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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Abatement in surface transport

Sources of abatement, surface transport (2050)

- Cars - zero-emission vehicles: 49%
- Vans - zero-emission vehicles: 19%
- HGVs - zero-emission vehicles: 10%
- Other - zero-emission vehicles: 18%
- Reducing demand: 4%

V2G – a game changer?

- Battery capacity: 40 kWh
- Needed for driving: 6 kWh/day
- Going spare?: 34 kWh/day

\[\text{Storage (energy) resource of } 34 \times 10^3 \times 31 \times 10^6 = 1.05 \text{TWh}\]

- 31 million vehicles

\[\text{Storage (power) resource of } 7 \times 10^3 \times 31 \times 10^6 = 217 \text{ GW}\]

- 31 million vehicles

Weekly driving distance, UK National Travel Survey 2019
How much electricity storage do we need?

Energy: 1050 GWh
Power: 217 GW

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)

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

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

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 CO₂ intensity and tariff that this could reduce the CO₂ 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


https://github.com/jamesjhdixon/EVCharging
Comparison of simulation and trial results

![Graph showing comparison of simulation and trial results. The x-axis represents battery size (kWh), and the y-axis represents average charging frequency (per day). The graph includes data from Simulation - Routine, Simulation - Minimal, and Electric Nation.]
V2G modelling

$$\min \sum_{t \in T} \sum_{e \in E} (c_{e,t}^{\text{imp}} p_{e,t}^{\text{imp}} - c_{e,t}^{\text{exp}} p_{e,t}^{\text{exp}}) \Delta t$$

s.t. \n\n$$p_{g,t}^{\text{G}} = \sum_{e \in E} (p_{e,t}^{\text{imp}} - p_{e,t}^{\text{exp}}) + \sum_{d \in D} p_{d,t}^{\text{D}} + \sum_{e \in E} p_{e,t}^{\text{L}}$$

$$p_{L,t}^{\text{L}} = B_{t} (\delta_{b,t} - \delta_{y,t})$$

$$-S_{t}^{\text{max}} \leq p_{L,t}^{\text{L}} \leq S_{t}^{\text{max}}$$

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

$$E_{e,\text{cost}} \geq E_{e,\text{end}}$$

$$0 \leq E_{e,t} \leq E_{e}^{\text{max}}$$

$$p_{e,t}^{\text{imp}} \leq \begin{cases} p_{e}^{\text{max}}, & \sigma_{e,t} \leq \gamma_{e} \\ \frac{1 - \sigma_{e,t}}{1 - \gamma_{e}} p_{e}^{\text{max}}, & \sigma_{e,t} > \gamma_{e} \end{cases}$$

$$p_{e,t}^{\text{exp}} \leq p_{e}^{\text{max}}$$

Satisfy energy/power constraints at minimum net cost

Charger rating (kW)

Required energy delivery (kWh)

Network constraints

Glasgow Southside network

Satisfy energy/power constraints at minimum net cost
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

‘Minimal’ charging; V2G (CO₂)

- Net Demand
- EV demand
- Domestic demand
- gCO2/kWh
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

-39%

-68%

-8%

-12%
Is it worth it?

Degradation cost from V2G = 3-9 p/kWh

Savings = -2-4p/kWh

12,000 km/yr

-£43 - £86/year

Savings = 5-11p/kWh

£108 - £238/year

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

https://www.youtube.com/watch?v=lXokJEzXwal&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?