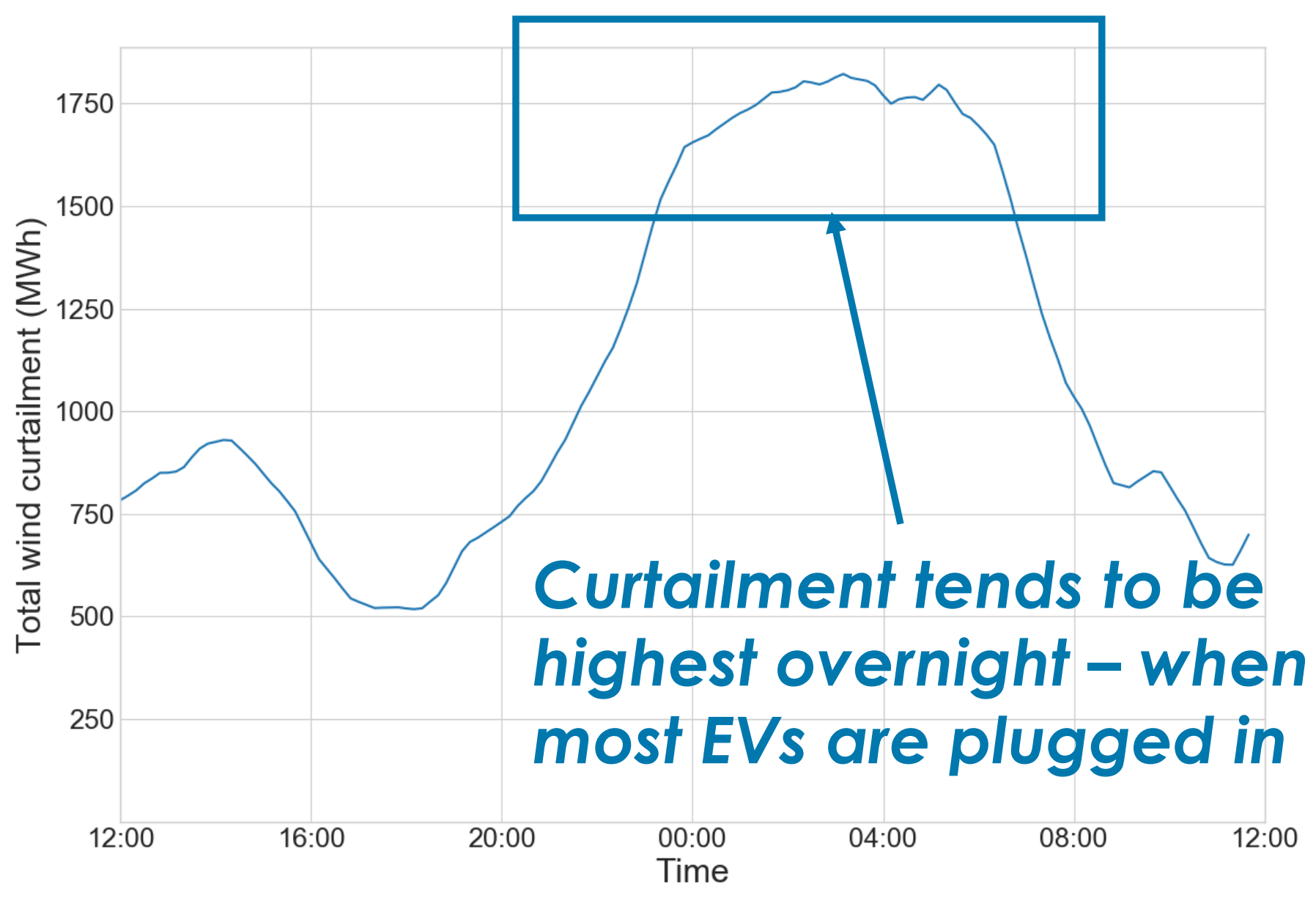
Total reduction in wind curtailment at Whitelee over period 1 June 2018 – 31 May 2019 from smart charging

Conclusion

- If ‘dumb’ charged from the current GB grid, *average* EVs’ emissions from their charging is **35-56 gCO_2/km**.
- This can be reduced **to 27-39 gCO_2/km** by smart charging – around **20-30% of the tailpipe emissions of an average new petrol/diesel car** sold in Europe [7]
- There is potential for EVs to absorb excess wind generation; **500,000 EVs (20% of Scotland’s current car fleet [8]) could absorb ~3/4 of curtailment at GB’s largest onshore wind farm**

Whitelee Wind Farm, Eaglesham (~15 Miles South of Glasgow)

- UK’s largest onshore wind farm: 215 turbines, 539 MW
- Curtailment in period 1 June 2018 – 31 May 2019 occurred on 112 out of 365 days; the total was 227,841 MWh [5]
- The wind farm is *paid* to curtail this generation at an average of **£70/MWh** [5] – bringing the total yearly sum to over **£15.9m**



Curtailment tends to be highest overnight – when most EVs are plugged in

Total curtailment at Whitelee wind farm by half-hourly settlement period, 1 June 2018 – 31 May 2019

Whitelee wind farm. Author’s own photograph *(note: pictured vehicle cannot absorb excess generation)*

Driver Behaviour Modelling and ‘Smart’ Electric Vehicle Charging

- Charging schedules derived from 10,000 week-long travel diaries from the UK National Travel Survey (NTS), according to **two models of driver behaviour…**

Example travel diary from UK NTS (car based trips)

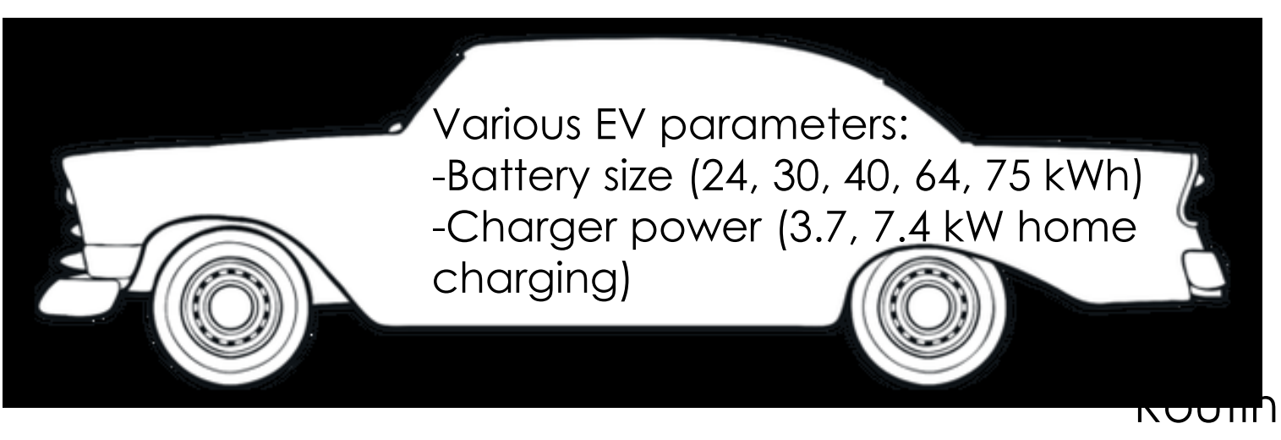
Trip #	Origin	Destination	Trip Start	Trip End	Distance (miles)
1	Home	Food shop	Tu 09:30	Tu 09:50	3
2	Food shop	Home	Tu 10:40	Tu 11:00	3
3	Home	Other escort	Tu 18:15	Tu 18:20	0.25
4	Other escort	Home	Tu 18:20	Tu 18:25	0.25
5	Home	Other escort	Tu 19:40	Tu 19:45	0.25
6	Other escort	Home	Tu 19:50	Tu 19:55	0.25
7	Home	Food shop	W 09:30	W 09:50	3
8	Food shop	Home	W 10:30	W 10:45	3
9	Home	Work	Su 07:40	Su 08:00	7
10	Work	Home	Su 17:00	Su 17:20	7

‘Minimal’ Charging

- Drivers seek to **minimise** the number of times they plug in
- Energy requirement tends to be **greater**; charge events are *less flexible*

‘Routine’ Charging

- Drivers plug in **every time they get home** (i.e. it’s ‘routine’)
- Energy requirement tends to be **smaller**; charge events are *more flexible*



Various EV parameters:
-Battery size (24, 30, 40, 64, 75 kWh)
-Charger power (3.7, 7.4 kW home charging)

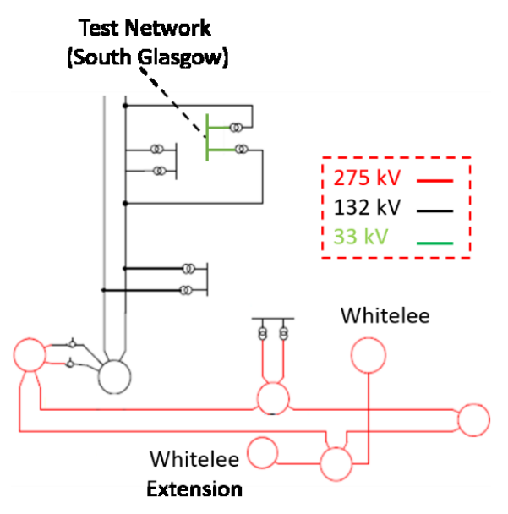
‘Minimal’ charging schedule for travel diary – 24 kWh battery, 3.7 kW AC charging, 88% efficiency

Trip #	Charge Type	Plug-in	Plug-out	E_{start} (kWh)	E_{end} (kWh)	P^{max} (kW)
8	home	W 10:45	Su 07:40	8.44	24	3.26

Routine’ charging schedule for travel diary – 24 kWh battery, 3.7 kW AC charging, 88% efficiency

Trip #	Charge Type	Plug-in	Plug-out	E_{start} (kWh)	E_{end} (kWh)	P^{max} (kW)
2	home	Tu 11:00	Tu 18:15	10.36	24	3.26
4	home	Tu 18:25	Tu 19:40	23.86	24	3.26
6	home	Tu 19:55	W 09:30	23.86	24	3.26
8	home	W 10:45	Su 07:40	22.36	24	3.26

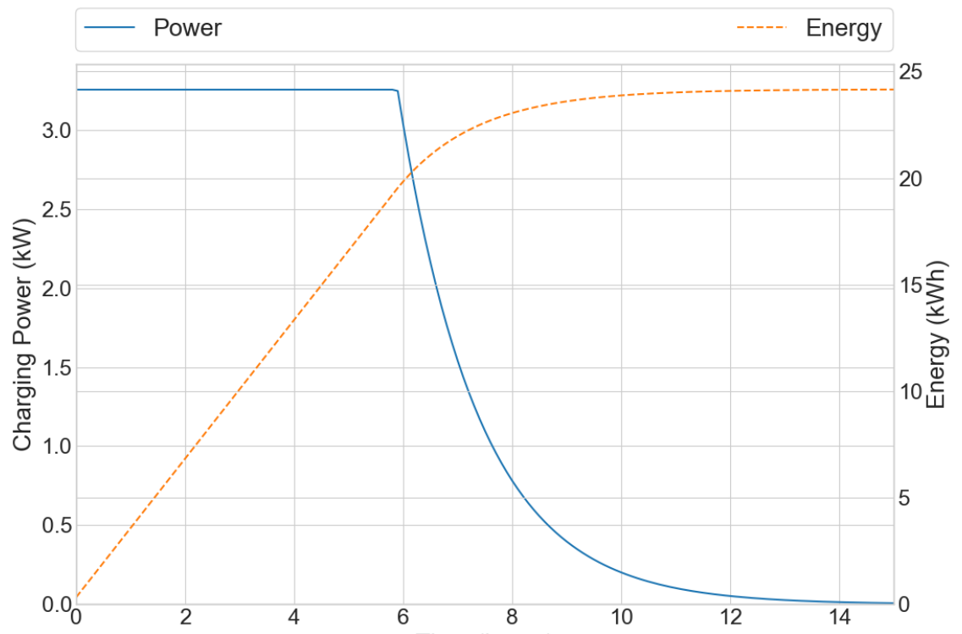
I need to get from E_{start} to E_{end} during the time I’m plugged in, subject to the maximum charging power P^{max}…



…Subject to network constraints…

…with the ***minimum possible CO_2***

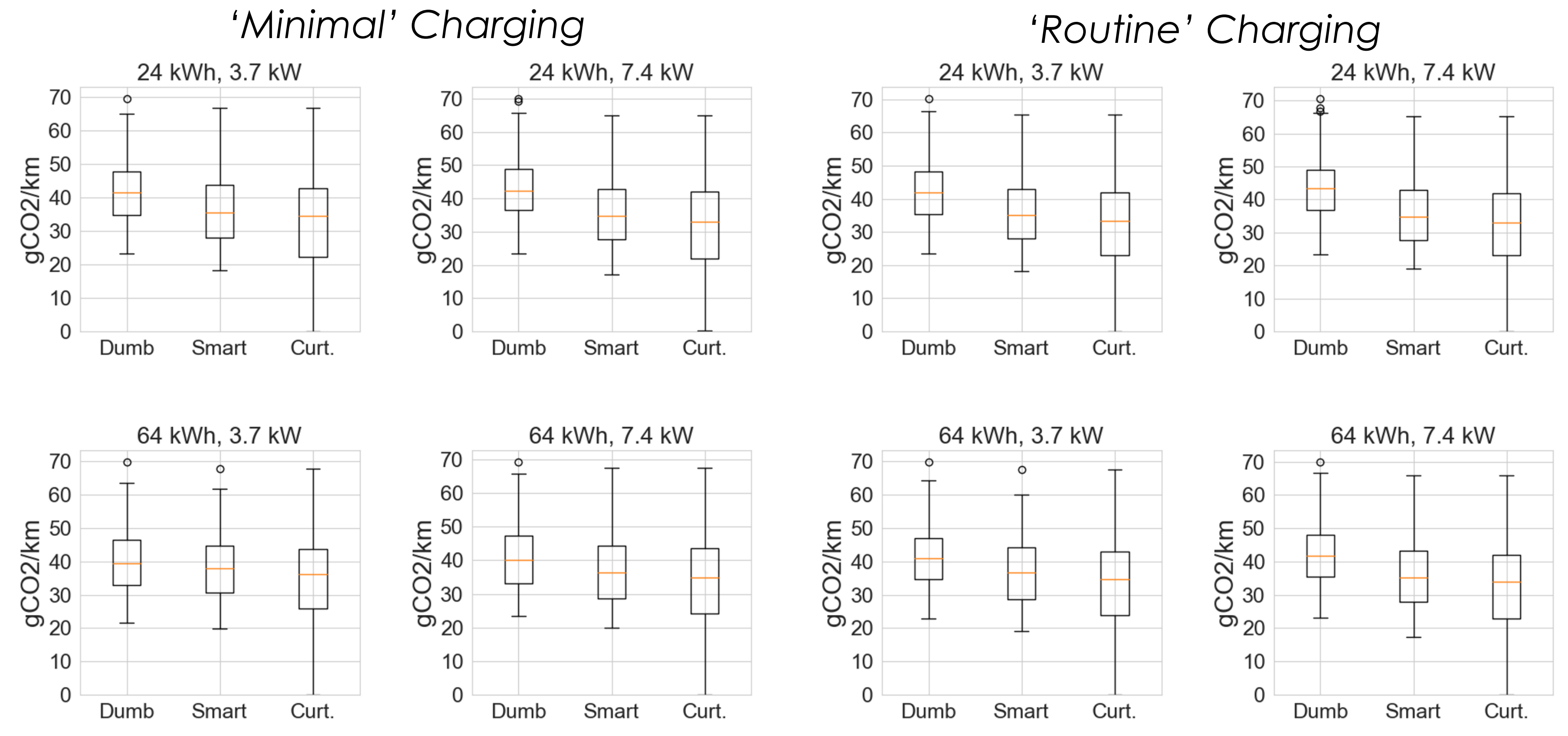
EV charging scheduling approach (using optimal power flow formulation)



Maximum power constraint: Lithium-ion charging profile

Results – CO_2 Emissions of EV Driving

- EVs smart-charged for minimum possible carbon intensity, given network and energy constraints
- Significant variation in results; up to **29% reduction in mean CO_2 emissions** from smart charging if local excess wind generation taken into account
- Routine charging enables greater reduction, especially for larger battery sizes (due to users charging less often under minimal charging model)



Box plots showing reduction in carbon intensity from controlled charging, with and without the inclusion of curtailment from Whitelee wind farm, for four combinations of battery size and charger power – minimal and routine charging behaviour

References

[1] BEIS, 2018 UK greenhouse gas emissions, provisional figures. [Online]. Available: bit.ly/2mybLm4
[2] Committee on Climate Change, “Net Zero: The UK’s contribution to stopping climate change”, 2019.
[3] National Grid, “Future Energy Scenarios 2019”, 2019. [Online]. Available: fes.nationalgrid.com
[4] RAC Foundation, “Spaced Out: Perspectives on parking policy”, 2012. [Online]. Available: goo.gl/AfPRDD
[5] Elexon, “Balancing Mechanism Reports”, 2019. [Online]. Available: bmreports.com
[6] National Grid, “Carbon Intensity API”, 2019. [Online]. Available: bit.ly/2mO0GOa
[7] European Environment Agency, “CO_2 emissions from new cars in 2018”, 2019. [Online]. Available: bit.ly/2mo8iXu
[8] Transport Scotland, “Scottish Transport Statistics: No. 35”, 2016. [Online]. Available: bit.ly/33kFi3o

Project Details

- This work was completed as part of a PhD studied at the EPSRC Centre for Doctoral Training in Future Power Networks and Smart Grids at the University of Strathclyde, Glasgow.
- The PhD’s start date was October 2016 and will conclude in December 2019 (extra 3 months’ funding due to external collaboration).
- The work presented in this poster is based on an upcoming publication; this started in September 2019.
- Grateful thanks are expressed to SP Energy Networks for the provision of network data and support of this project.

University of Strathclyde Glasgow

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