Electric Vehicle Destination Charging Demand Characterisations at Popular Amenities using Smartphone GPS Data

James Dixon
University of Strathclyde, Glasgow
james.dixon@strath.ac.uk

15 October 2018
E-Mobility Integration Symposium
KTH, Stockholm

Electric Vehicle Charging

A question of *energy*

- Cars in Britain drove 408 billion km in 2017
- Typical energy consumption ~18 kWh/100 km
- 100% private transport electrification -> ~73 TWh of generation (22% more than last year)

A question of *power*

- This is much more uncertain…
- When will people charge?
- Where will people charge?
- How will people charge?

The Future of EV Charging?

University of Strathclyde Engineering

- Most of the academic literature to date has focussed on a predominantly domestic-based EV charging system

- ***Is this realistic?***

Lack of off-street parking

Lack of *range confidence*

Changing car ownership

Four Types of Charging

University of Strathclyde Engineering

Rapid

- Power > 50 kW
- Charging window < 20 mins

Destination

- Power 10-50 kW
- Charging window 20 mins – 3 hours

Workplace

- Power < 20 kW
- Charging window 3 – 9 hours

Domestic

- Power < 10 kW
- Charging window > 9 hours

LESS FLEXIBLE → MORE FLEXIBLE

HIGH POWER ← LOW POWER

Human Behaviour

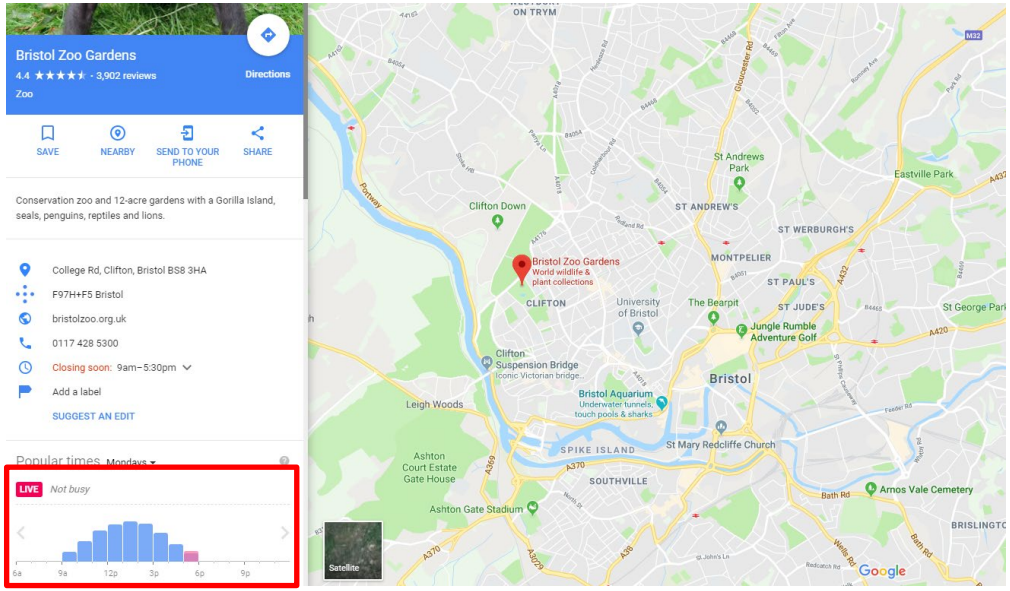
- Widespread EV uptake hasn't happened yet
- It's difficult to predict how people will behave
- Most of the work to date is based on surveys, which represents peoples' *perception* of their behaviour

GPS Data – Google Maps Popular Times

- Collected from Smartphone users with the Google Maps application (and location history enabled)
- Hourly popularity (= occupancy) (%) data based on ‘peak popularity’ for a given day of the week

+

- Captures users’ actual movement patterns
- Constantly changing
- ‘Sample size’ is potentially very large

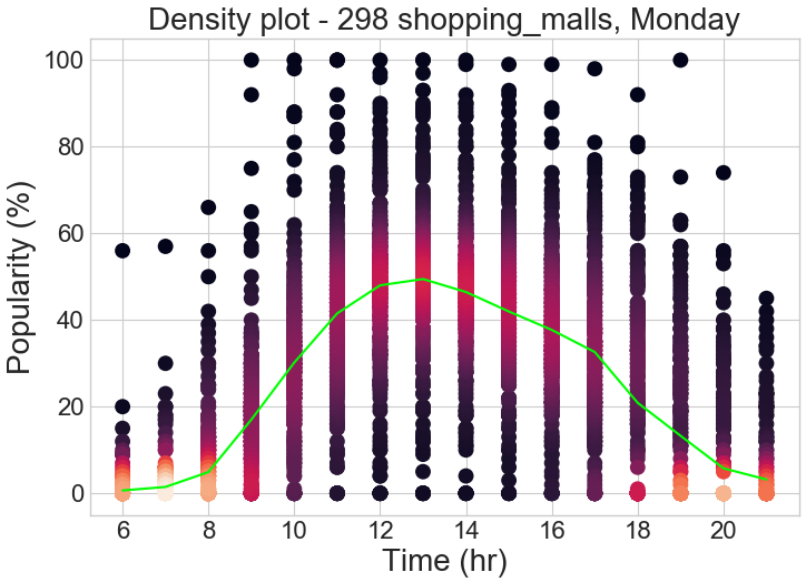


-

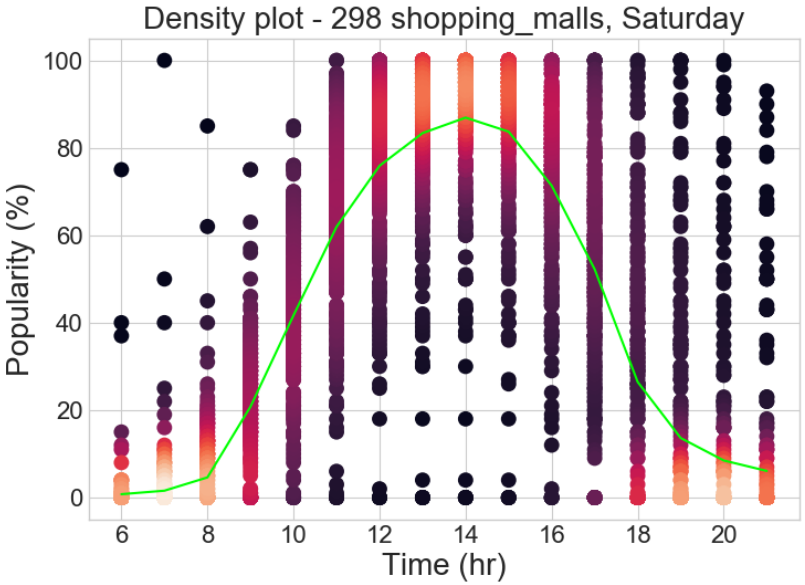
- No absolute numbers
- No seasonal variation
- Selection bias?

Popular Times data – Shopping Centres

MONDAY

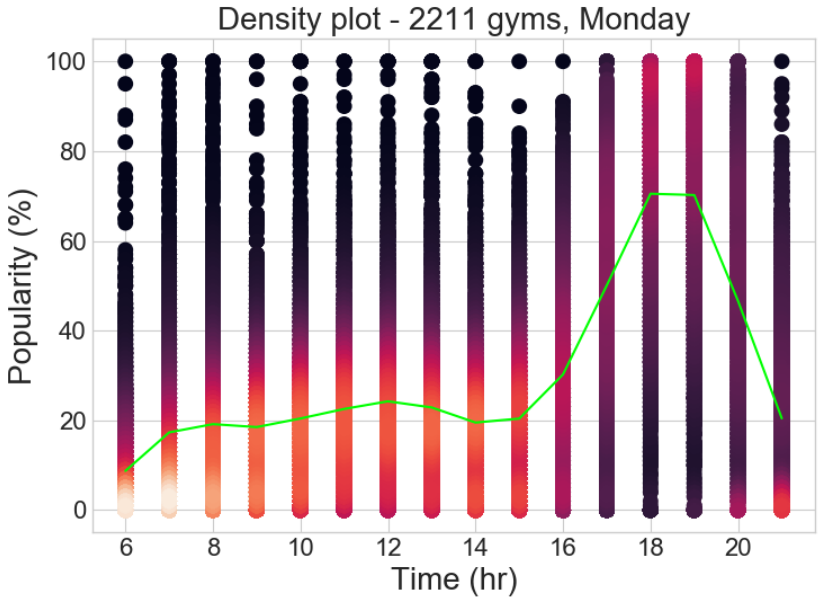


SATURDAY

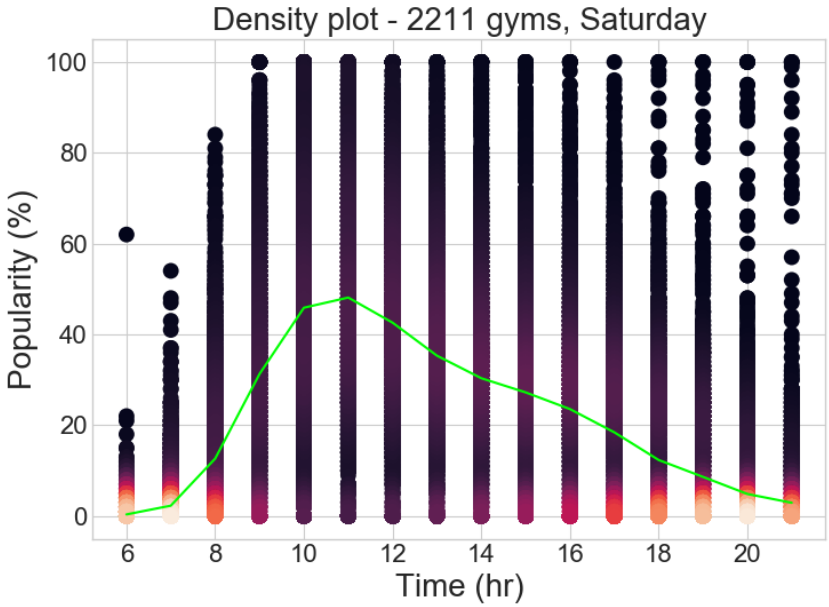


Popular Times data – Gyms

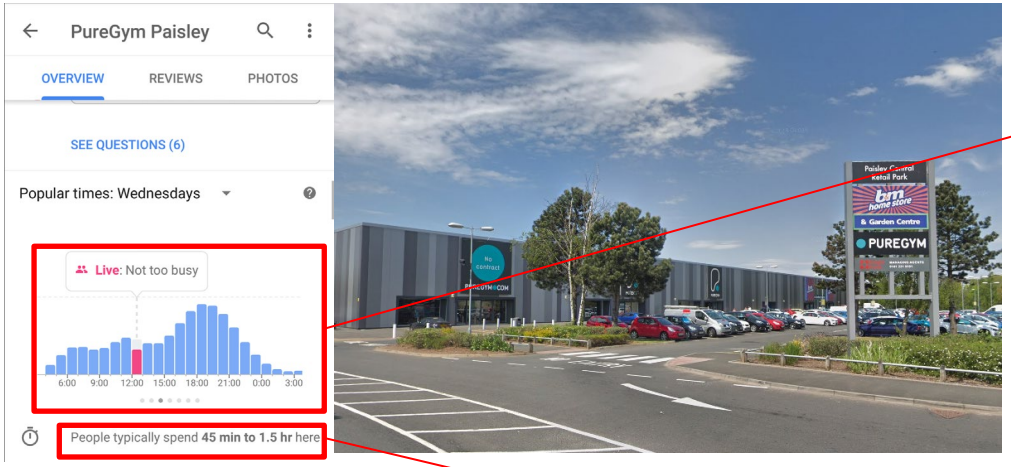
MONDAY



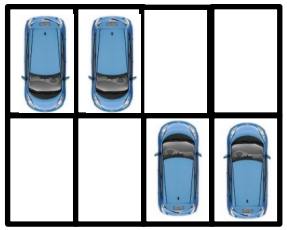
SATURDAY



Using the Data – Arrivals Profile



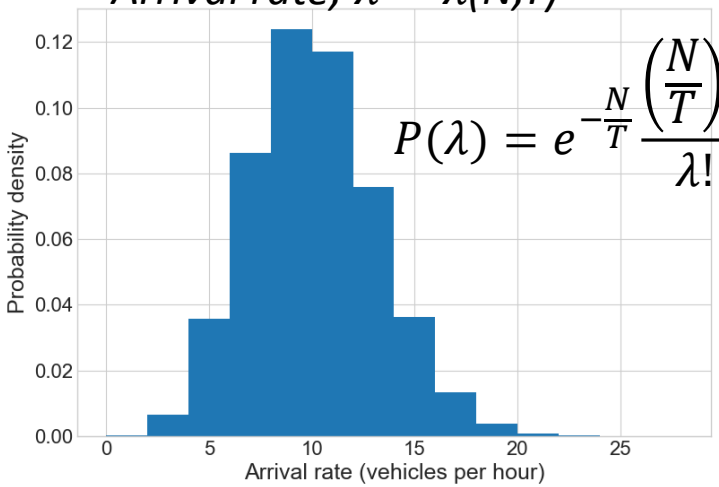
Occupancy, N



How busy would the EV charging facility be at this hour?

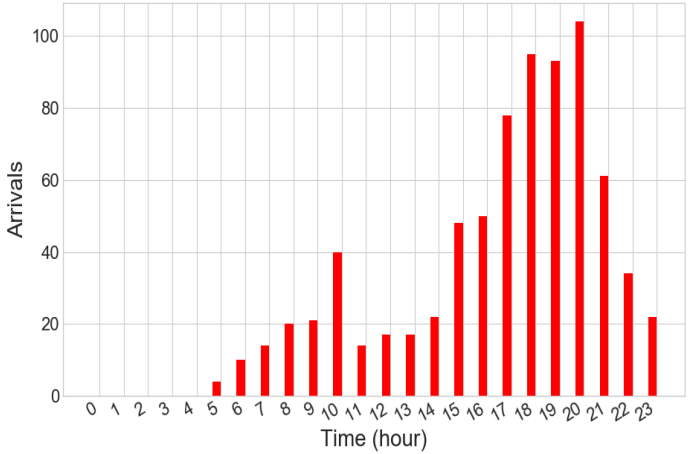
Mean visit duration, T

Arrival rate, $\lambda = \lambda(N,T)$



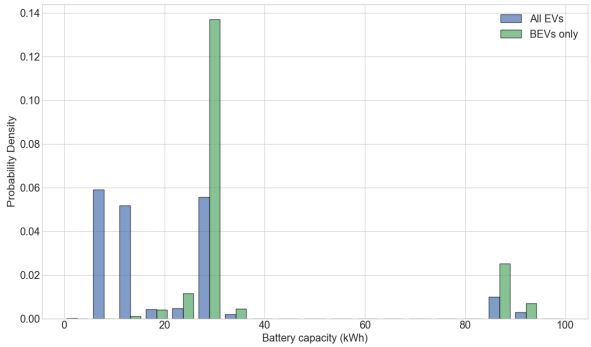
$$P(\lambda) = e^{-\frac{N}{T}} \frac{\left(\frac{N}{T}\right)^{\lambda}}{\lambda!}$$

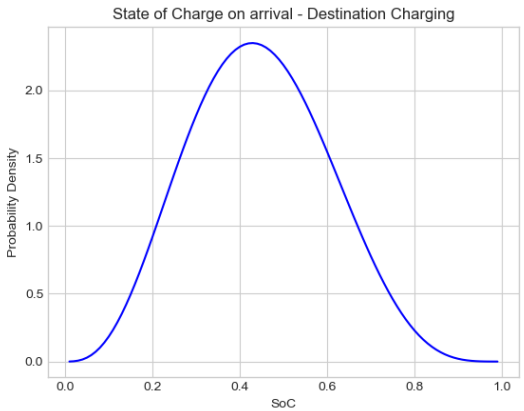
Arrivals Profile

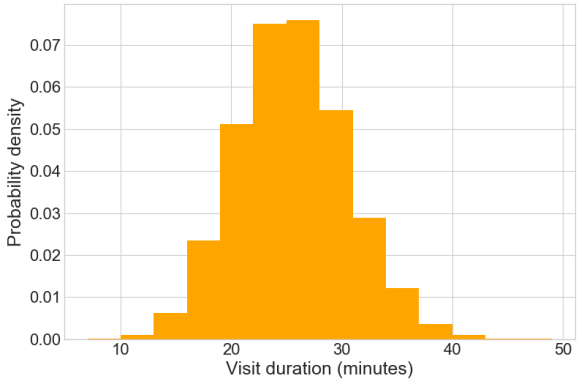


Charging Car Park Simulator – New Arrivals

UK EV Sales, 2017[1]







Battery capacity (kWh)

Battery State of Charge on arrival (%)

Visit duration (mins)

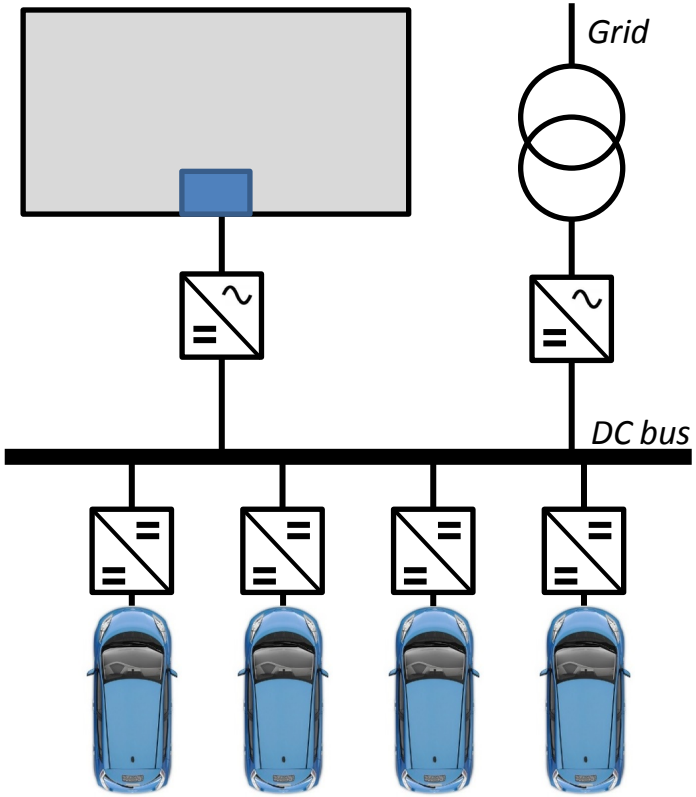
Power rating per charger

Number of spaces

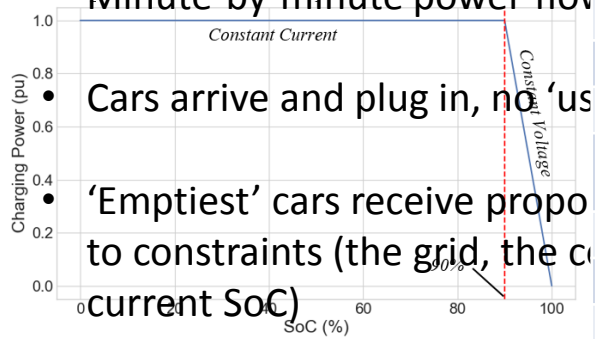
Grid import capacity

[1] RAC Foundation, "Plug-in grant eligible vehicles licensed," 2017. [Online]. Available: https://goo.gl/ZnR1fZ.

‘Simple-Smart’ Charging Algorithm



Li-Ion battery charging profile[2]



In English:

- Minute-by-minute power flow
- Cars arrive and plug in, no ‘us
- ‘Emptiest’ cars receive propo to constraints (the grid, the c current SoC)

Symbol	Parameter
TER_j	Total Energy Requirement at j^{th} minute
n_j	Car park occupancy at j^{th} minute
SoC_{ij}	State of Charge of ith car at j^{th} minute
C_i	Battery capacity of ith car
PCR_{ij}	Potential Charge Rate of ith car at j^{th} minute
P_G	Grid capacity
P_C	Converter capacity
P_{Bij}	Battery charge limit
P_{EV}	EV charge rate capacity

In Maths:

1) Find Total Energy Requirement of car park

$$TER_j = \sum_{i}^{n_j} (1 - SoC_{ij}) \cdot C_i$$

2) Establish ‘Potential Charge Rate’ of each vehicle

$$PCR_{ij} = \frac{(1 - SoC_{ij}) \cdot C_i}{TER_j} \cdot P_G$$

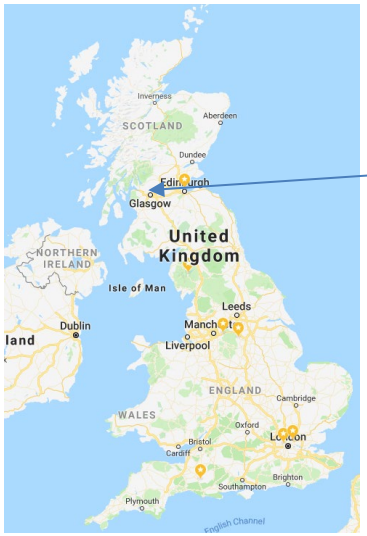
3) Charge Rate of each vehicle is the minimum of the PCR and any constraints

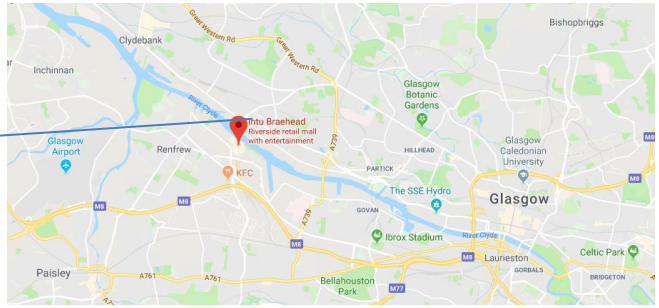
$$CR_{ij} = min(PCR_{ij}, P_{B_{ij}}, P_C, P_{EV})$$

[2] M. Tabari and A. Yazdani, “An Energy Management Strategy for a DC Distribution System for Power System Integration of Plug-In Electric Vehicles,” *IEEE Trans. Smart Grid*, vol. 7, no. 2, pp. 659–668, 2016

Case Study 1: Braehead Shopping Centre

- Large indoor shopping/ entertainment complex ~10 km west of Glasgow, Scotland
- 6,500 car parking spaces
- Close to M8 motorway
- Potential location for large, transmission-connected EV charging car park

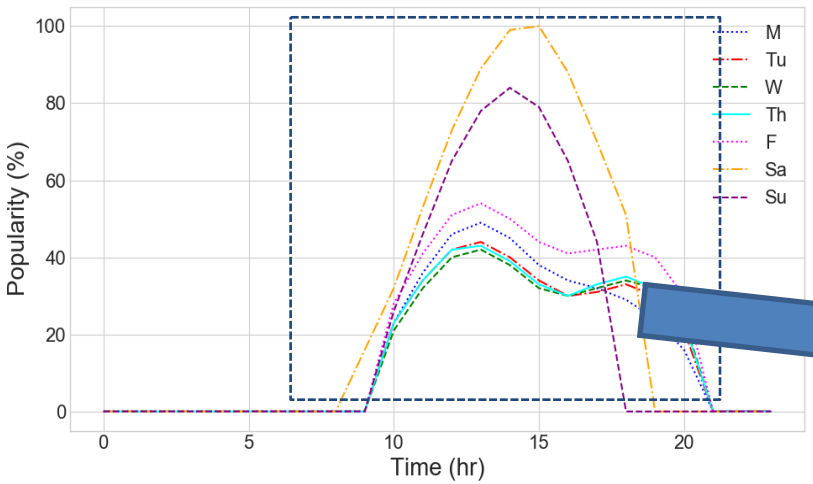




Case Study 1: Braehead Shopping Centre

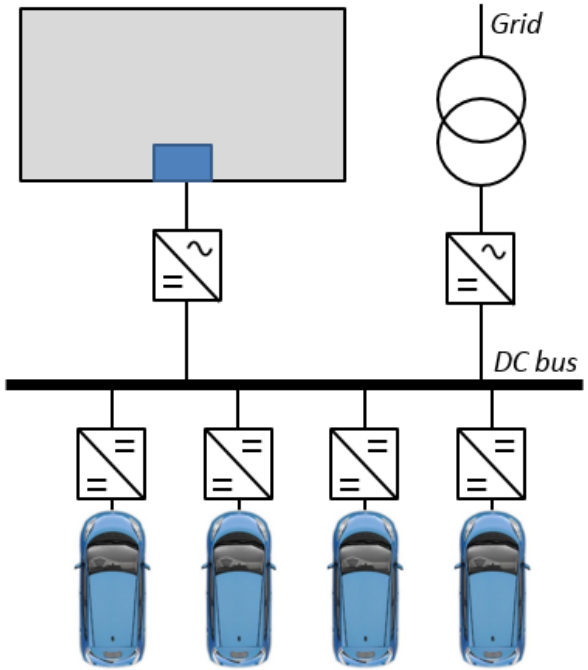
University of Strathclyde Engineering

Popular Times data



Destination charging simulation

- 6,500 spaces
- Average time spent = 134 minutes[3]



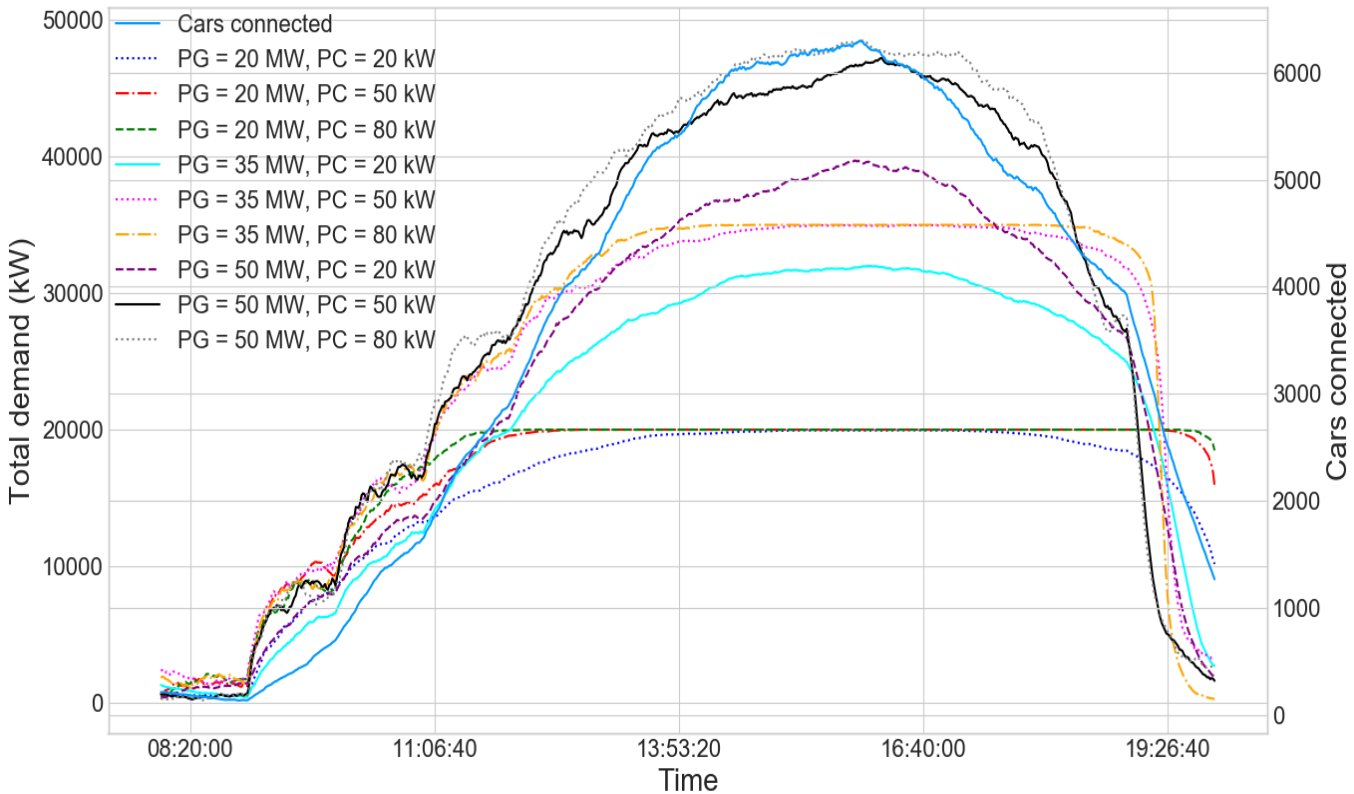
Variable car park parameters

Parameter	Low	Medium	High
Grid capacity, P_G	20 MW	35 MW	50 MW
Converter capacity, P_C	20 kW	50 kW	80 kW

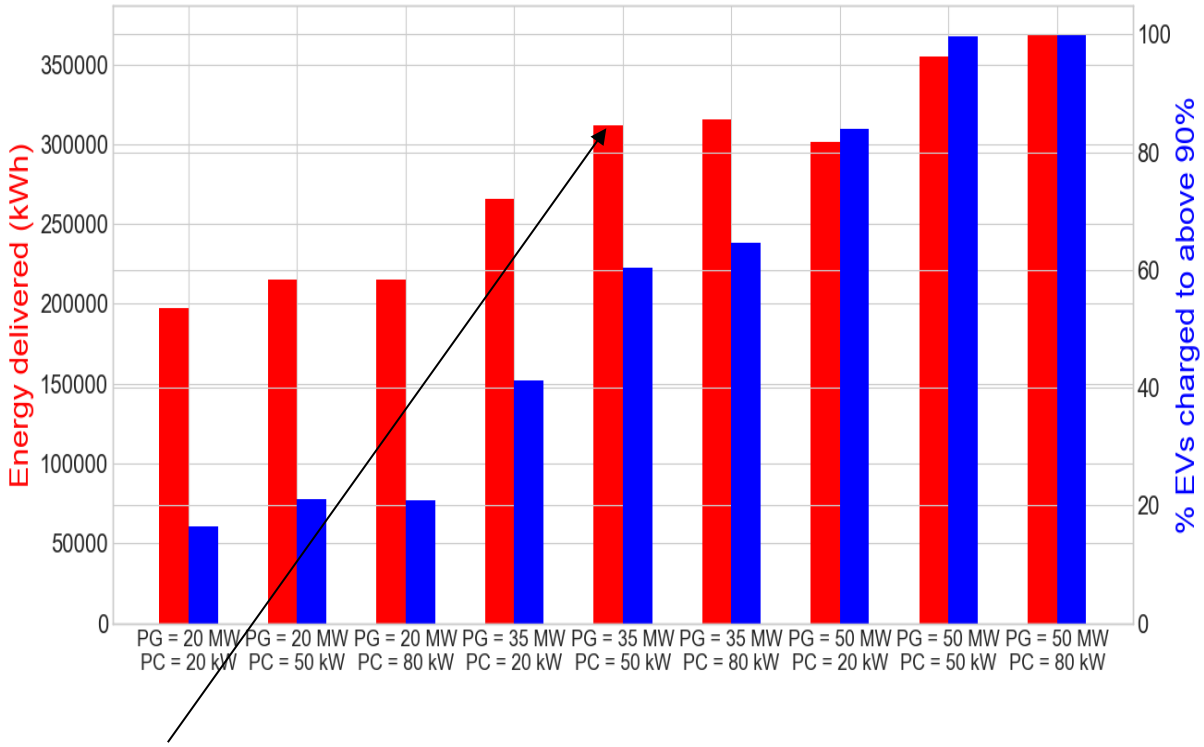
[3] Intu Braehead, "Corporate Strategy Overview." [Online]. Available: https://goo.gl/rviMoG.

Braehead – Expected Demand Profile

Expected demand profile for varying P_G, P_C



Braehead – Service Provision

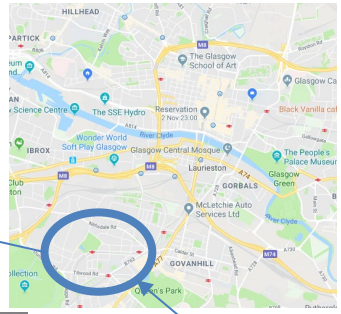


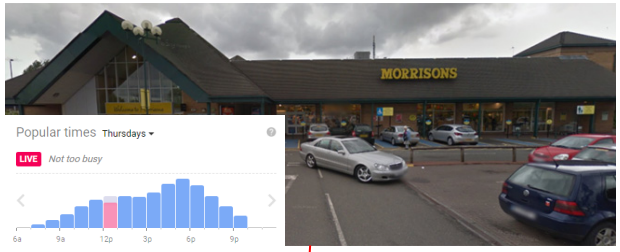
(How much service does the charging station operator *want* to provide?)

- Assume that we can buy electricity at ~11 p/kWh[4] and sell at 20 p/kWh (i.e. matching Ecotricity charge points)
- 300,000 kWh @ 9 p/kWh = £27k (Saturday)
- Saturday footfall ~ 21% of weekly footfall (from Popular Times data)
- →expected revenues ~ **£6.7m/year**

[4] Department for Business Energy & Industrial Strategy, "Gas and electricity prices in the non-domestic sector," 2018. [Online]. Available: https://goo.gl/u4rJXv..

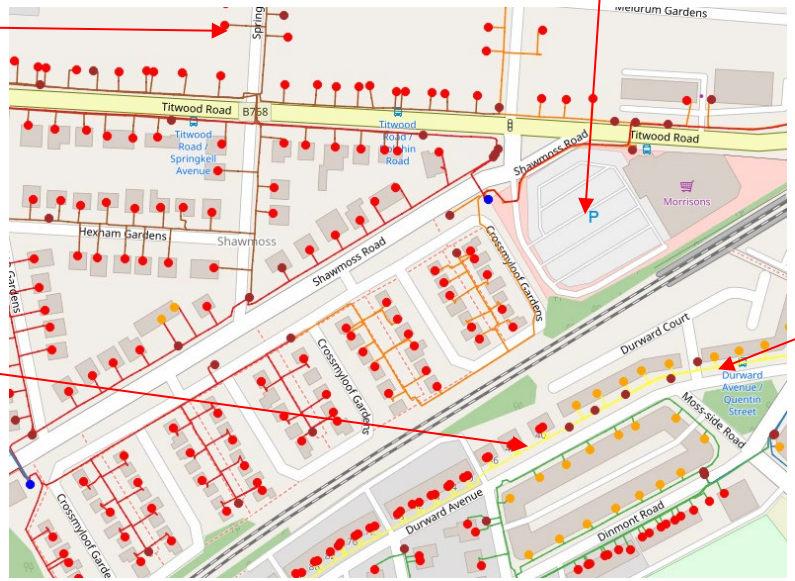
Case Study 2: Glasgow Southside Supermarket



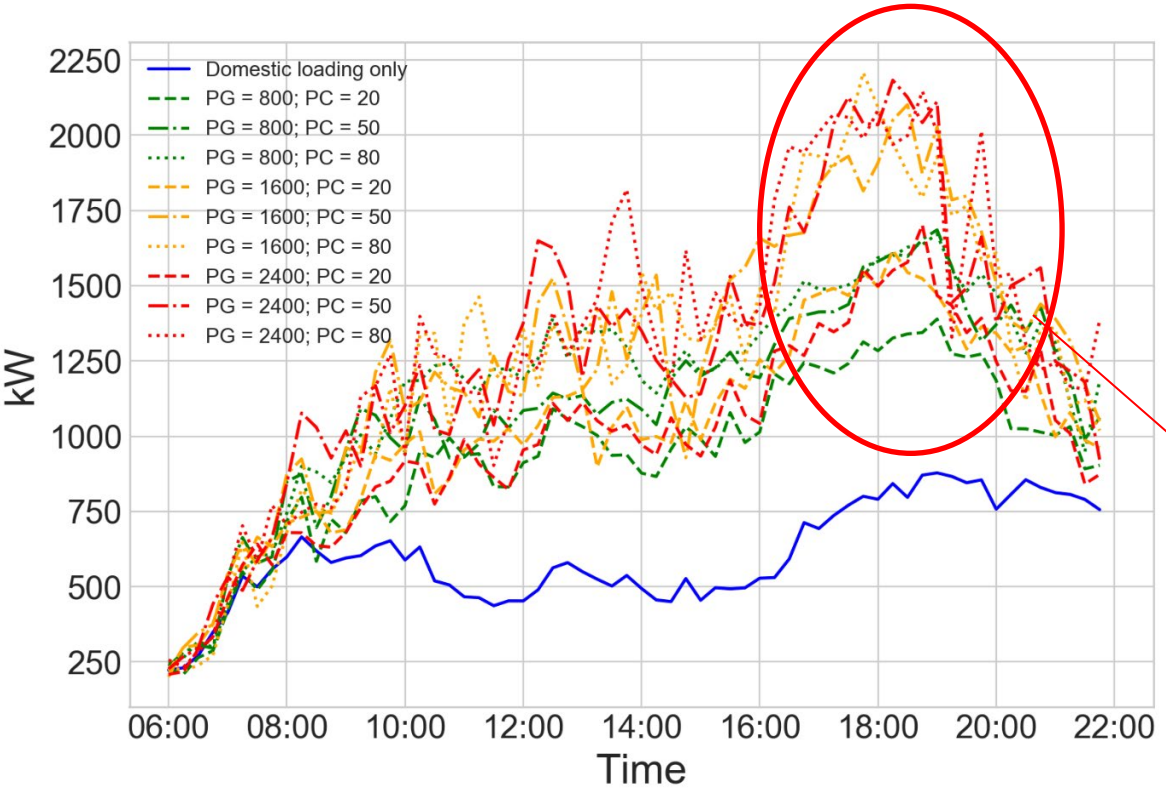


- 50 charging stations
- Variable grid connection and converter capacity

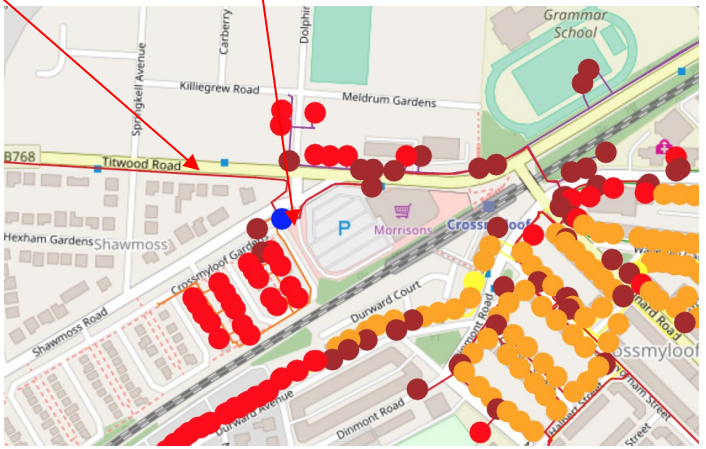
Distribution network assets – GIS data



Glasgow Southside Supermarket – Line Loading

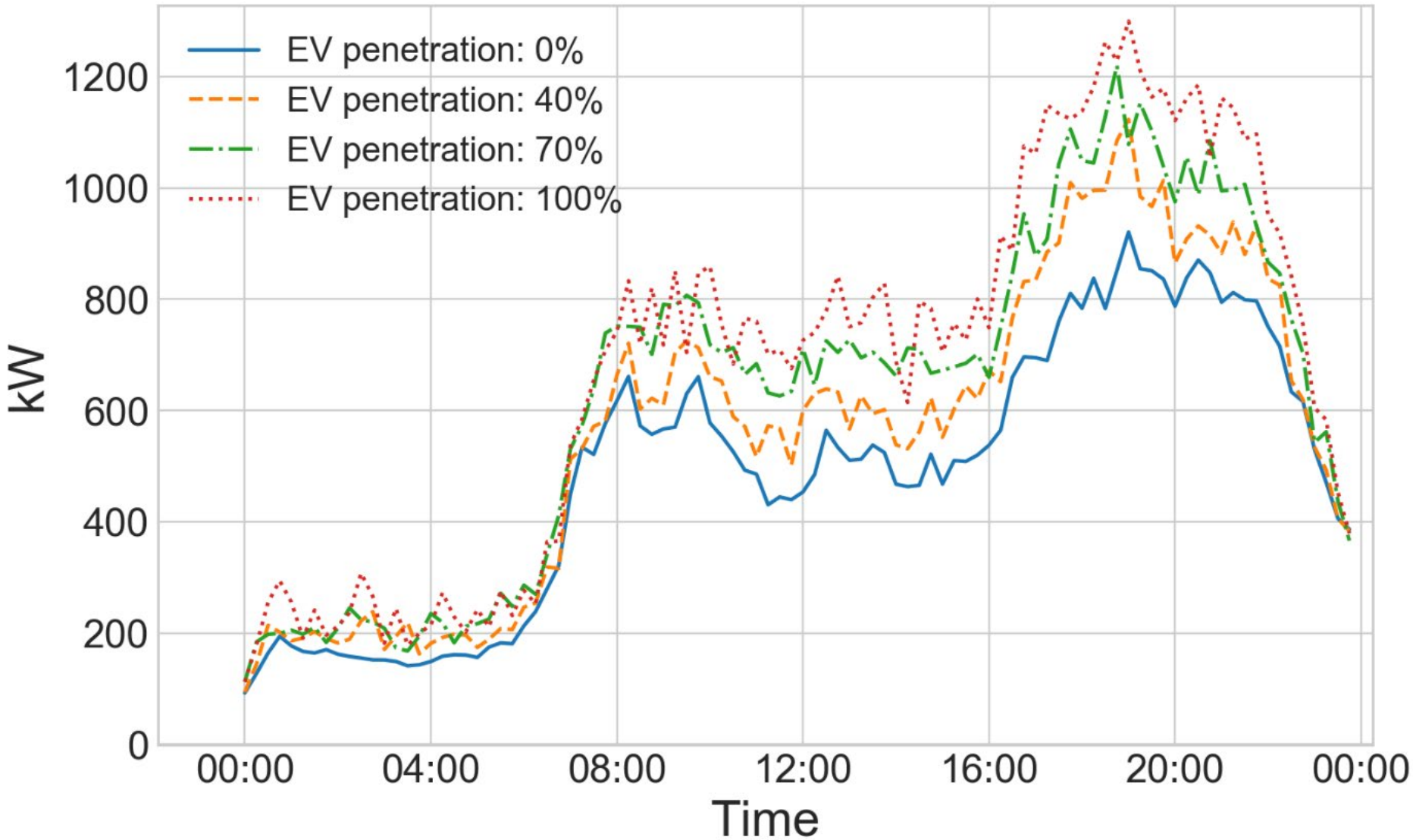


11 kV feeder from primary to secondary substation (blue dot)

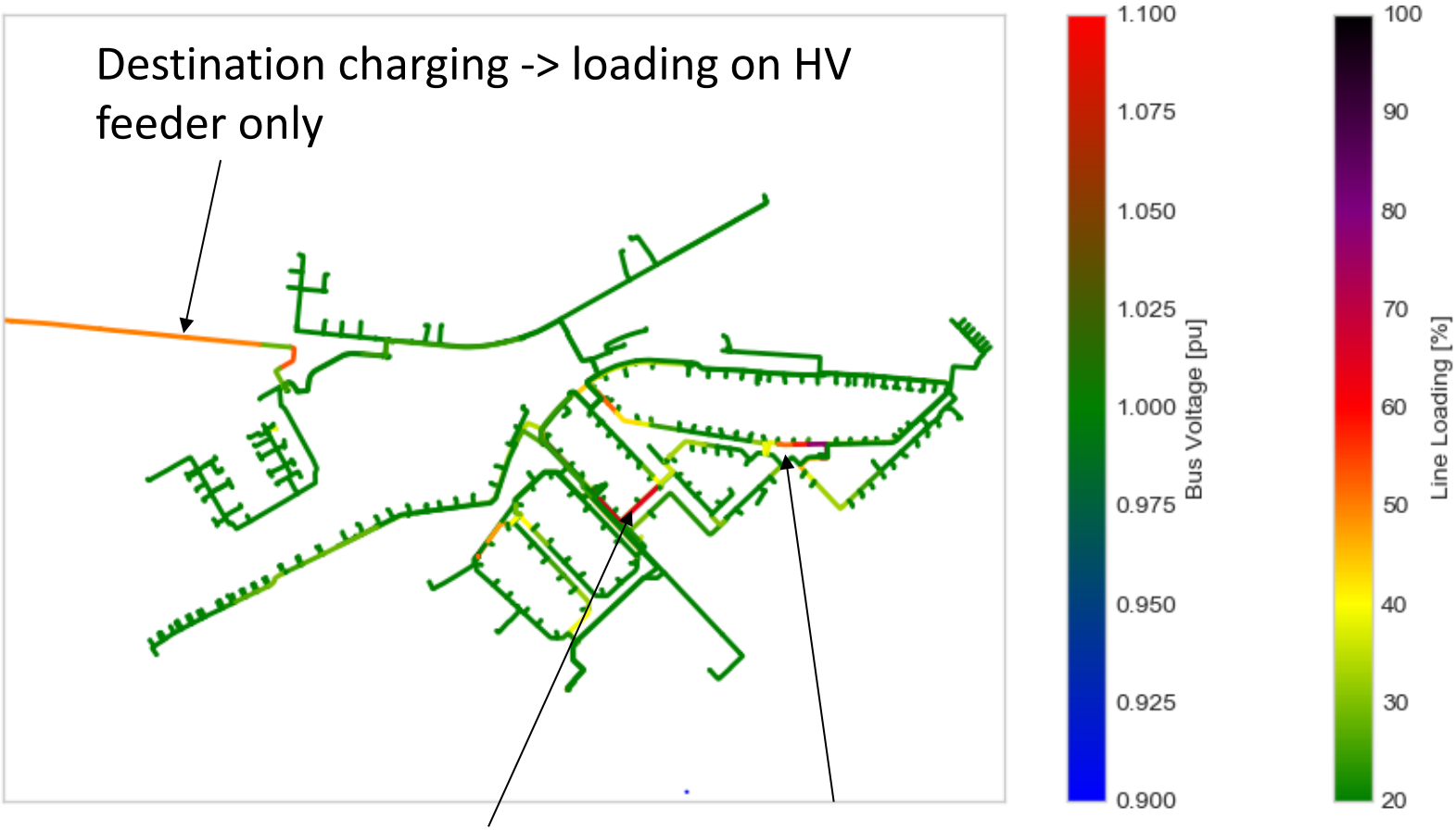


Charging infrastructure connected to dedicated secondary substation straight to 11 kV network

Comparison – Domestic Charging



- Load flow simulation @ peak EV load (18:45)
- 70% domestic EV penetration *and* 1600/50 kW charging car park



Domestic charging -> local voltage and loading issues

Interesting Questions

University of Strathclyde Engineering

- How do these charging types interact with one another?
- Given a total ‘energy budget’, what’s the best way of providing an EV charging system for a fleet of EVs?
- What *should* the future EV charging system look like?
- Are there opportunities for ‘smart grid’ technologies to play a part in making this easier?
  - Demand side management (AKA ‘smart charging’)
  - Dynamic tariffs??
  - Distribution-level interconnection (RC switching, soft open points)
  - Storage (stationary, or the vehicle itself?)

Some Conclusions

University of Strathclyde Engineering

- Destination charging could be a key part of EV charging infrastructure
- Charging load is likely to vary significantly based on where it is
- This method can be used to look at the **temporal variation** in demand between charging at different types of amenities
- We can then examine how the profiles of different kinds of charging (including **rapid** and **domestic**) interact with one another…
- …and look at how we can best deal with it

University of Strathclyde Engineering

Questions?

james.dixon@strath.ac.uk

University of Strathclyde Glasgow