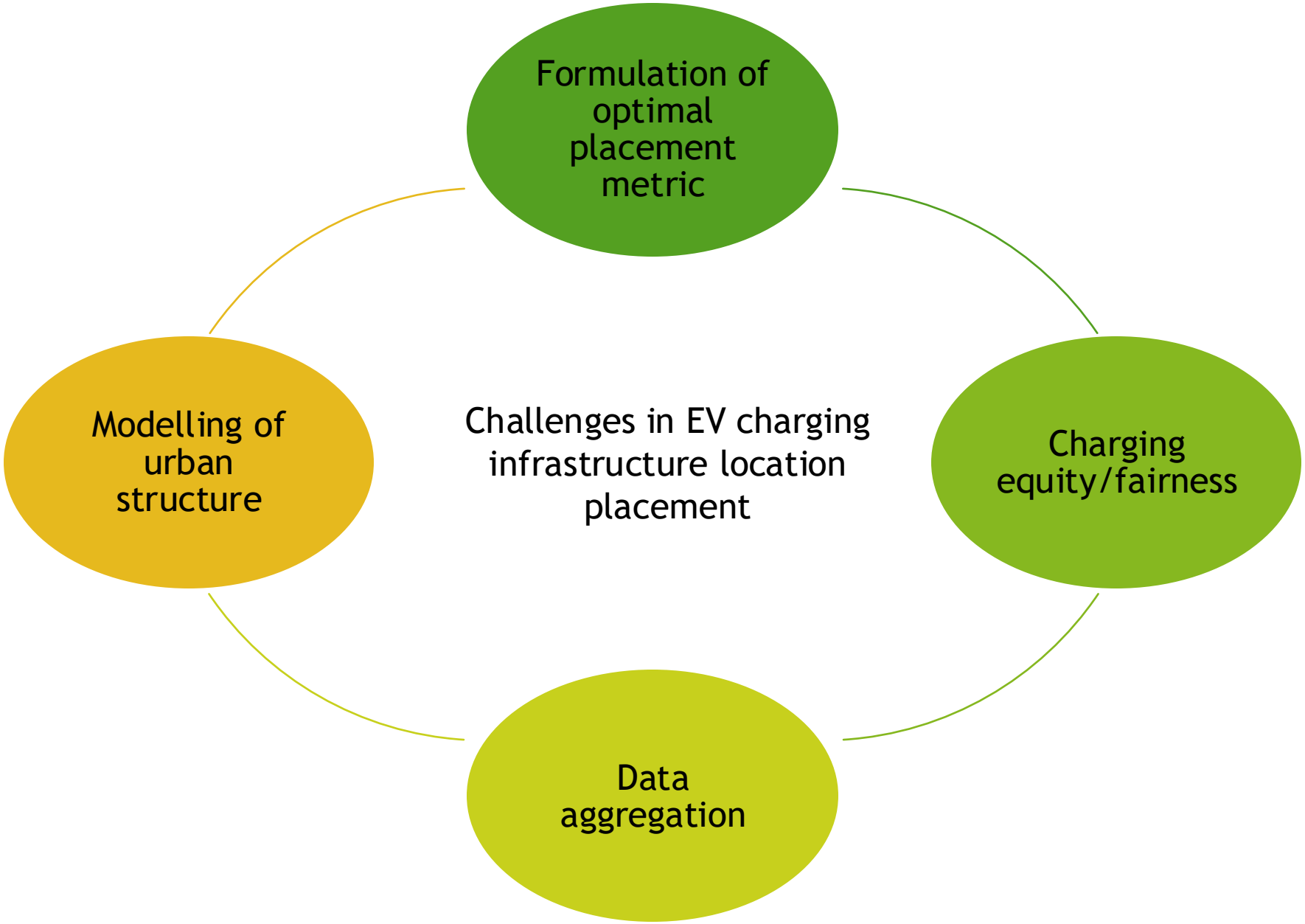
Geodemographic Aware EV Charging Infrastructure Placement for Enhanced Site Selection using Graph Neural Networks (Case Study of Scotland)

Authors: Djordje Batic, Vladimir Stankovic, Lina Stankovic

University of Strathclyde, Glasgow, UK

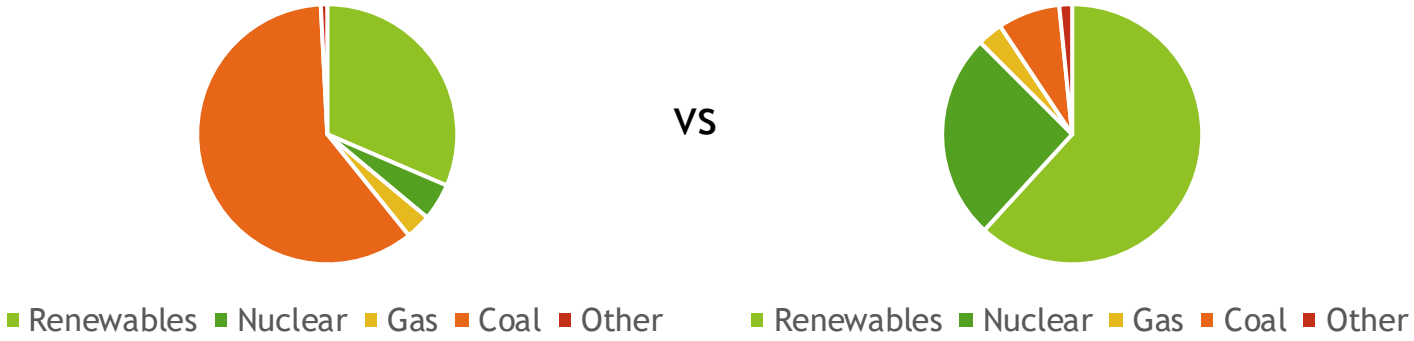
This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 955422.

Introduction



EV lifecycle assessment for Scotland

- Lifecycle assessment: Environmental performance of EVs is largely influenced by the charging energy source
- EV charging: Energy mix largely relies on fossil fuels != Energy mix relies on renewables



- Scotland's energy mix:
  - 98.6% of all electricity used comes from renewable sources
  - Large amount of excess energy is exported
- Ideal position for EV deployment – highest potential for CO_2 reduction

EV charging – largest EV adoption barrier

- Global CO_2 reduction limited by slow adoption of EVs (reliance on oil)
- While consumer demand for EVs keeps increasing, EVs still make up a small minority of vehicles used
- One of the largest barriers for EV adoption is lack of charging infrastructure:
  - Range anxiety
  - Poor infrastructure placement
  - Lack of equity consideration during placement decisions

Level 1

Full charge:
8 – 10 hours

Level 2

Full charge:
3 – 4 hours

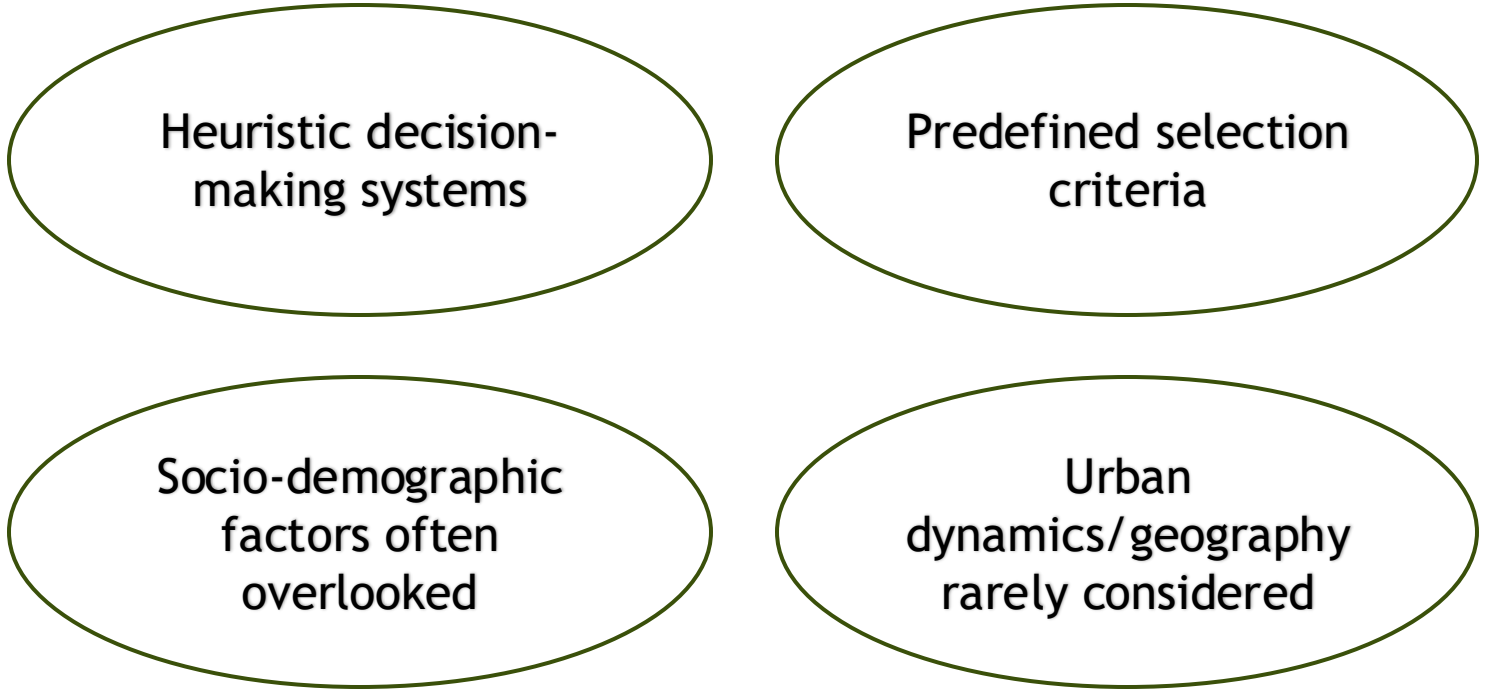
Level 3

Full charge:
.5 – 1 hour

Addressing EV charging infrastructure and equity from technology perspective

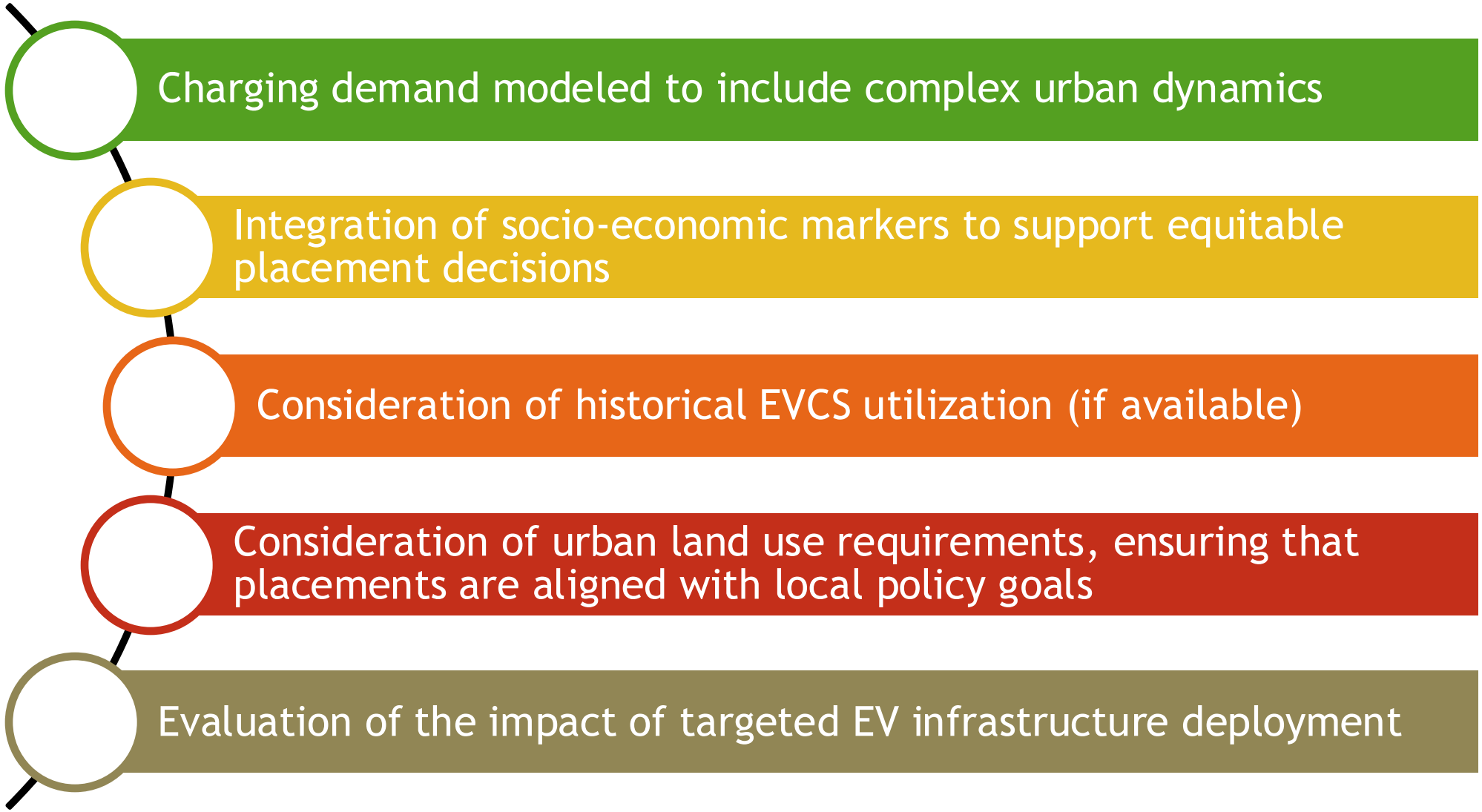
- Early adopters of EV technology tend to be homeowners that utilize home-based charging
- As EV ownership continues to rise, publicly accessible charging is increasingly needed
- However, in many counties EV adoption has outpaced charging infrastructure development
- Current EV charging station (EVCS) distribution often favors affluent area

How is EVCS problem usually approached?



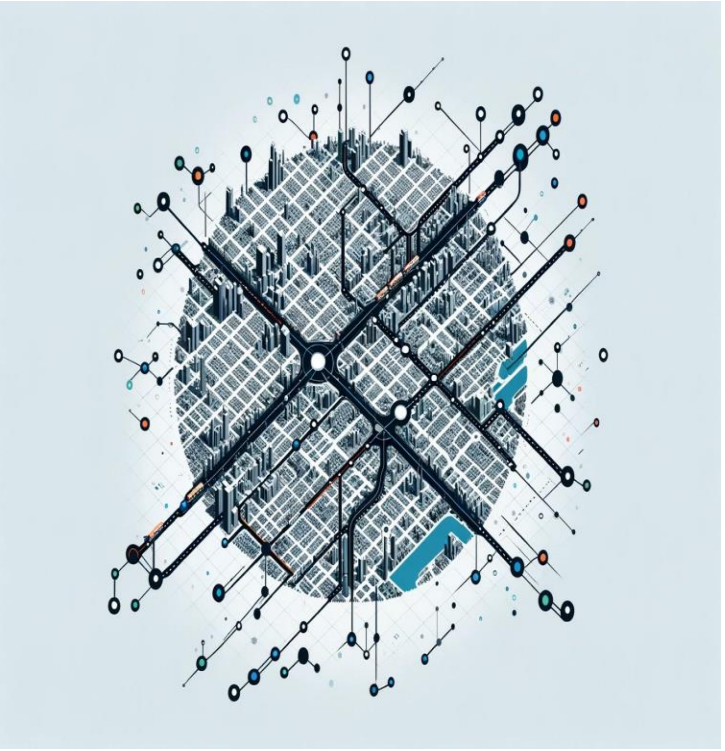
- Lack of capability to capture complex relationships within data
- Lack of urgency over need for consideration of equity in approaches to site selection

How should we address the problem of EVCS placement in an equitable way?



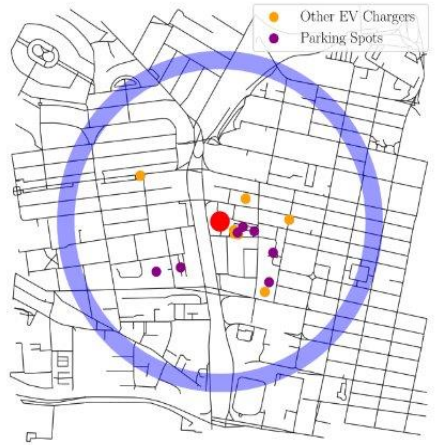
Graphs in Urban Networks

- Charging behavior largely dependent on the location within a city
- Transforming obstacles into opportunities: leveraging urban charging demand network
- Graphs have been used to represent urban networks
- They can be used to model:
  - Transport networks
  - Traffic networks
  - Utility networks
  - Encoding of proximity
- The use of graphs allows for the representation of these systems in a manner that highlights the relationships and interactions between different components

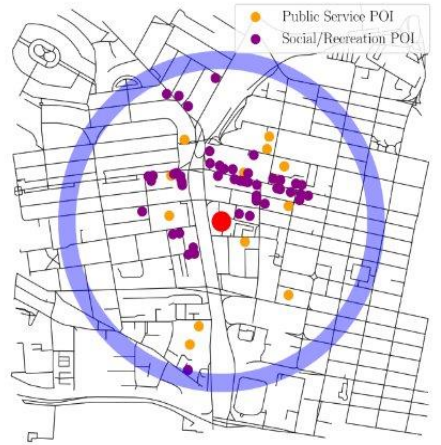


Charging Demand Nodes

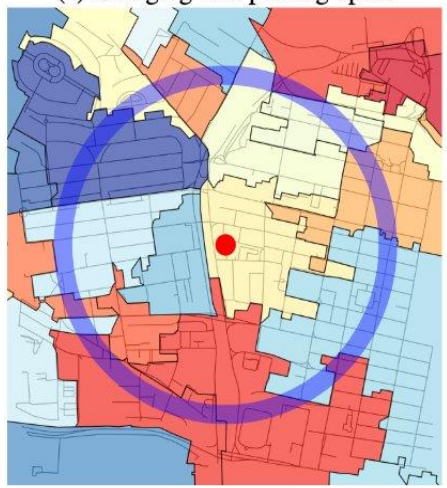
- Graph contains a set of nodes that are connected by a set of edges
- Charging node
  - area within a *r* radius around a charging station
- Charging edge
  - Distance-based connection between the nodes
- Demand node statistics:
  - Counts, Area Shares, Area Sizes
  - Existing chargers, parking spots, POIs, traffic flow, socio-demographic factors, connectivity, reachability, land use, utilization, etc.
- Statistics vary drastically between different land uses



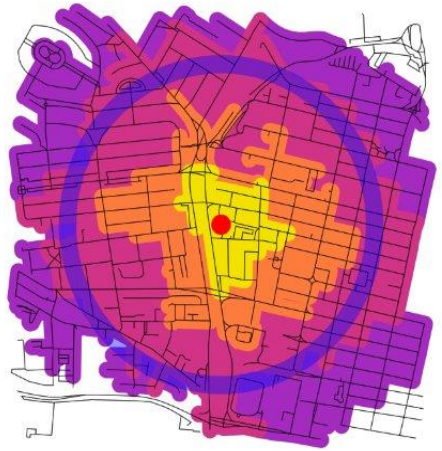
(a) Charging and parking spots



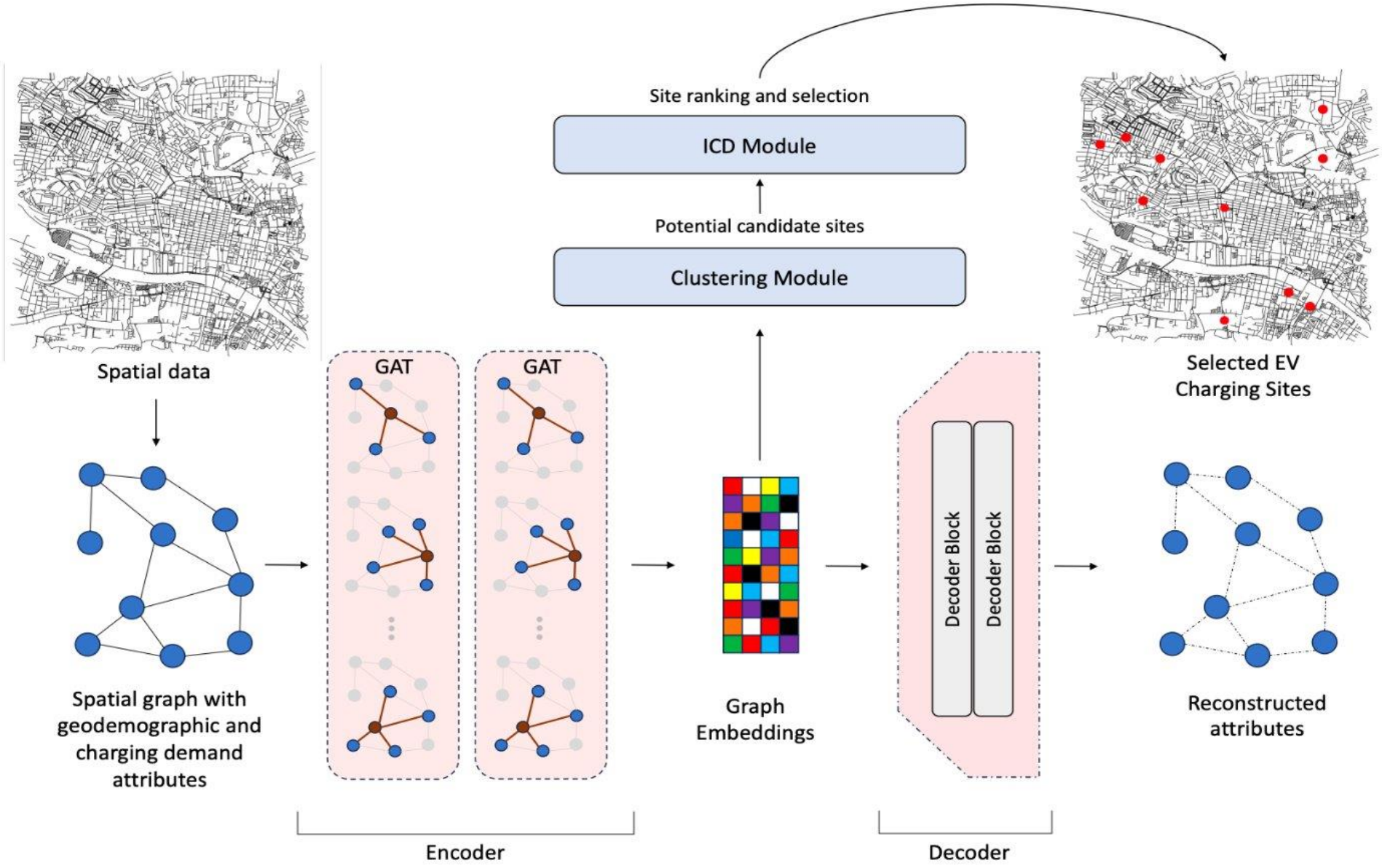
(b) Public service and social POI



(c) SIMD values per data zone



(d) Isochrone distance from node

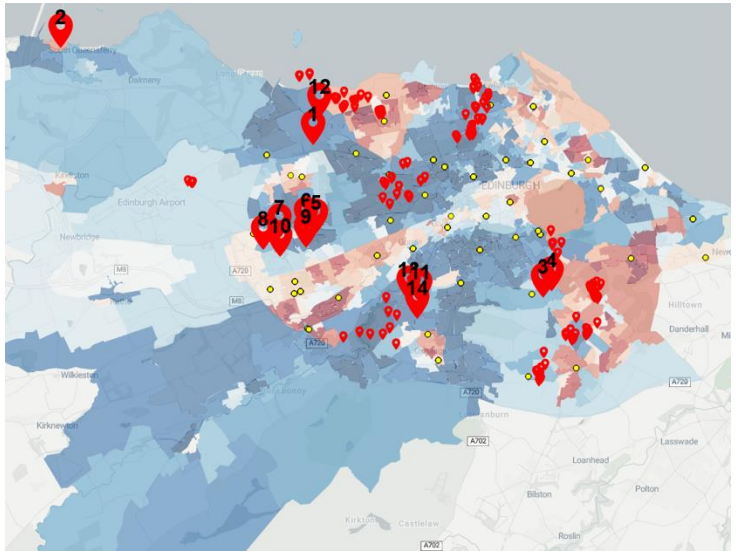

Site ranking and selection
ICD Module
Potential candidate sites
Clustering Module
Spatial data
Selected EV Charging Sites
GAT
GAT
Decoder Block
Decoder Block
Spatial graph with geodemographic and charging demand attributes
Graph Embeddings
Reconstructed attributes
Encoder
Decoder

Graph Neural Networks (GNNs) for EVCS placement

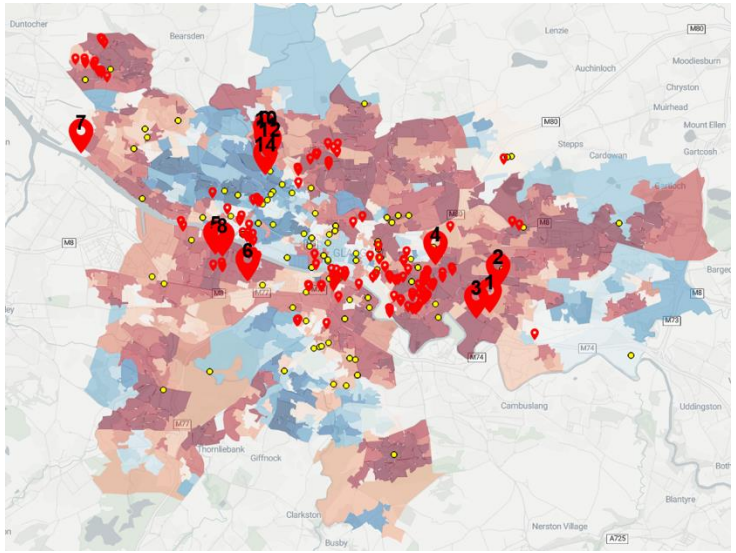
- GNNs used as unsupervised framework to model the urban charging graph and identify high potential areas based on historical utilization
- Charging demand - influencing factors
- Data aggregation
- New metric for actual utility of a newly installed charging station
- Targeted recommendations based on land use by modeling of total annual charging demand coverage [%] increase

Case Study - Scotland

- Charging infrastructure is already developed
- However, the inequality is high
- GNNs used to identify charging potential using clustering of GNN embeddings
- Medium and high potential areas are selected and charging station locations are ranked based on an incremental utility of installation
- Placement decisions are targeted per land use area type
  - Residential, Commercial, Industrial modules
- Modeling of total annual charging demand coverage [%] to select optimal stations



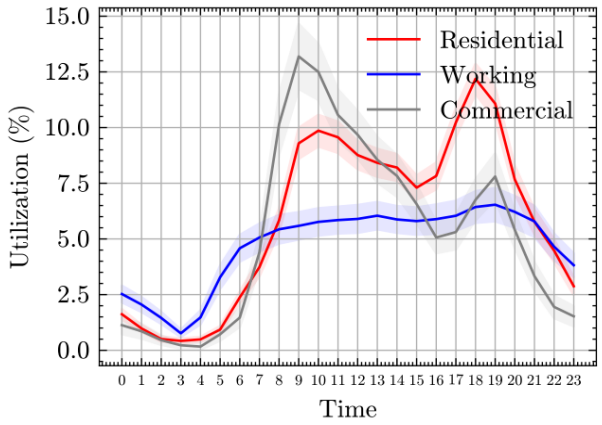
(a) Residential 22kW Edinburgh



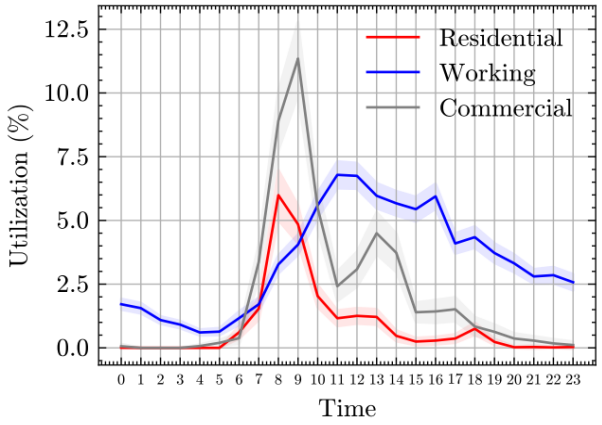
(b) Working Area 22kW Glasgow

What is charging utilization equity like in Scotland?

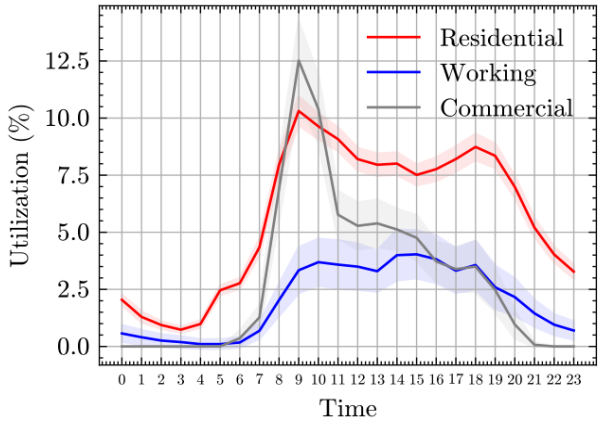
(a) Deprived areas of Glasgow



(b) Non-deprived areas of Glasgow



(c) Deprived areas of Edinburgh

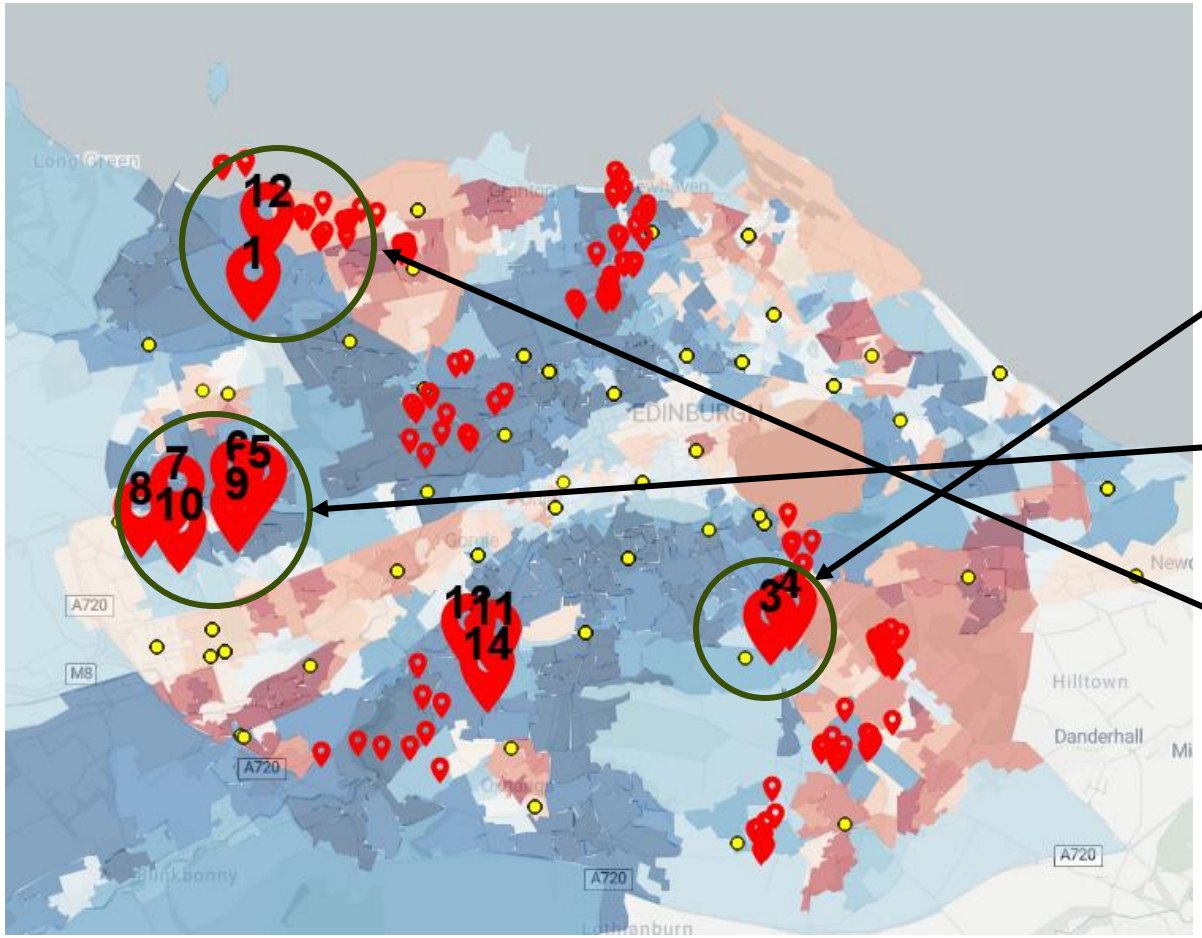


(d) Non-deprived areas of Edinburgh

What is charging utilization equity like in Scotland?

- Common issue – high overstay periods
- Edinburgh:
  - Large difference between utilization in deprived vs. non-deprived areas
  - Area with lowest utilization – deprived residential
  - Main issue - high overstay periods, combined with limited access to public charging
- Glasgow:
  - Deprived residential areas show similar utilization compared to non-deprived areas.
  - However, larger majority of Glasgow area falls within the lower 50th percentile of Scottish deprivation index.
  - 6pm peak in deprived residential areas could benefit from additional infrastructure and match the peak in non-deprived areas.

Results: Edinburgh residential areas – slow overnight charging (7kW)

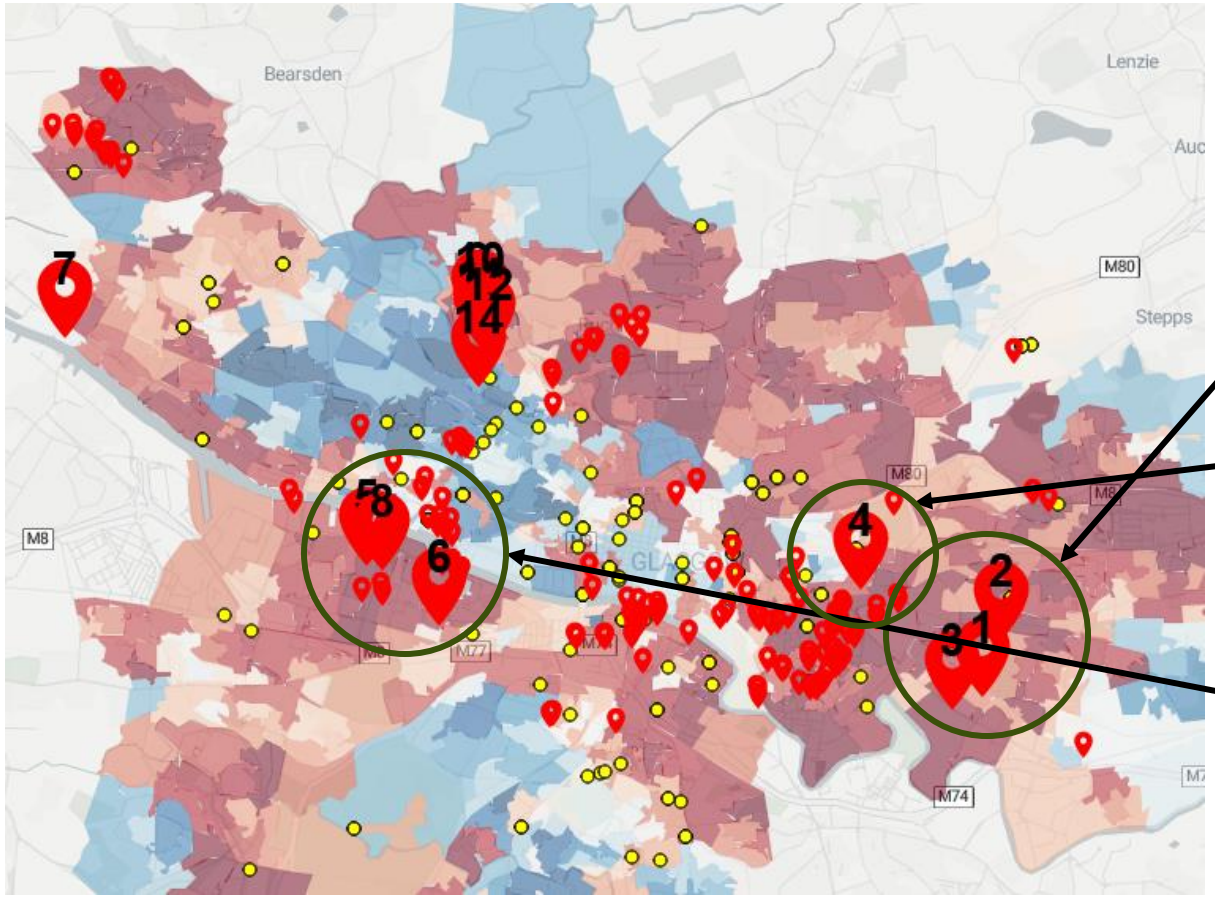


Lack of existing infrastructure, close to major road

Numerous shops, major road, Edinburgh Zoo

Lack of existing infrastructure, close to major road

Results: Glasgow working/industrial areas –34kW chargers

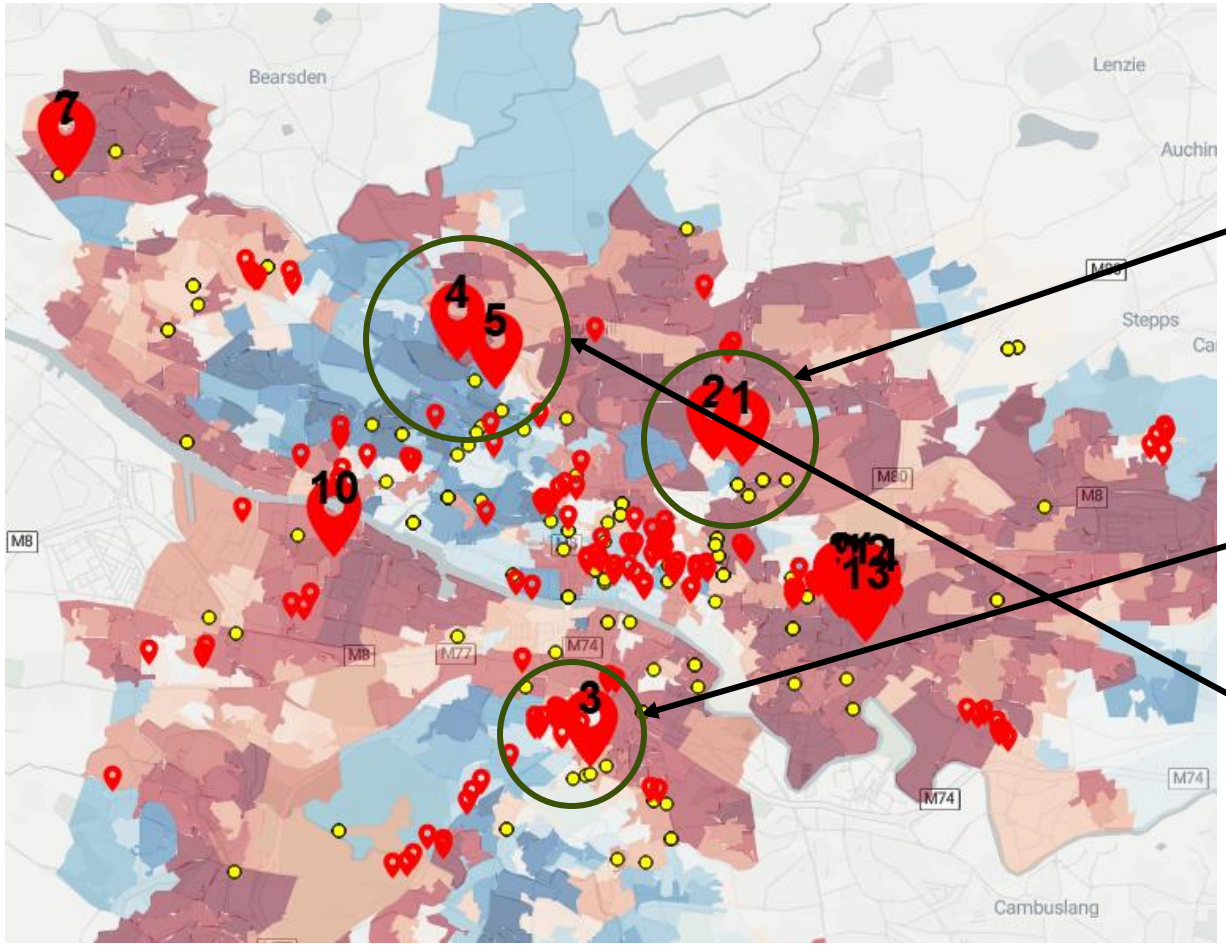


Number of large factories within the area

Food production, warehouse

Large recycling center, warehouses, subway depot. Lacks general charging infrastructure.

Results: Glasgow commercial areas – 34kW chargers



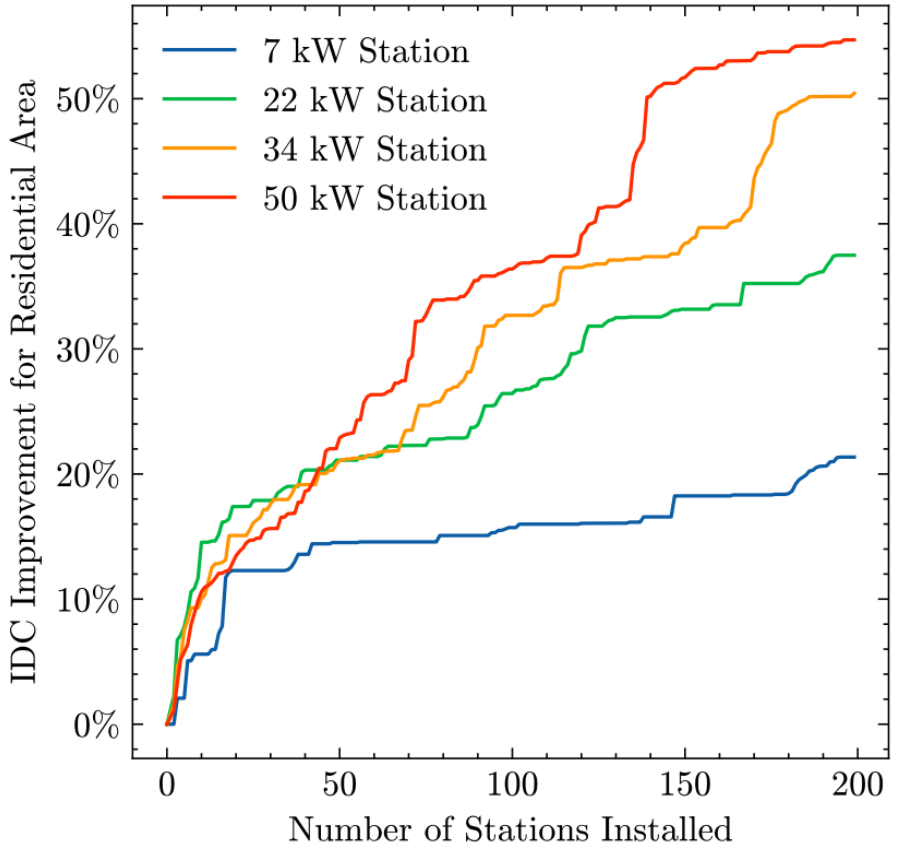
Large retail center

Major road, large amount of shops

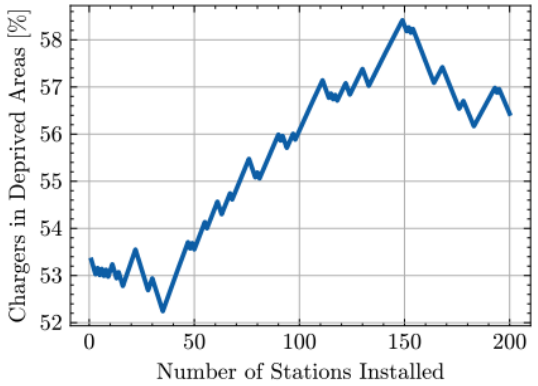
Large retail center

Case Study - Scotland

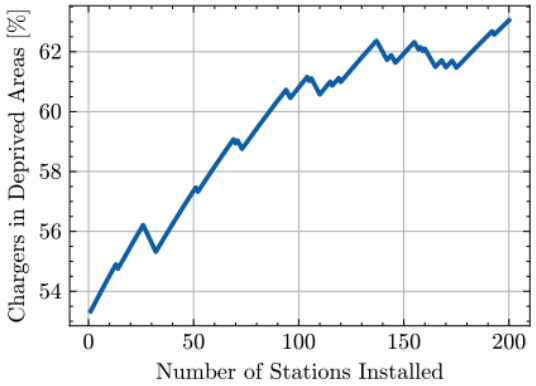
- Use case: installation of *n* charging stations with a certain energy capacity
- Charging coverage considered factors: ev penetration, ev traffic flow, avg. battery capacity, and charging demand node total power output
- Simulate how installation of new charging stations affects the coverage of existing nodes
- Insight into different deployment strategies on charging demand
- ”More power” is not always better
- Cost reduction + higher utilization
- Consideration of underserved communities (highest benefit approach)



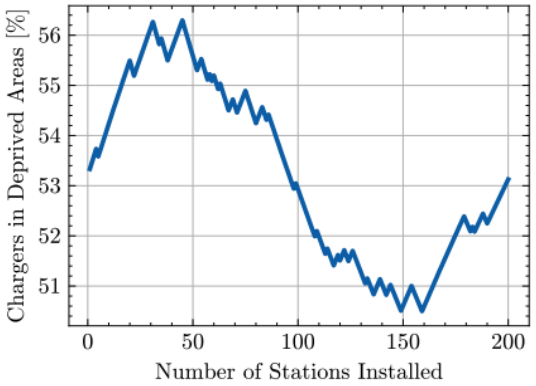
Placement decisions ratio



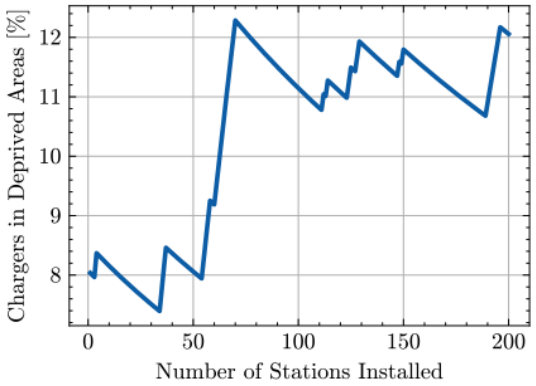
(a) 22kW infrastructure, Glasgow residential area



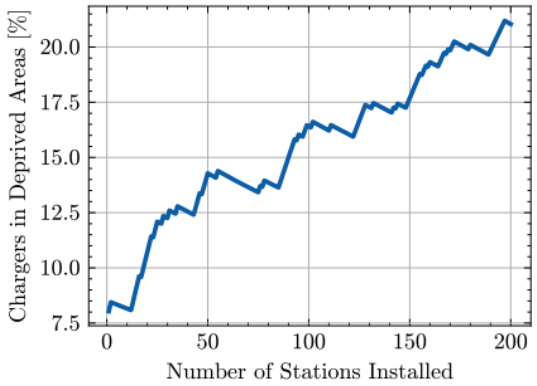
(b) 22kW infrastructure, Glasgow working area



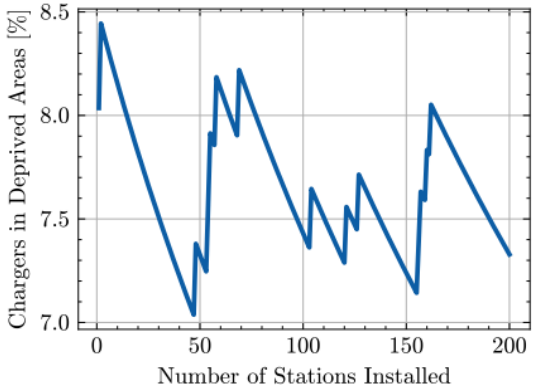
(c) 34kw infrastructure, Glasgow commercial area



(d) 7kW infrastructure, Edinburgh residential area



(e) 22kW infrastructure, Edinburgh working area



(f) 34kW infrastructure, Edinburgh commercial area

Scotland public EV Charging Dataset

University of Strathclyde Engineering

EEDAL Energy Efficiency in Domestic Appliances and Lighting

- 3000+ EV Charging Stations in whole of Scotland
- Over 1 year of recordings (Since October 2022)
- Organized per local council area
- 30 min resolution
- Energy consumed + generation mix, carbon intensity index, occupancy status
- Charger capacity, connector type, land use, socio-demographic indicators

1	timestamp	consumed_total	occupied	biomass	coal	imports	gas	nuclear	other	hydro	solar	wind	forecast	index	region_id
2	2023-01-14 22:00:00	6.807777778	1	0.003	0	0.002	0.008	0.077	0	0.049	0	0.861	5	very low	2
3	2023-01-14 22:30:00	11	1	0.004	0	0.013	0.011	0.074	0	0.042	0	0.855	11	very low	2
4	2023-01-14 23:00:00	11	1	0.003	0	0.003	0.011	0.075	0	0.04	0	0.869	6	very low	2
5	2023-01-14 23:30:00	11	1	0.003	0	0	0.011	0.076	0	0.037	0	0.872	5	very low	2
6	2023-01-15 00:00:00	11	1	0.002	0	0	0.01	0.076	0	0.04	0	0.872	4	very low	2
7	2023-01-15 00:30:00	11	1	0.002	0	0	0.012	0.077	0	0.041	0	0.868	5	very low	2
8	2023-01-15 01:00:00	11	1	0.003	0	0	0.011	0.077	0	0.044	0	0.866	5	very low	2
9	2023-01-15 01:30:00	11	1	0.003	0	0	0.011	0.077	0	0.043	0	0.866	5	very low	2
10	2023-01-15 02:00:00	7.992222222	1	0.002	0	0	0.011	0.081	0	0.041	0	0.864	5	very low	2
11	2023-01-15 02:30:00	0	1	0.004	0	0	0.013	0.084	0	0.038	0	0.861	6	very low	2
12	2023-01-15 03:00:00	0	1	0.004	0	0	0.014	0.087	0	0.038	0	0.856	6	very low	2
13	2023-01-15 03:30:00	0	1	0.005	0	0	0.015	0.086	0	0.041	0	0.854	6	very low	2
14	2023-01-15 04:00:00	0	1	0.005	0	0	0.015	0.087	0	0.043	0	0.85	7	very low	2
15	2023-01-15 04:30:00	0	0	0.005	0	0	0.012	0.091	0	0.044	0	0.848	5	very low	2

University of Strathclyde Engineering

EEDAL Energy Efficiency in Domestic Appliances and Lighting

Thank you!

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 955422.