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CENTRE FOR RESEARCH INTO ENERGY DEMAND SOLUTIONS

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Plug and play

The impact of plug-in frequency on the potential of vehicle to grid to support transport and electricity system decarbonisation

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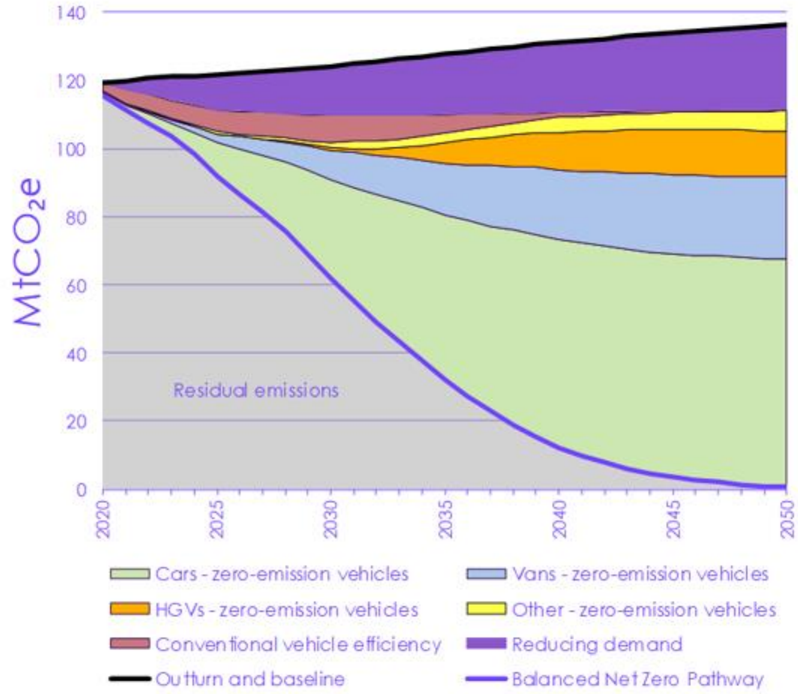
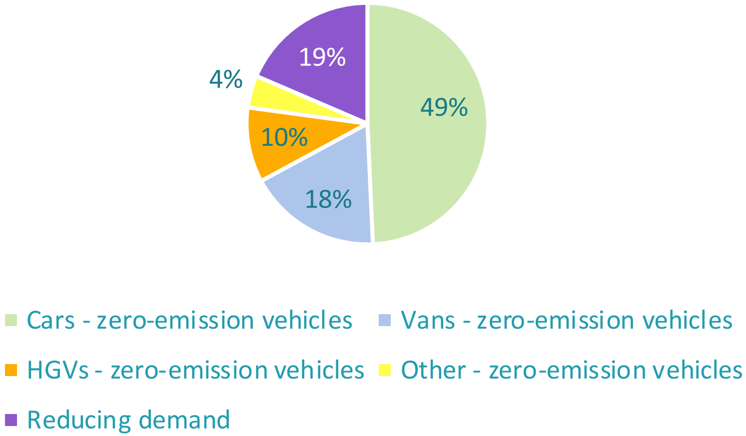
Worcester College, Oxford

Abatement in surface transport

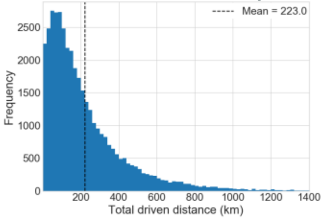




Climate Change Committee, "Sixth Carbon Budget," 2020. [Online]. Available: https://bit.ly/3tTOvMv.

V2G – a game changer?

Weekly driving distance, UK National Travel Survey 2019



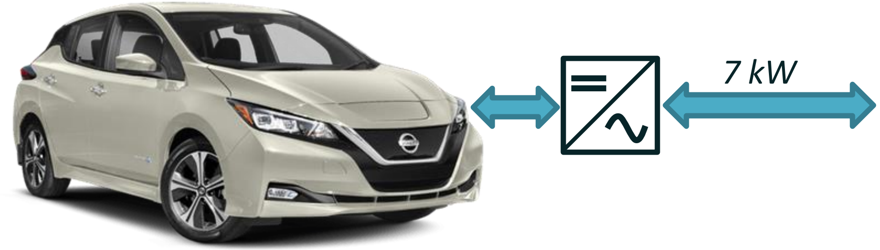
~35 km (25 mi)

Battery capacity 40 kWh

Needed for driving 6 kWh/day

Going spare? 34 kWh/day

- 31 million vehicles
- Storage (energy) resource of $34\times10^3 \times 31\times10^6$ = **1.05 TWh**



- 31 million vehicles
- Storage (power) resource of $7\times10^3 \times 31\times10^6$ = **217 GW**

How much electricity storage do we need?

Box 1: Storage and Flexibility

Because of greater intermittent renewable penetration, Net Zero pathways have a greater requirement for system balancing.

This can be achieved through supply side flexibility, demand side flexibility and energy storage in various forms.

	Clockwork		Patchwork	
Energy storage in 2050 (non-fossil)	**Volume (GWh)**	**Power Rating (GW)**	**Volume (GWh)**	**Power Rating (GW)**
Electricity storage	35	8	29	4

Energy: 1050 GWh
Power: 217 GW

X 31 million

3% of UK cars as a storage resource could meet the 'high' Net Zero electricity storage option

(or all UK cars used 3% of their potential)

Energy Systems Catapult, "Innovating to net zero," 2019. [Online]. Available: https://bit.ly/36vByi7.

A design for flexible electricity demand – PAS 1878/1879

- The EV charger can engage in two-way communications with a 'Demand Side Response Service Provider' (DSRSP)
  - E.g. an *aggregator*
- It can be bid into valuable (and lucrative) markets as flexible load/generation, including Dynamic Containment and the Balancing Mechanism
- But all the EV charger (and its owner) sees is a variable price of electricity

BSI Energy Smart Appliances Programme | https://bit.ly/3vnzzaO

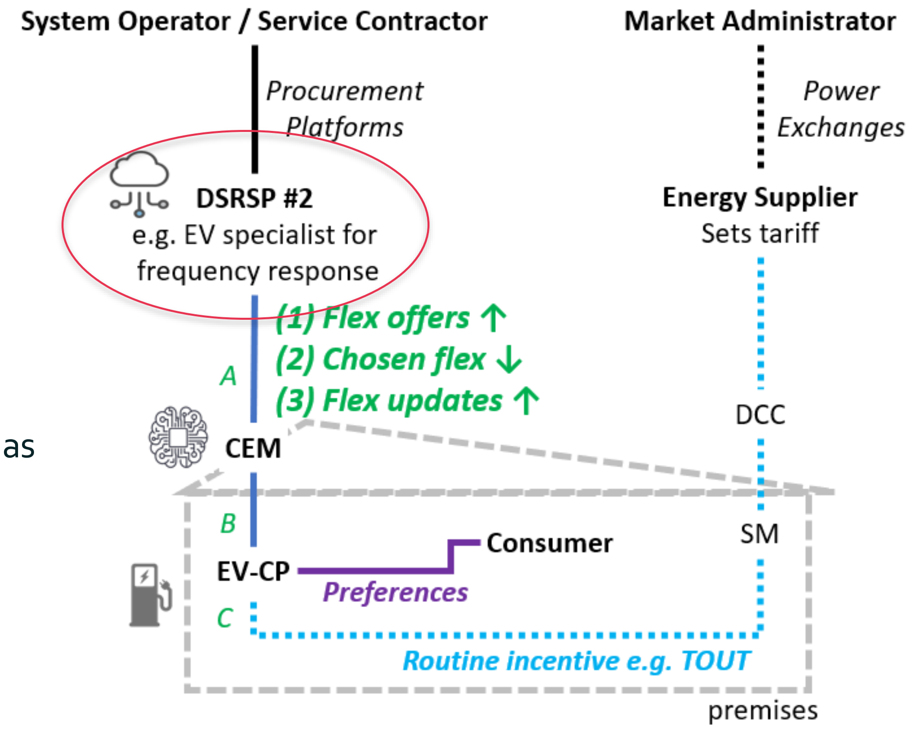
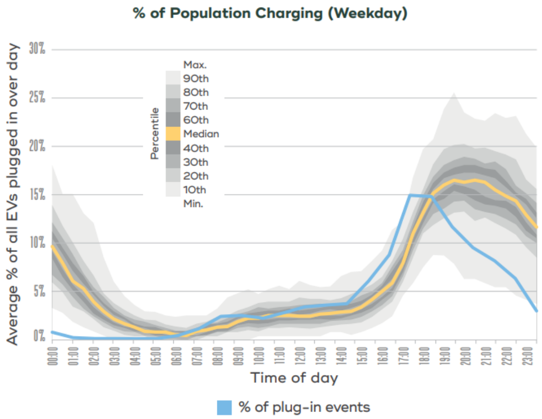
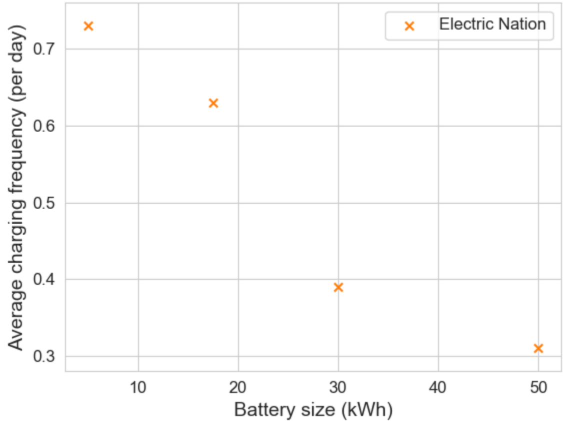


Diagram courtesy of Dr Nina Klein (BEIS) (https://www.youtube.com/watch?v=iSf259SP6ls&t=199s)

The problem

- V2G as a resource relies on vehicles being plugged in as often as possible
- Aggregators currently *don't know* how much resource you could expect from a fleet of EVs
- *Electric Nation (2016-2019)* found that drivers don't plug in every time they arrive home
- ***Plug-in frequency ↓ with battery size ↑***





https://www.electricnation.org.uk/wp-content/uploads/2019/07/Electric-Nation-Trial-Summary-A4.pdf

Research questions

1. How could EV driver charging 'behaviour' (plug-in frequency) affect the resource provided by V2G (and its contribution to electricity storage)?

2. Would drivers be effectively incentivised to plug-in more through a ToU tariff (making more use of cheap prices by being extra flexible)?

3. Is V2G worth it for the consumer, given UK tariffs and additional costs of degradation?

4. Is there sufficient correlation between CO_2 intensity and tariff that this could reduce the CO_2 intensity of charging?

Modelling how drivers might charge

“Minimal”

Drivers seek to *minimise* plug-ins

“Routine”

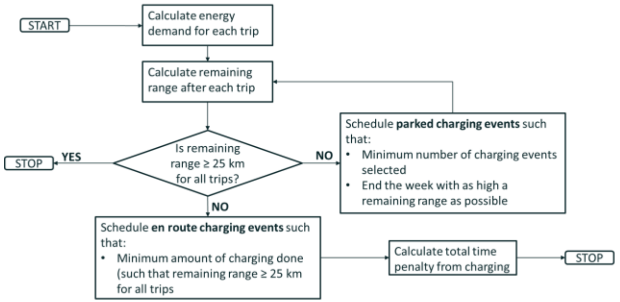
Drivers plug in *whenever they get home*

UK National Travel Survey (NTS) travel diaries

2002-2019 →
~150,000 7-day car-based travel diaries

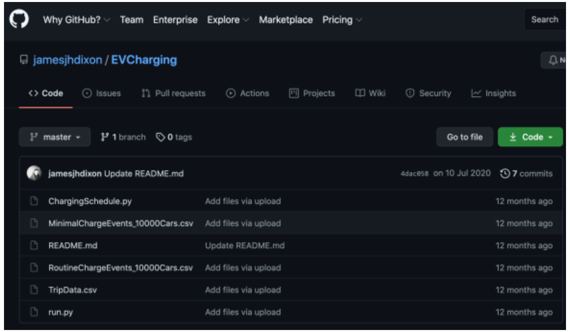
Algorithm

Charging schedules

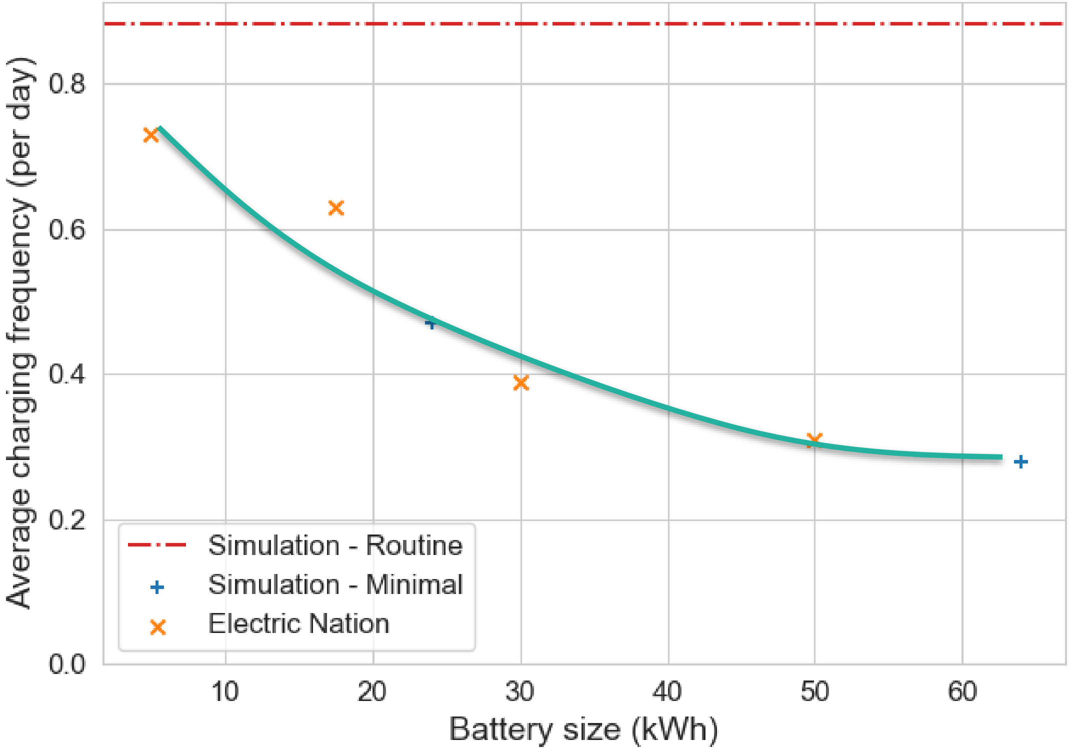


Dixon, J., Andersen, P. B., Bell, K., & Træholt, C. (2020). On the ease of being green: An investigation of the inconvenience of electric vehicle charging. *Applied Energy*, *258*. doi: 10.1016/j.apenergy.2019.114090

https://github.com/jamesjhdixon/EVCharging



Comparison of simulation and trial results



= arrivals at home per day

V2G modelling

min

$$\sum_{t\in\mathcal{T}}\sum_{e\in\mathcal{E}}(c_t^{\mathrm{imp}}p_{e,t}^{\mathrm{imp}} - c_t^{\mathrm{exp}}p_{e,t}^{\mathrm{exp}})\Delta t$$

s.t.

$$\sum_{g\in\mathcal{G}} p^{\mathrm{G}}_{g,t} = \sum_{e\in\mathcal{E}}(p^{\mathrm{imp}}_{e,t}-p^{\mathrm{exp}}_{e,t}) + \sum_{d\in\mathcal{D}} p^{\mathrm{D}}_{d,t} + \sum_{l\in\mathcal{L}} p^{\mathrm{L}}_{l,t}$$

$$p^{\mathrm{L}}_{l,t} = -\mathrm{B}_l\left(\delta_{b,t}-\delta_{b',t}\right)$$

$$-\mathrm{S}_l^{\mathrm{max}} \le p^{\mathrm{L}}_{l,t} \le \mathrm{S}_l^{\mathrm{max}}$$

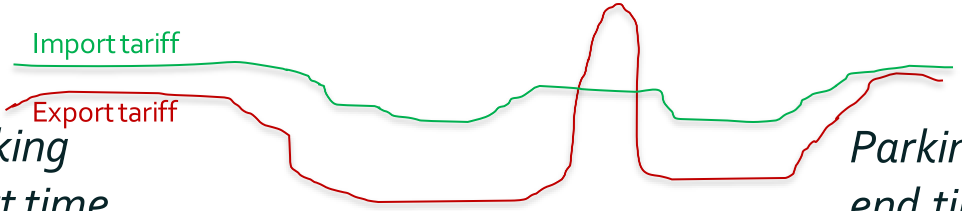
$$E_{e,t} = (\eta p^{\mathrm{imp}}_{e,t} - \frac{1}{\eta}p^{\mathrm{exp}}_{e,t})\Delta t + E_{e,t-1}$$

$$E_{e,\mathrm{t}_e^{\mathrm{out}}} \ge \mathrm{E}_e^{\mathrm{end}}$$

$$0 \le E_{e,t} \le \mathrm{E}_e^{\mathrm{max}}$$

$$p^{\mathrm{imp}}_{e,t} \le \begin{cases} \mathrm{P}_e^{\mathrm{max}}, & \sigma_{e,t} \le \gamma_e \\ \left(\dfrac{1-\sigma_{e,t}}{1-\gamma_e}\right)\mathrm{P}_e^{\mathrm{max}}, & \sigma_{e,t} > \gamma_e \end{cases}$$

$$p^{\mathrm{exp}}_{e,t} \le \mathrm{P}_e^{\mathrm{max}}$$



Parking start time

Parking end time

Charger rating (kW)

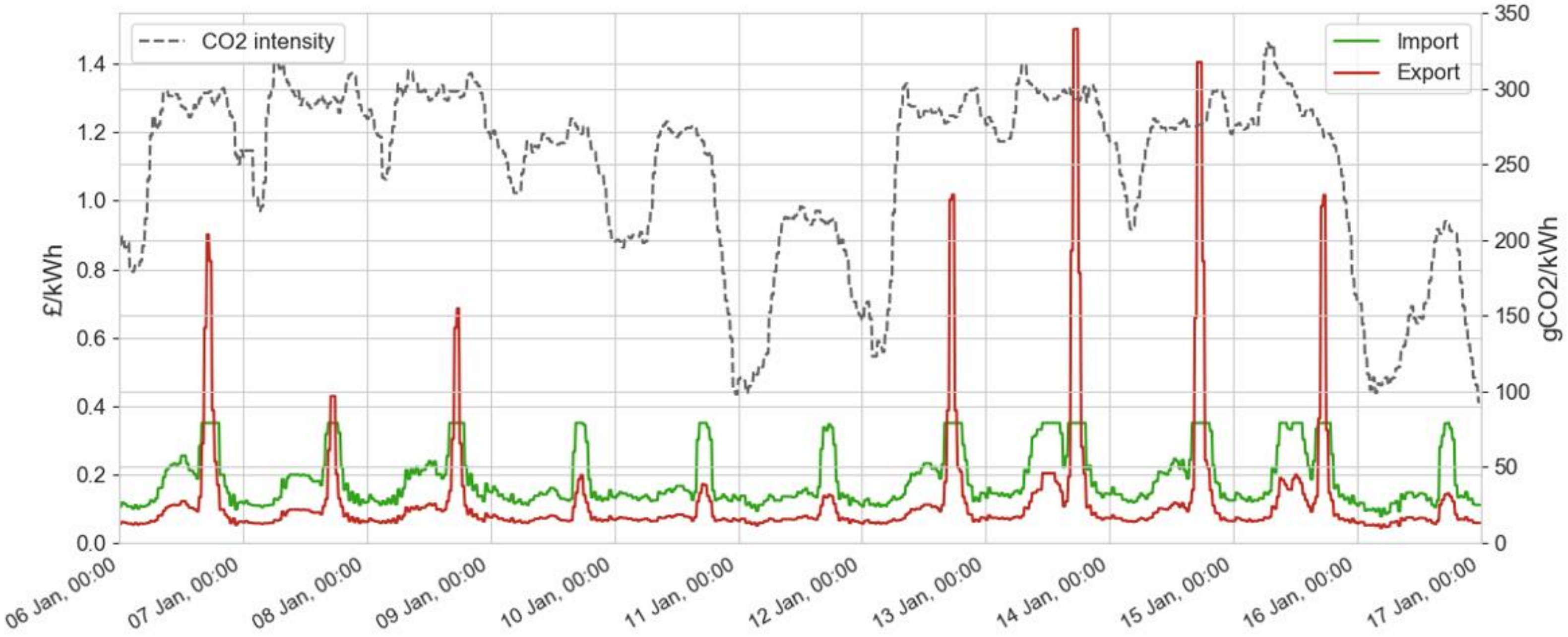
Required energy delivery (kWh)

Satisfy energy/power constraints at minimum net cost

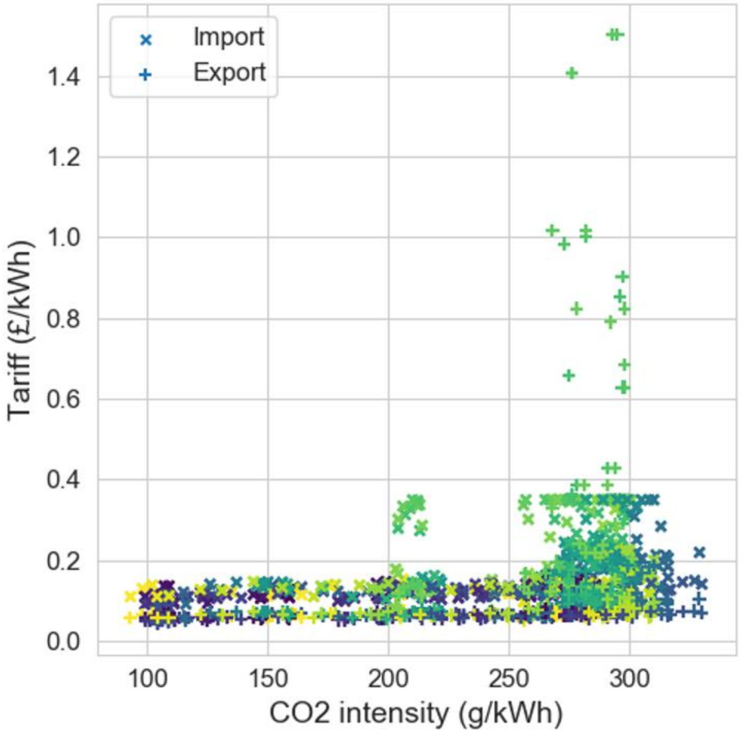
Network constraints

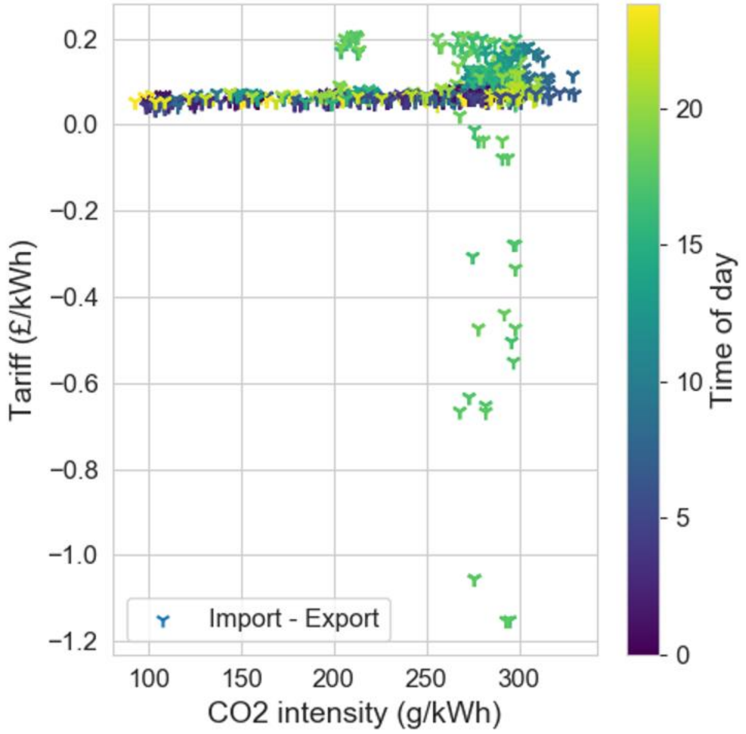
Glasgow Southside network

Octopus *Agile* Tariff, January 2021

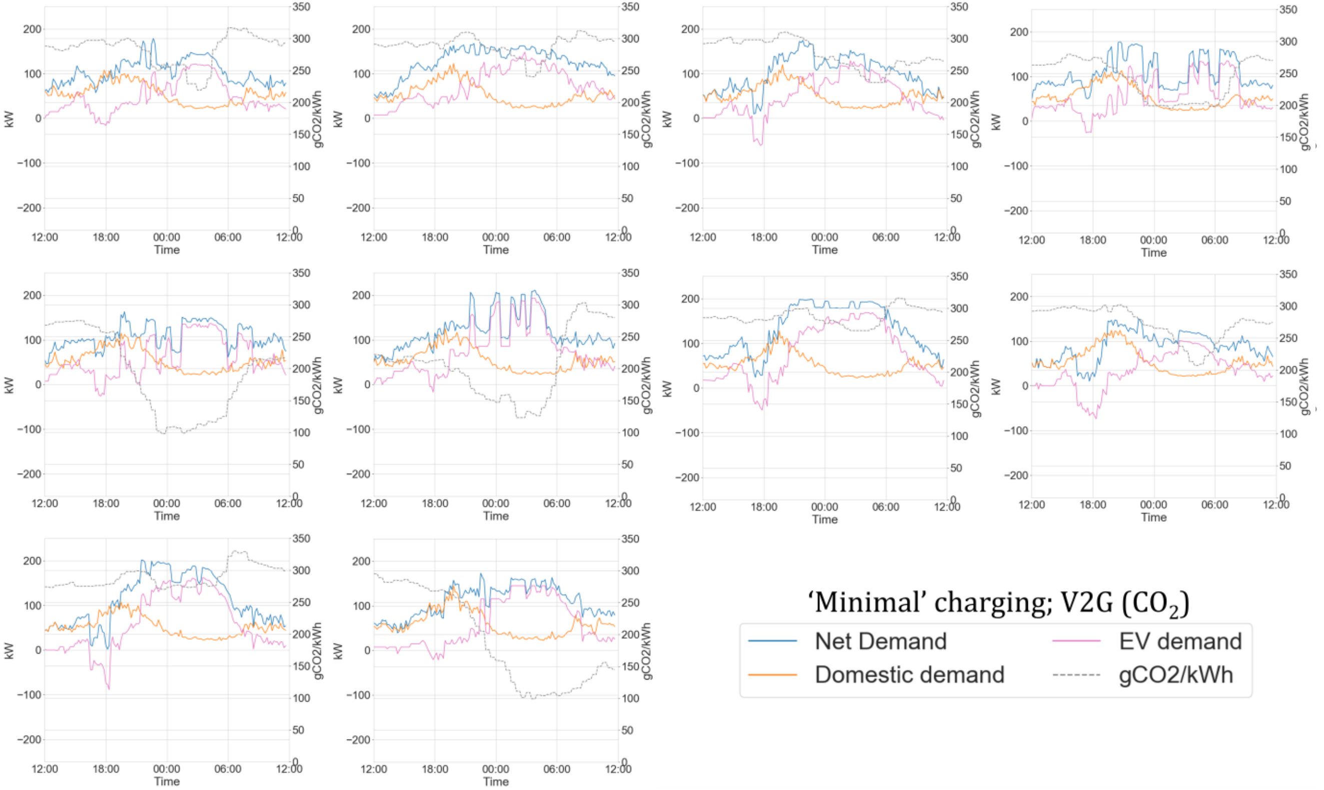


Price and CO_2 intensity



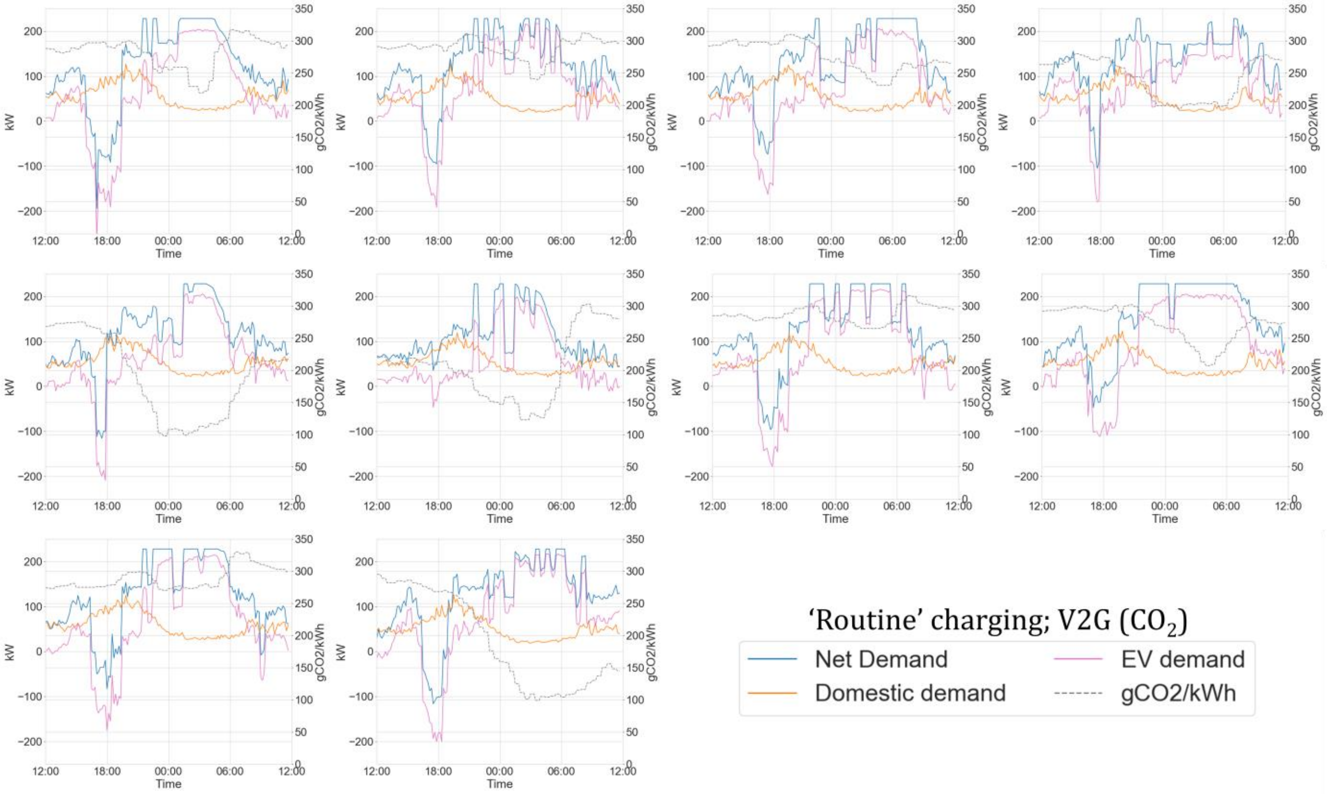


Network flows (Minimal charging)



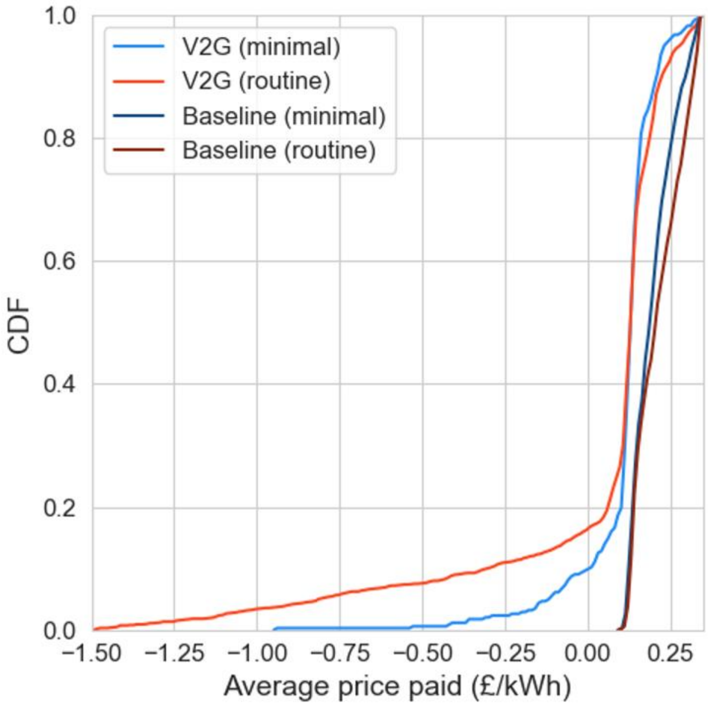
- Uncontrolled charging: consistent evening peak; increasing ADMD by ~2-3x
- V2G: network constraints respected; steep changes in power

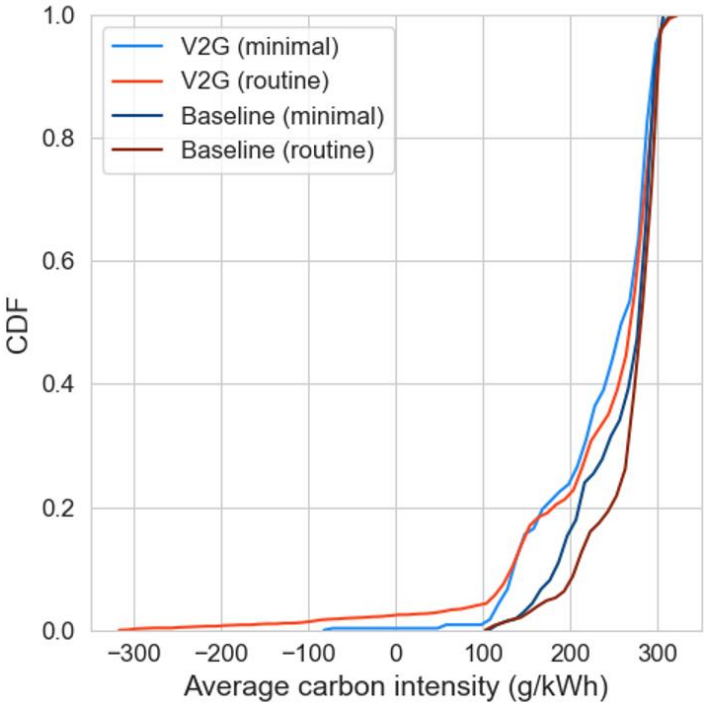
Network flows (Routine charging)



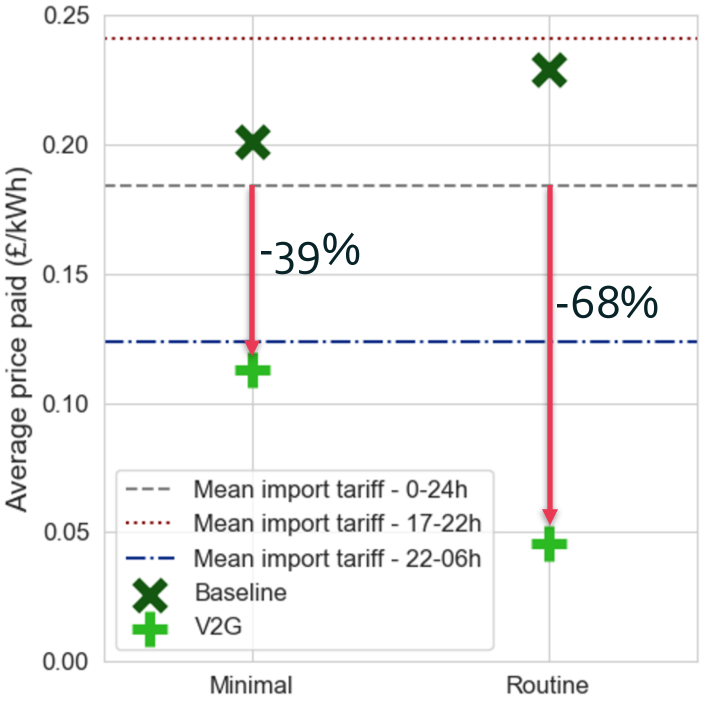
- Uncontrolled charging: consistent evening peak; increasing ADMD by ~3-3.5x
- V2G: higher rates of export, higher rates of import: more flexible resource is 'used' more

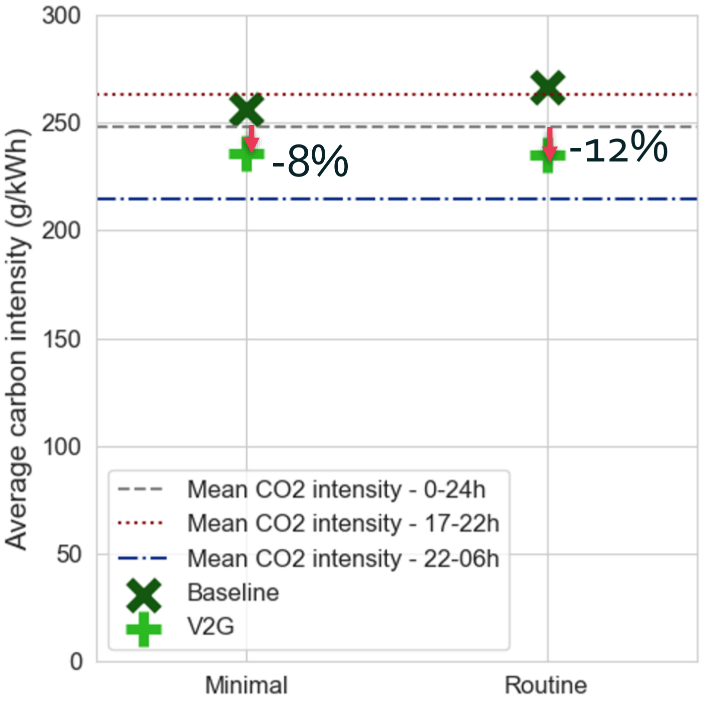
Price paid and carbon intensity



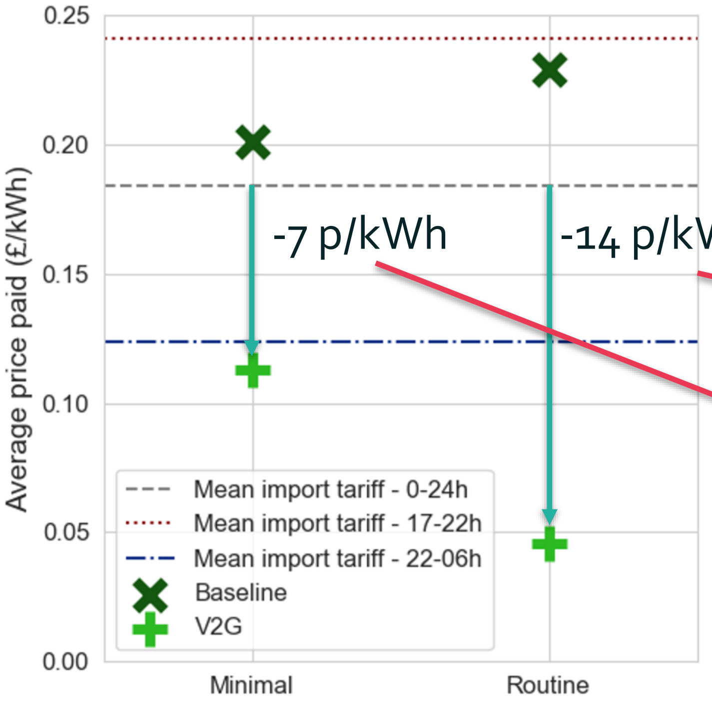


Mean price paid and carbon intensity



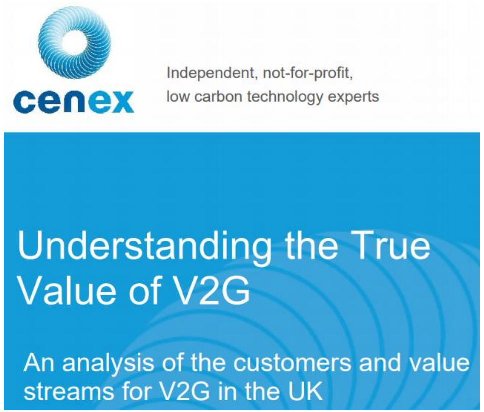


Is it worth it?



-7 p/kWh

-14 p/kWh



Degradation cost from V2G = 3-9 p/kWh

Savings = -2-4p/kWh

Savings = 5-11p/kWh

12,000 km/yr

-£43 - £86/year

£108 - £238/year

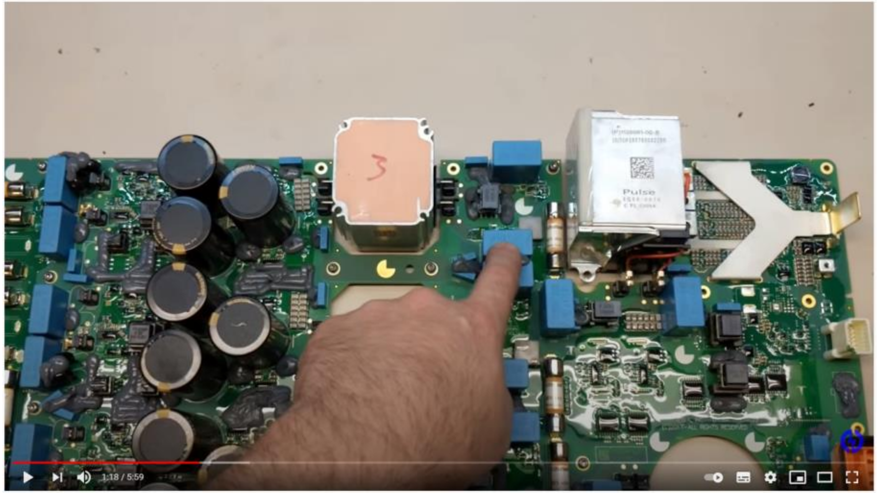
Cenex, "Understanding the True Value of V2G," , 2019. [Online]. Available: http://bit.ly/2MWwNpk

Policy implications; barriers

- There are currently no EVs on the market that are capable of *exporting* through their AC/DC converter (the converters are uni-directional)

- This means that in order to *do* V2G, you have to buy a ~£5k+ V2G charger (an AC/DC converter for your driveway)

- By switching to bidirectional converters, there would be a significant cost saving and this barrier to V2G would be removed



OAKLEY
Tesla vehicle to grid: Debunked!

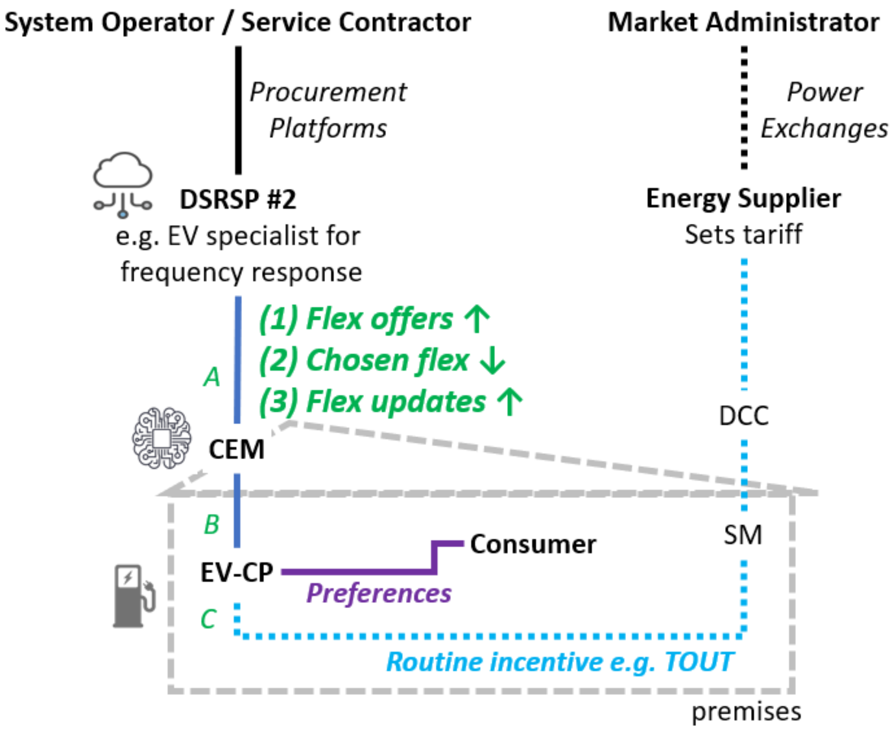
https://www.youtube.com/watch?v=lXokJEzXwaI&t=20s

- Policy: why are vehicle manufacturers not including functionality for bidirectional charging?

- What can be done to incentivise them to do so?

Watch this space?

- Load controllers (DSRSPs; aggregators) need confidence in how much resource they have from a fleet of distributed EVs
- Customers need to know what the implications are for their participation in these services
- Architectures for residential electricity demand flexibility need to become reality, so that lots of low-cost resource for rapid system decarbonisation can be realised



Thanks for listening!

- Questions?