Centre for Process Systems Engineering

Imperial College London

Agent-based modelling of spatial and temporal energy and transport demands

Workshop on integrated energy system models incorporating spatial and temporal detail

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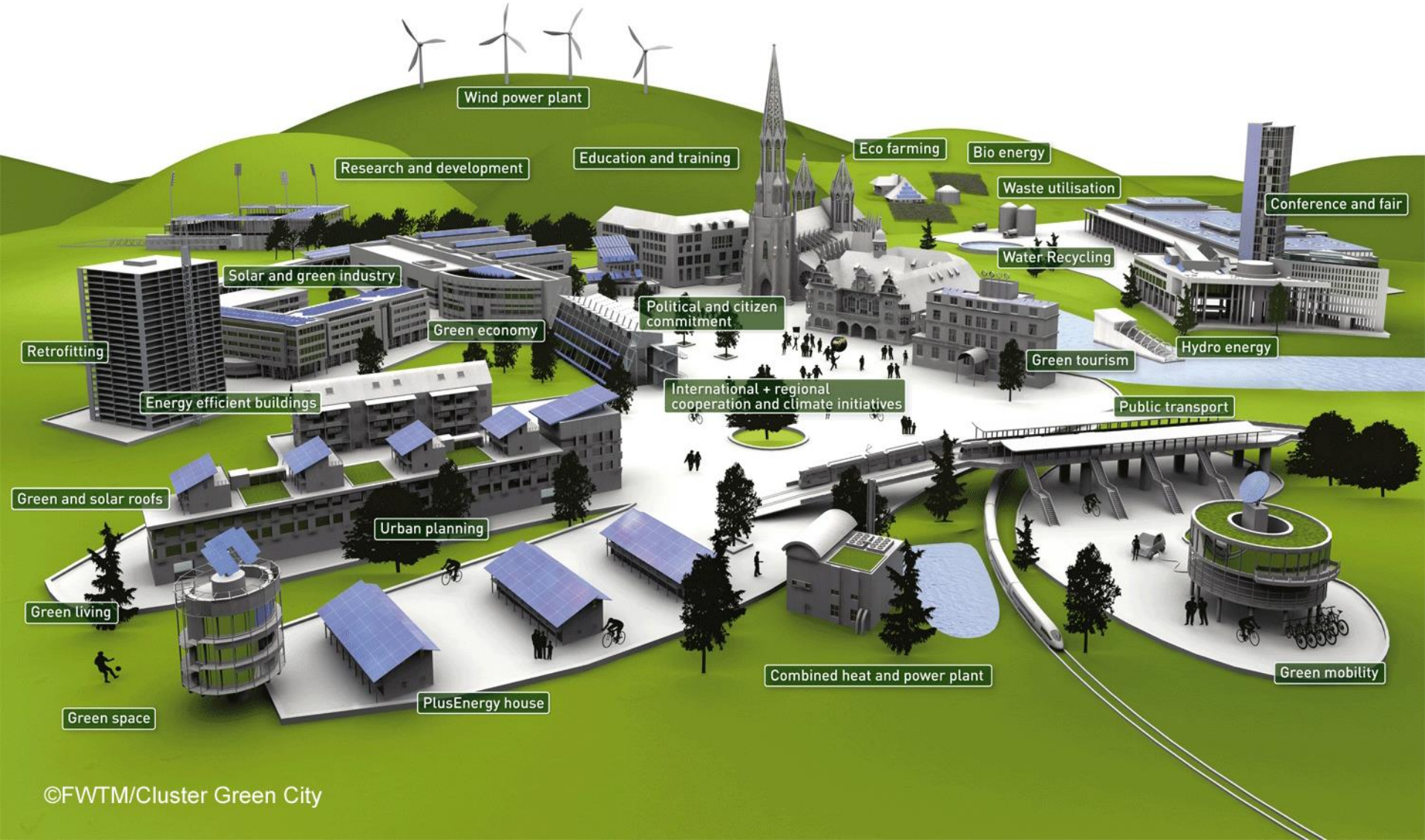
24 May 2016

Overview

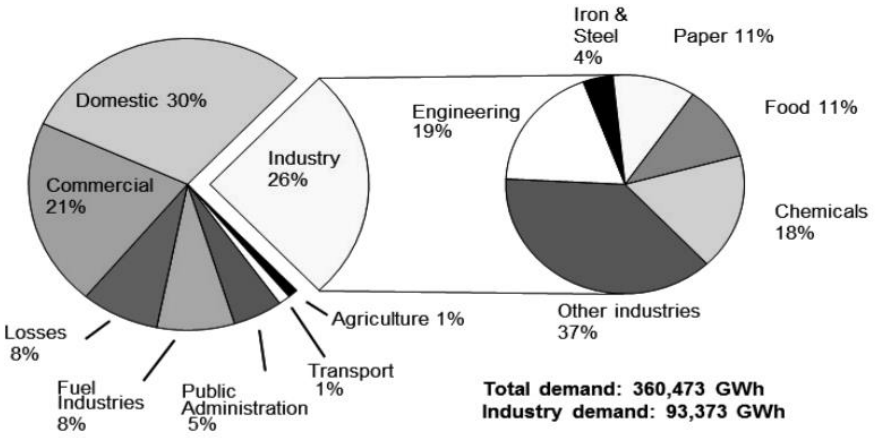
- Context – smart cities
- Methodology – representing decision makers as agents
- Case study 1 – smart charging of electric vehicles
- Case study 2 – heat and electricity demand Isle of Dogs
- Software tools – a quick look at Repast Simphony
- Final thoughts…

Context


Wind power plant
Research and development
Education and training
Eco farming
Bio energy
Waste utilisation
Conference and fair
Water Recycling
Solar and green industry
Political and citizen commitment
Green economy
Retrofitting
Hydro energy
Green tourism
Energy efficient buildings
International + regional cooperation and climate initiatives
Public transport
Green and solar roofs
Urban planning
Green living
Combined heat and power plant
Green mobility
Green space
PlusEnergy house
©FWTM/Cluster Green City

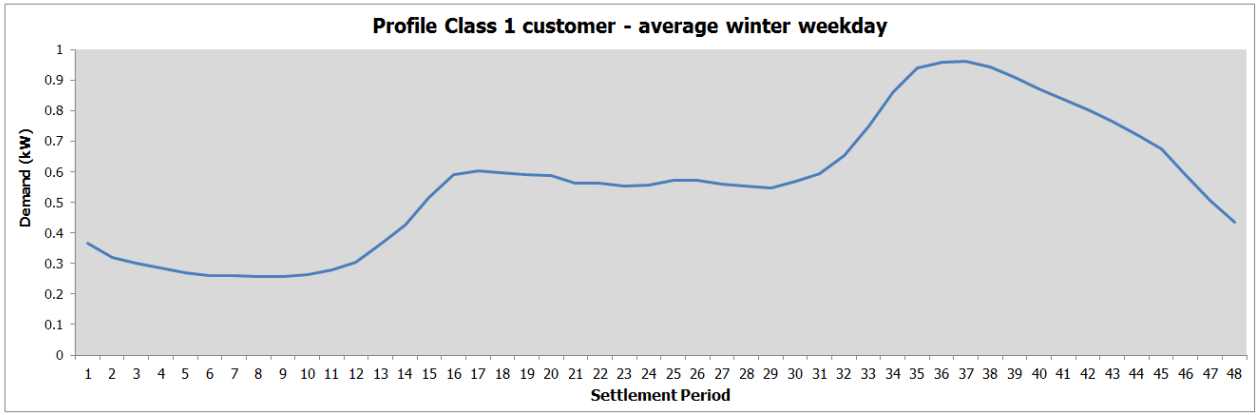
New technologies to be integrated in cities

Understanding spatial and temporal demand



(Dukes 2015)

(DECC National Heat Map 2015)



(Elexon 2015)

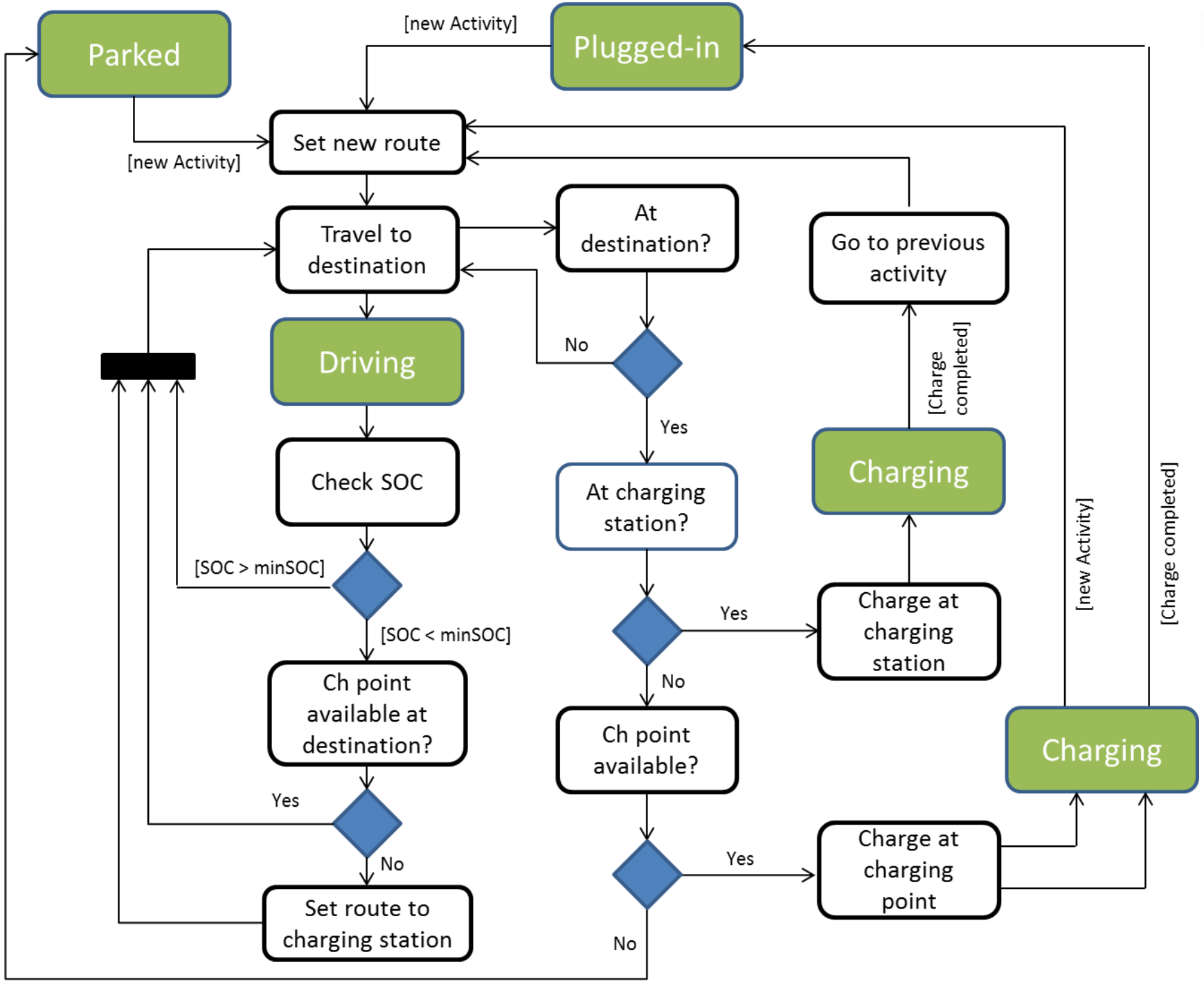
Methodology

Activities leading to energy demand

Agent-based modelling

- Agent-based modelling is a *computational* method that enables a researcher to create, analyze, and e*xperiment* with *models* composed of *agents* that interact within an *environment* (Nigel Gilbert, 2007)
- Self-organisation and emergence

- Modelling the decision maker, rather than the output of the decision


Parked
[new Activity]
Plugged-in
Set new route
[new Activity]
Travel to destination
At destination?
Go to previous activity
Driving
No
[Charge completed]
Yes
Check SOC
At charging station?
Charging
[SOC > minSOC]
[SOC < minSOC]
Yes
Charge at charging station
[new Activity]
[Charge completed]
No
Ch point available at destination?
Ch point available?
Charging
Yes
Yes
No
Charge at charging point
Set route to charging station
No

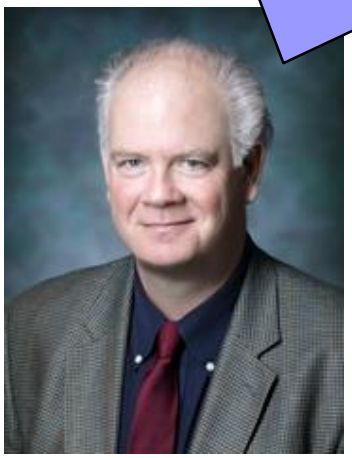
Advantages of bottom-up approach

- Change city layout, infrastructure, technology access…
- Policies that affect behaviour, pricing, taxes…

What I cannot create, I do not understand!

(Richard Feynman, 1988)

If you didn't grow it, you didn't explain it!

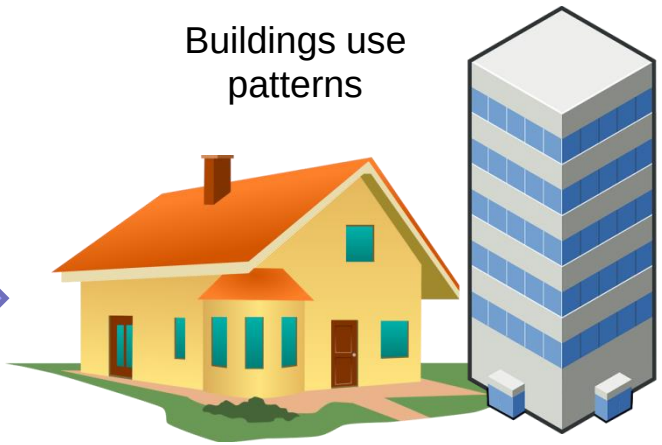


(Joshua Epstein, 2005)

Agent-based energy demand model

Activities

Buildings use patterns



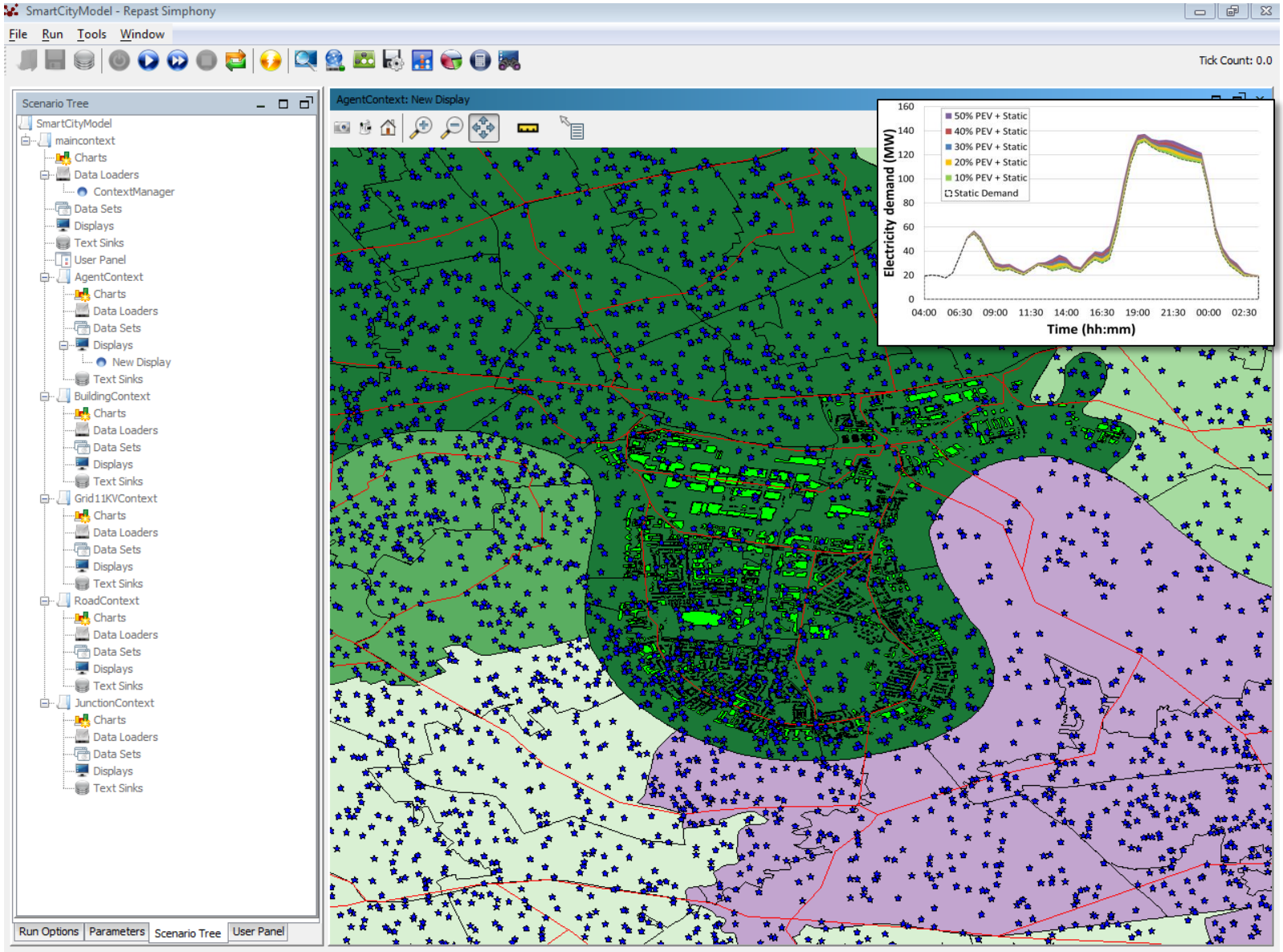
Static electricity and heat demand

Transport behaviour

Transport energy

Mobile electricity demand

Implementation in Repast



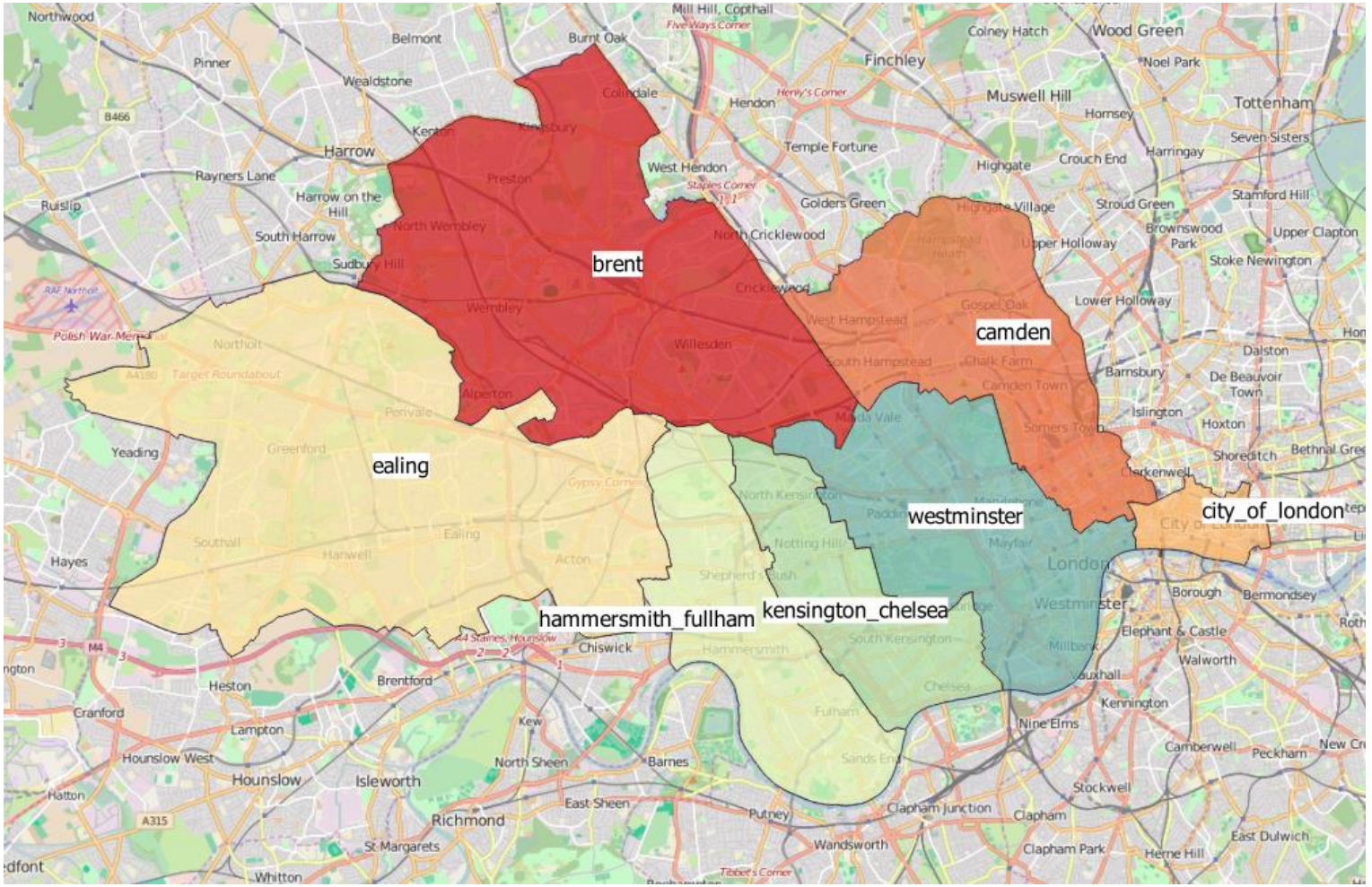
Case study 1

- Spatial: London boroughs – individual cars
- Temporal: 24 hours – 5 minute resolution

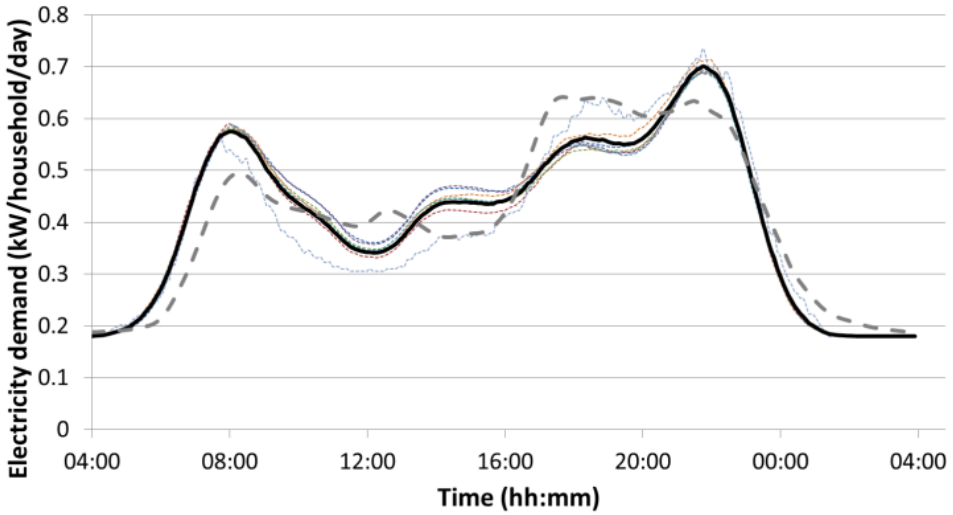
Case 1 – Smart charging of electric vehicles

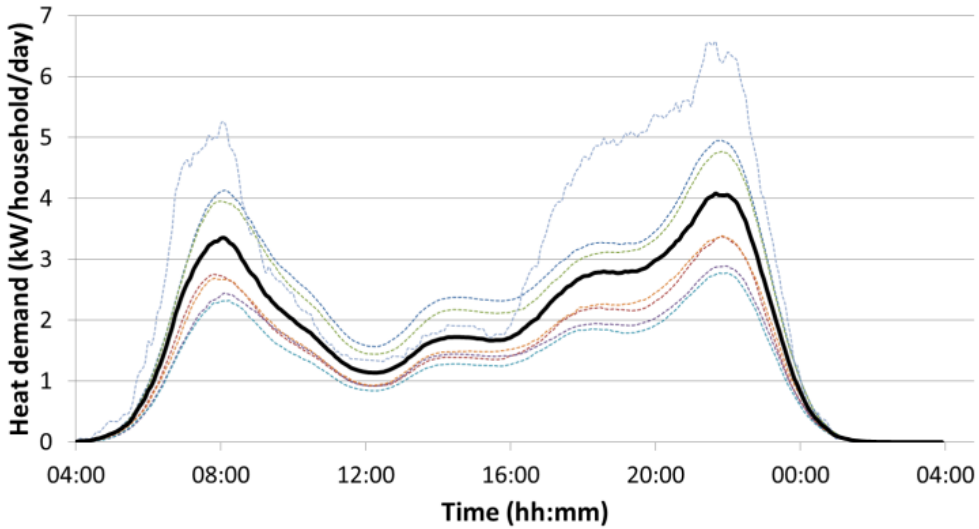
- Determining optimal charging of electric vehicles is key in developing an efficient and robust smart-grid
- Need to **understand** vehicle movements and **predict** demands to **analyse** impact on grid and **optimise** charging profiles
- Link energy and transport infrastructures
- Understand combined effects of electrification of transport and electrification of heating

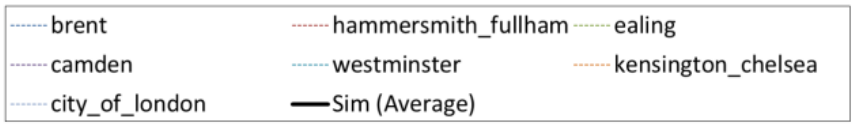
Case study area – West London

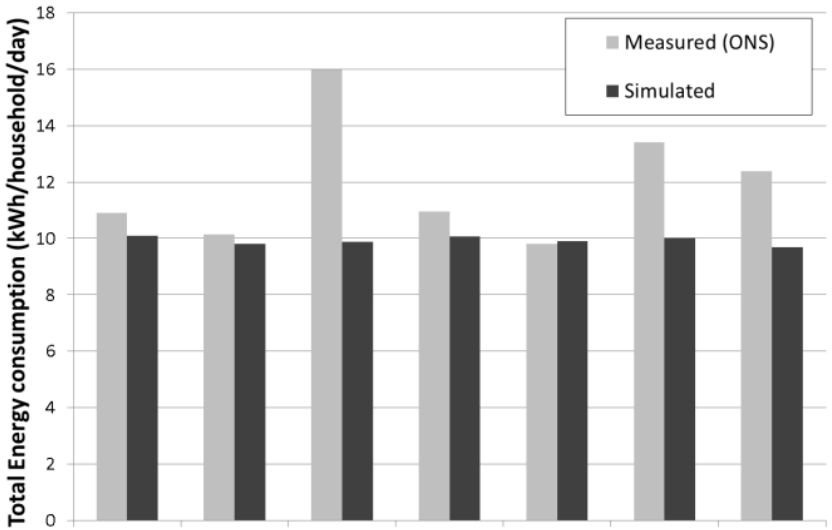


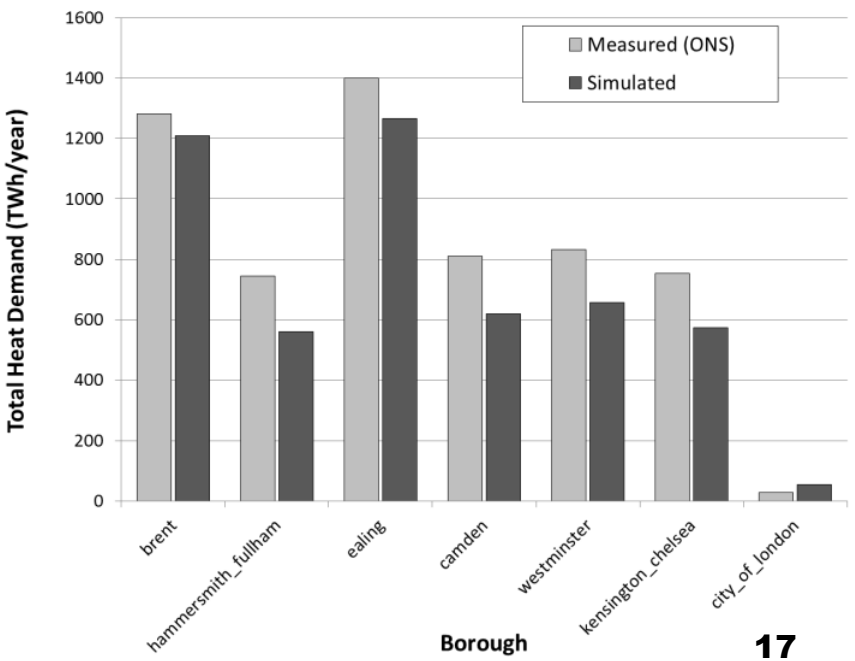
Energy demand - Baseline



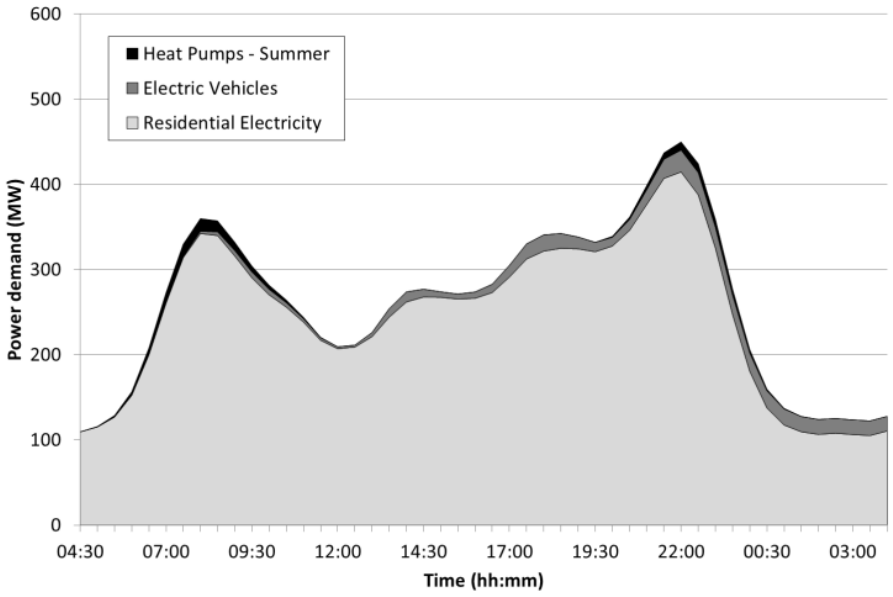


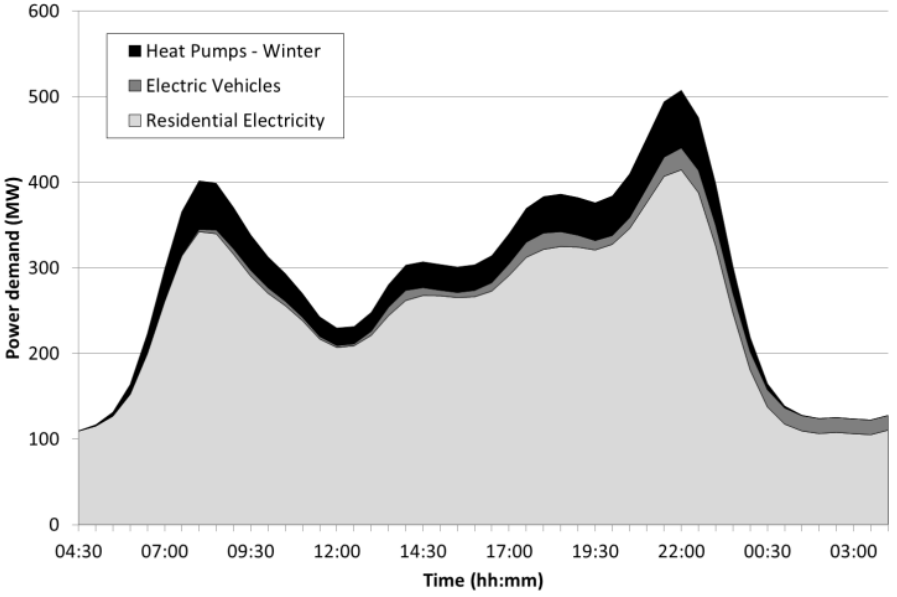






Impact of electric vehicles and heat pumps

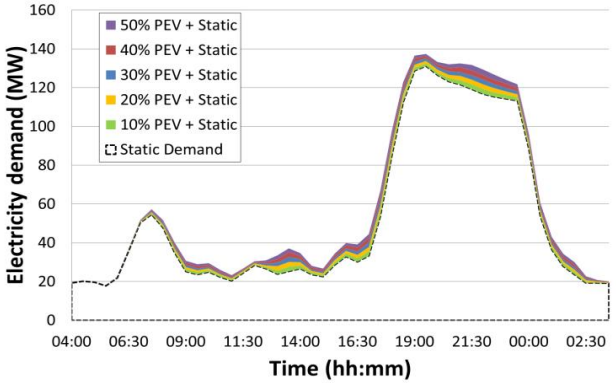




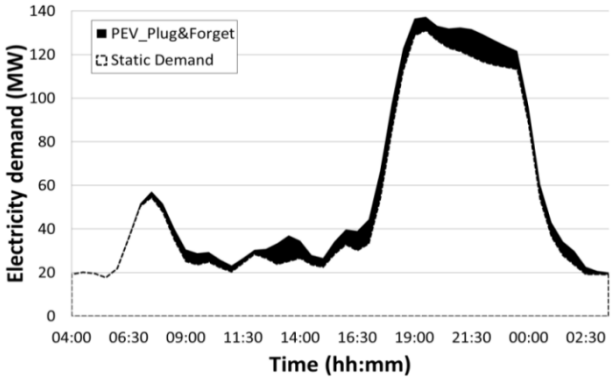
Gonzalo Bustos-Turu, Koen H. van Dam, Salvador Acha, Christos N. Markides, Nilay Shah (2016), *Simulating residential electricity and heat demand in urban areas using an agent-based modelling approach*, IEEE Energycon 2016, Leuven, Belgium

Different smart charging strategies

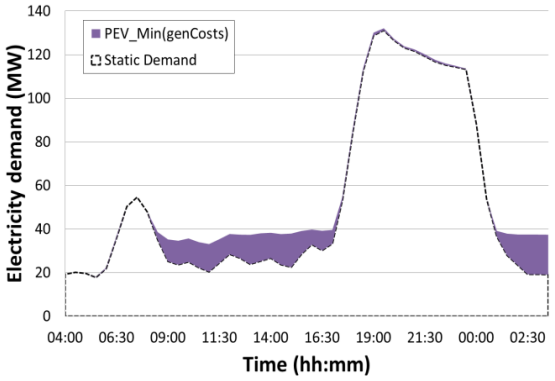
Plug and forget



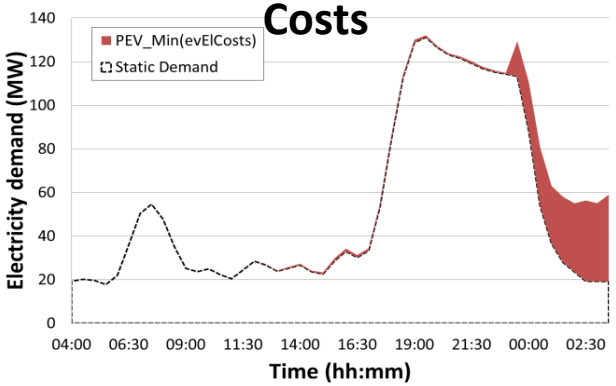
Plug and forget (50%)



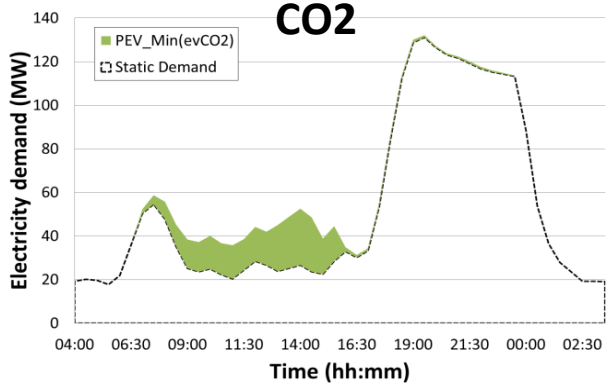
Network Costs



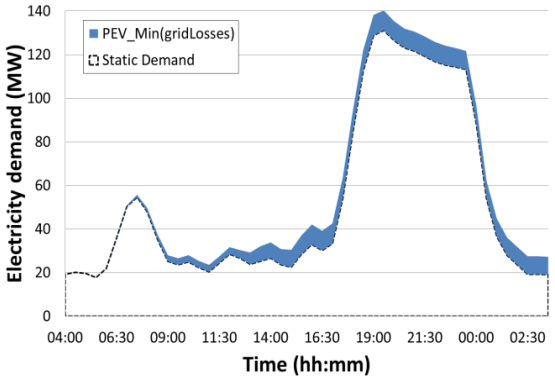
EV Charging Costs



EV Charging CO2

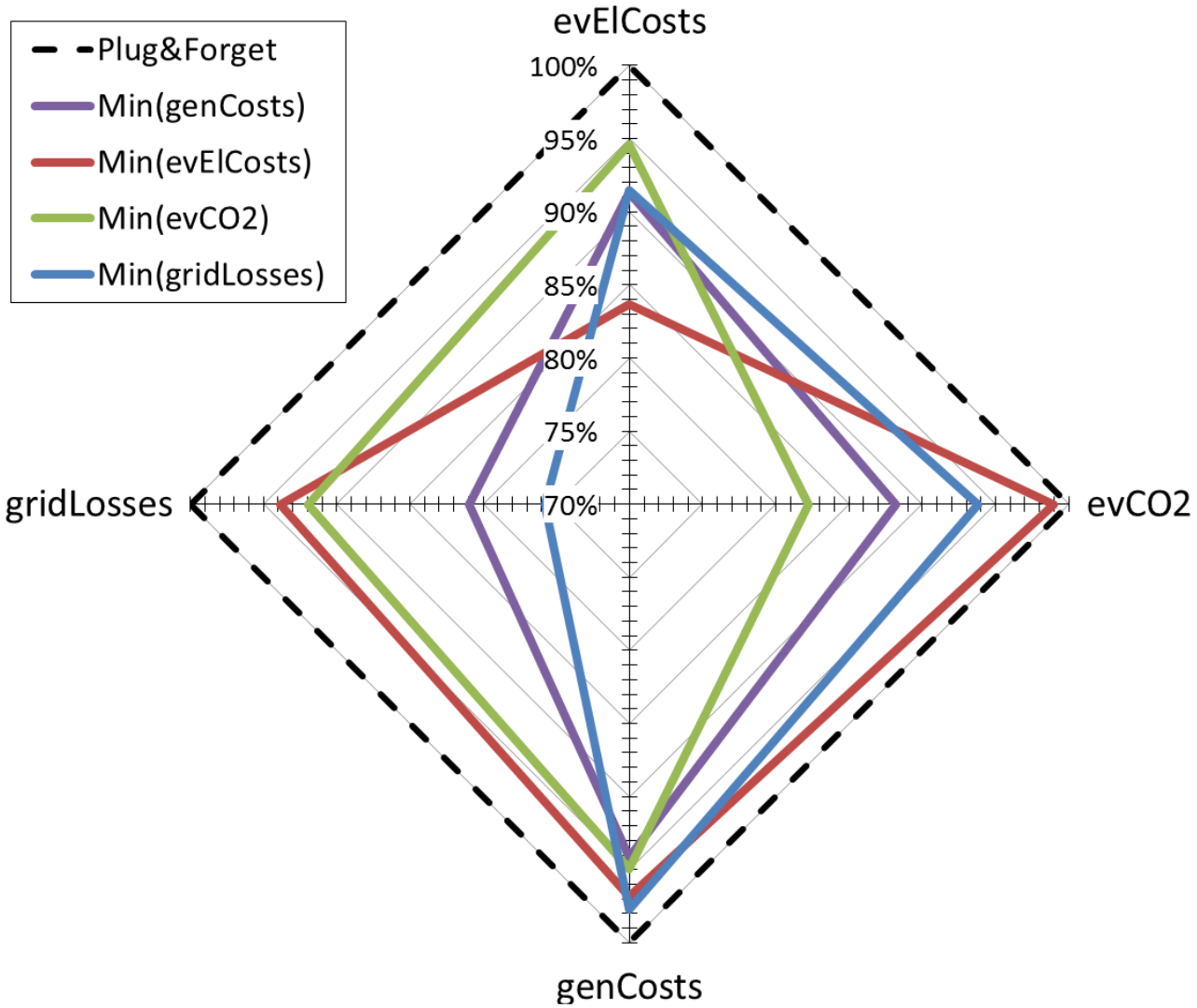


Network Losses



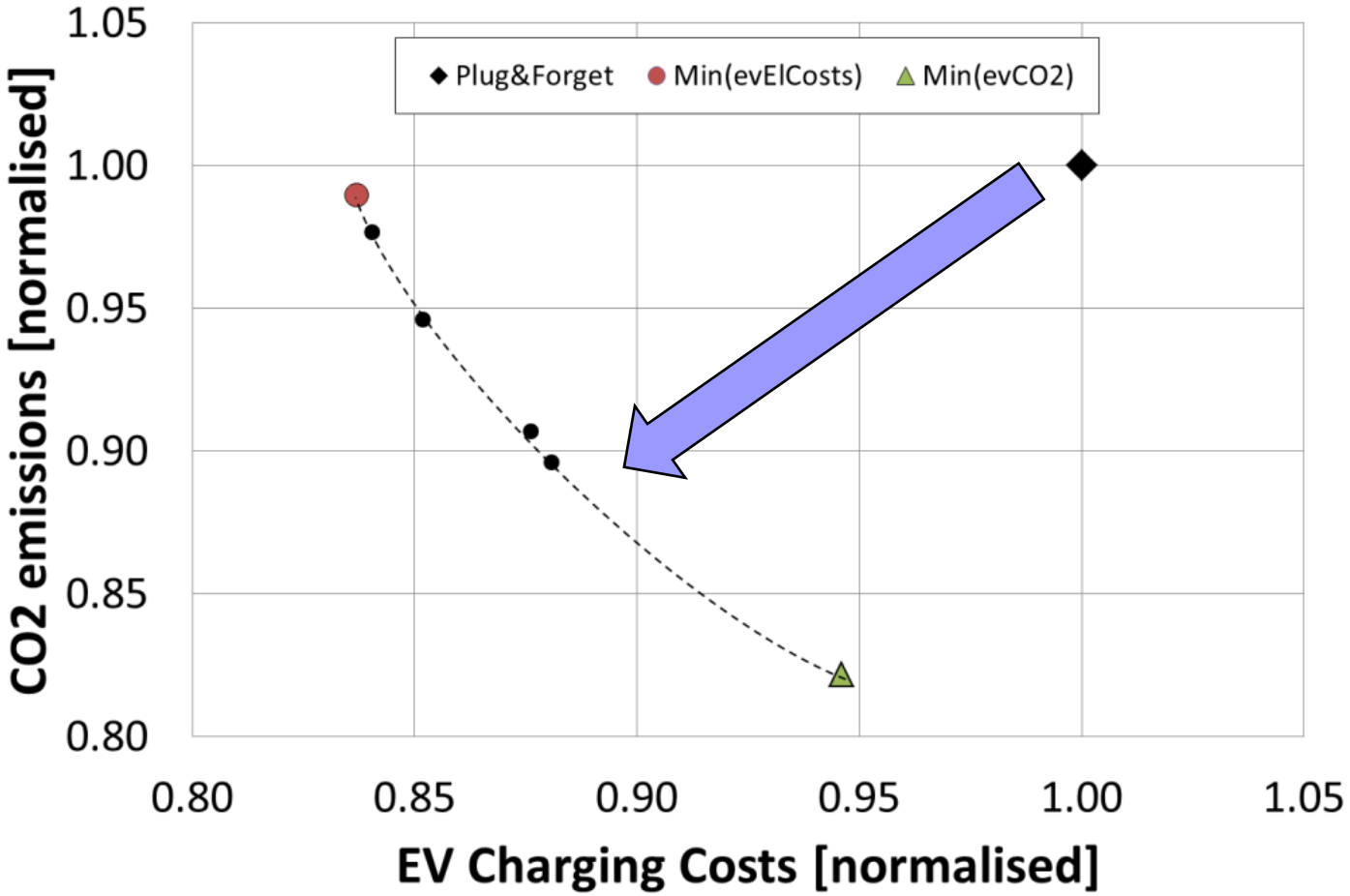
(Bustos-Turu, van Dam, Acha and Shah, 2015)

Results: Single-objective optimisation

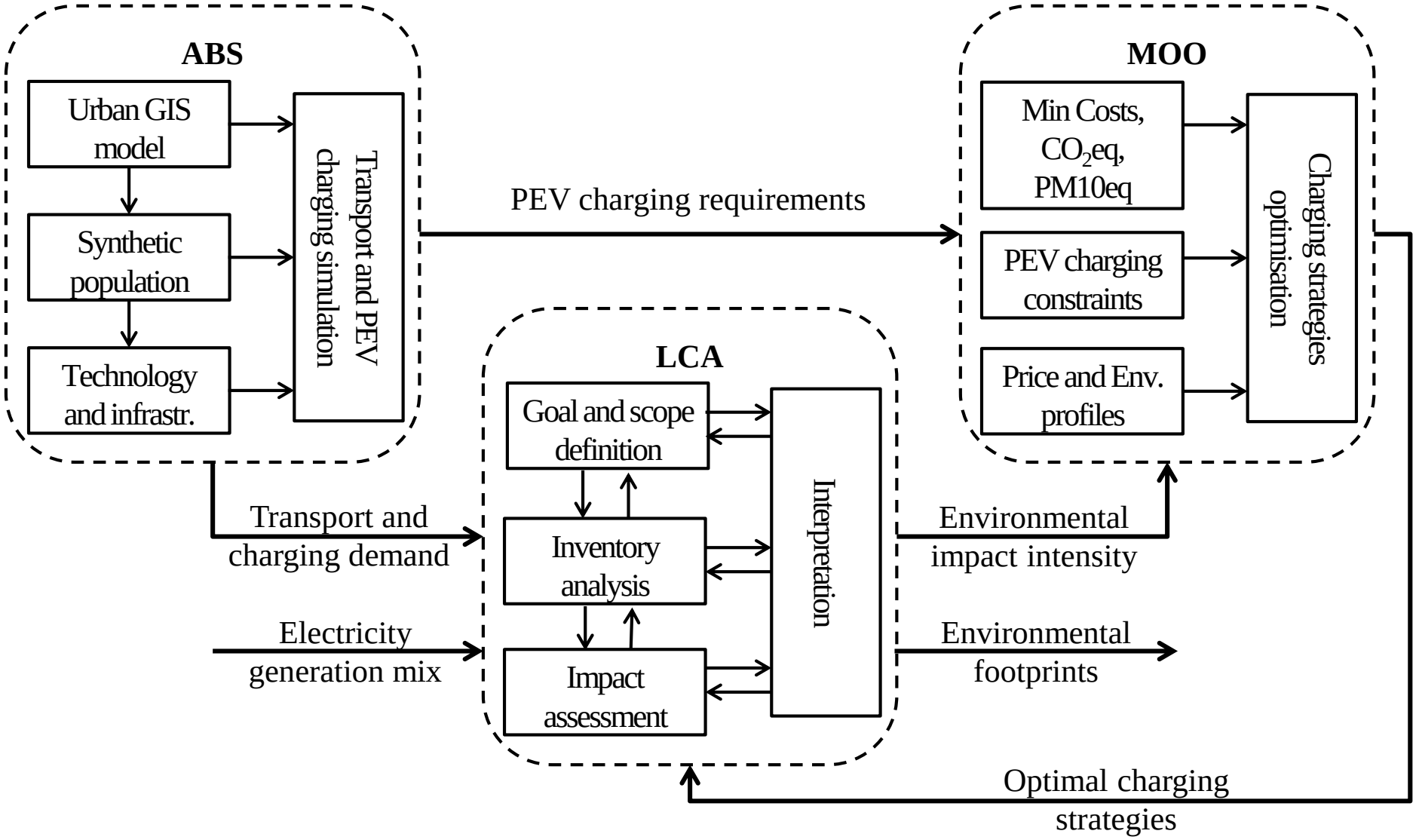


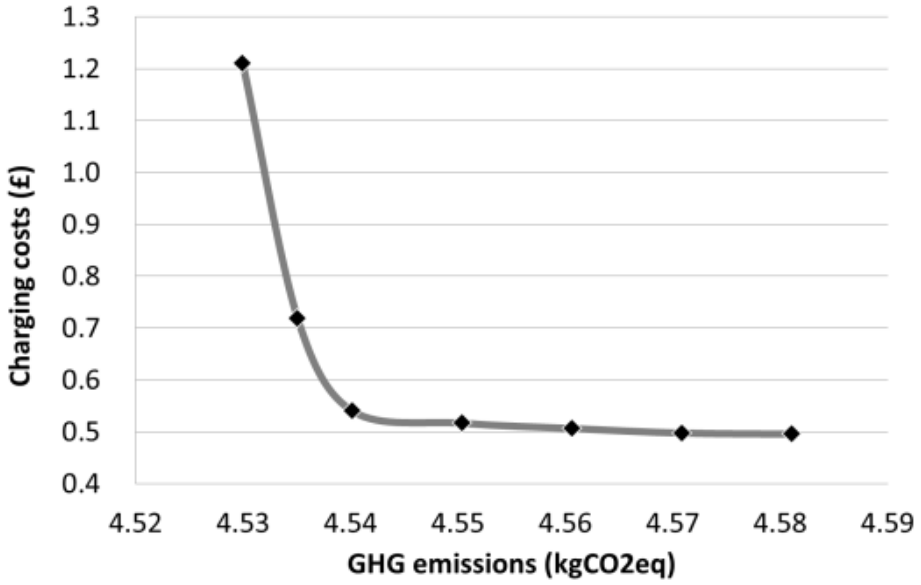
Results: Multi-objective optimisation

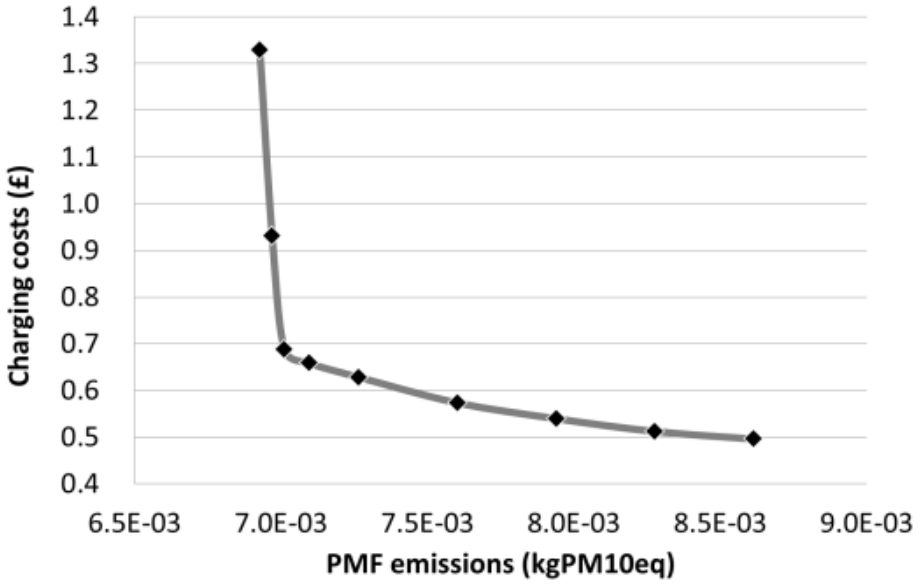
$$\min f(EvP_{n,t}) = \omega_1 \times EvCh(EvP_{n,t}) + \omega_2 \times EvCO2(EvP_{n,t})$$

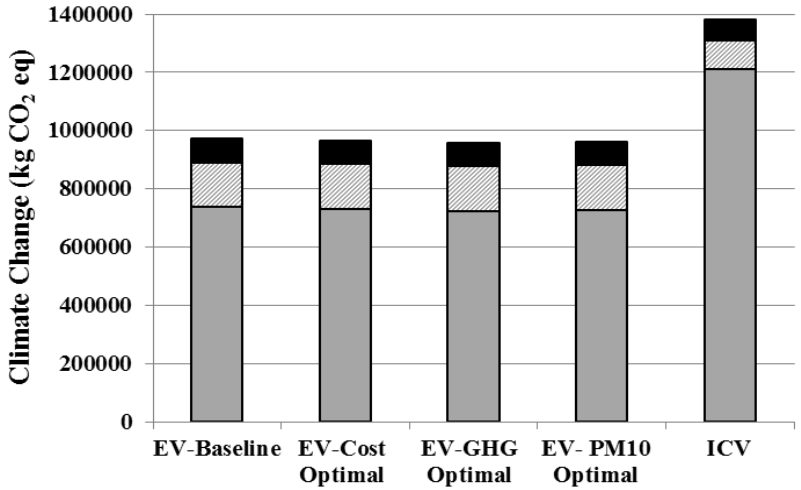


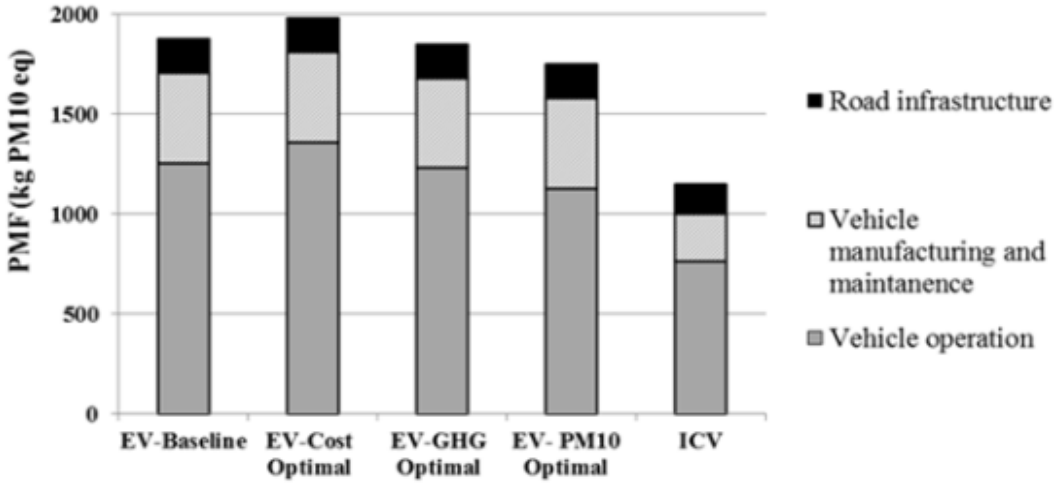
Model integration – ABS/MOO/LCA











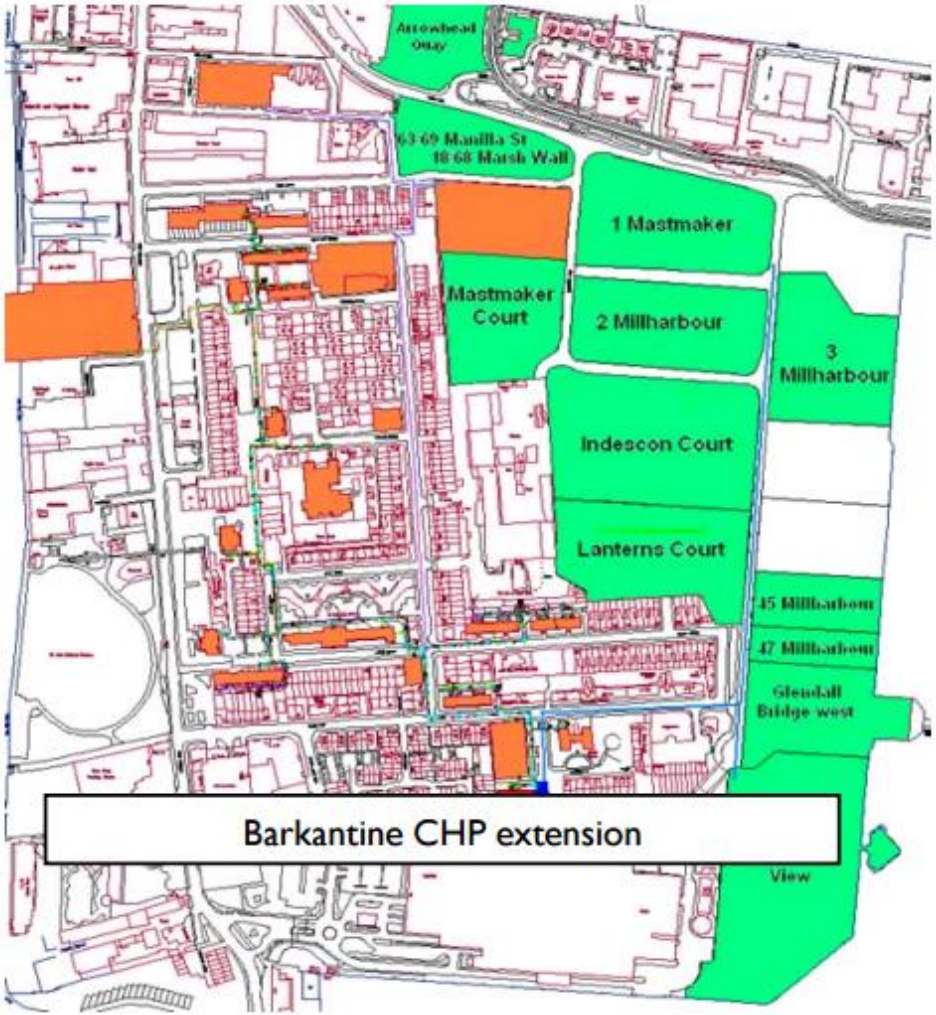
Incorporating life cycle assessment indicators into optimal electric vehicle charging strategies: An integrated modelling approach (ESCAPE2016)

Gonzalo Bustos, Miao Guo, Koen H. van Dam, Salvador Acha, Nilay Shah

Case study 2

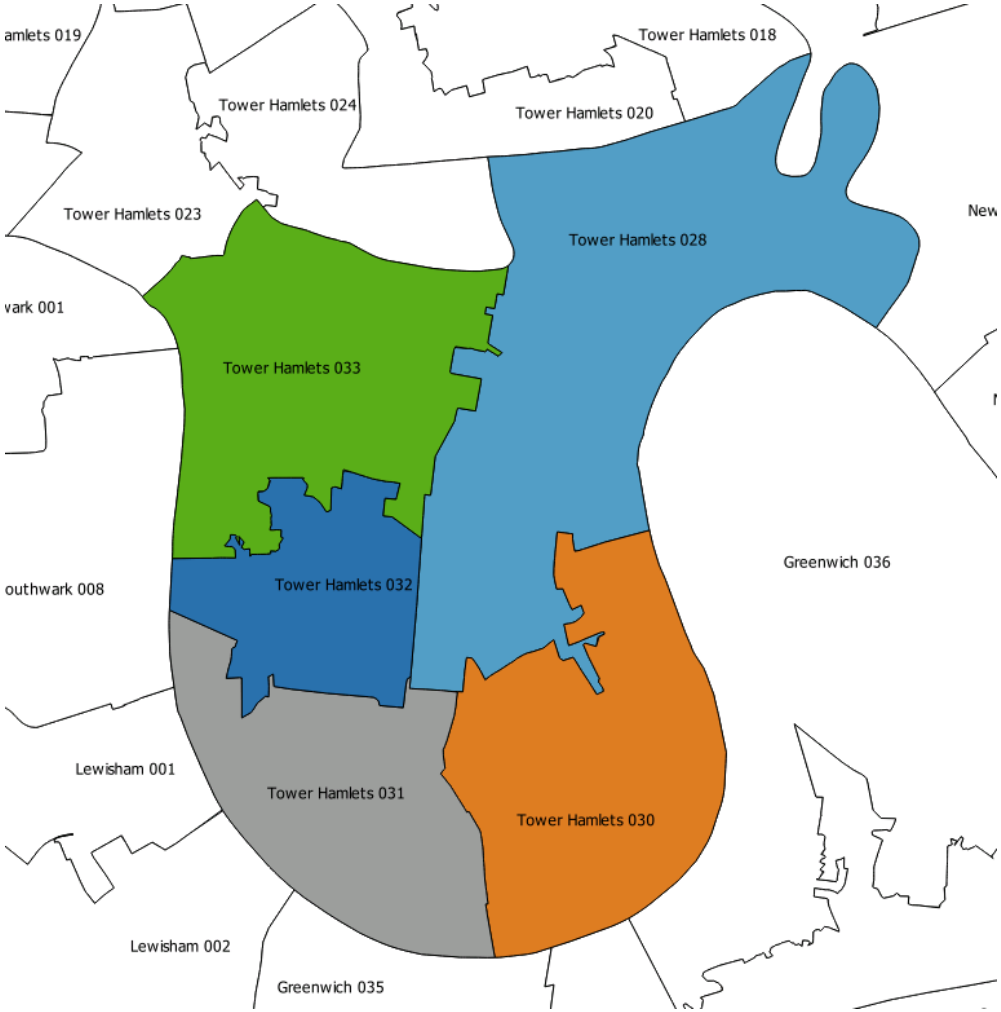
- Spatial: MSOAs – individual buildings
- Temporal: 24 hours – 5 minute resolution in summer/winter

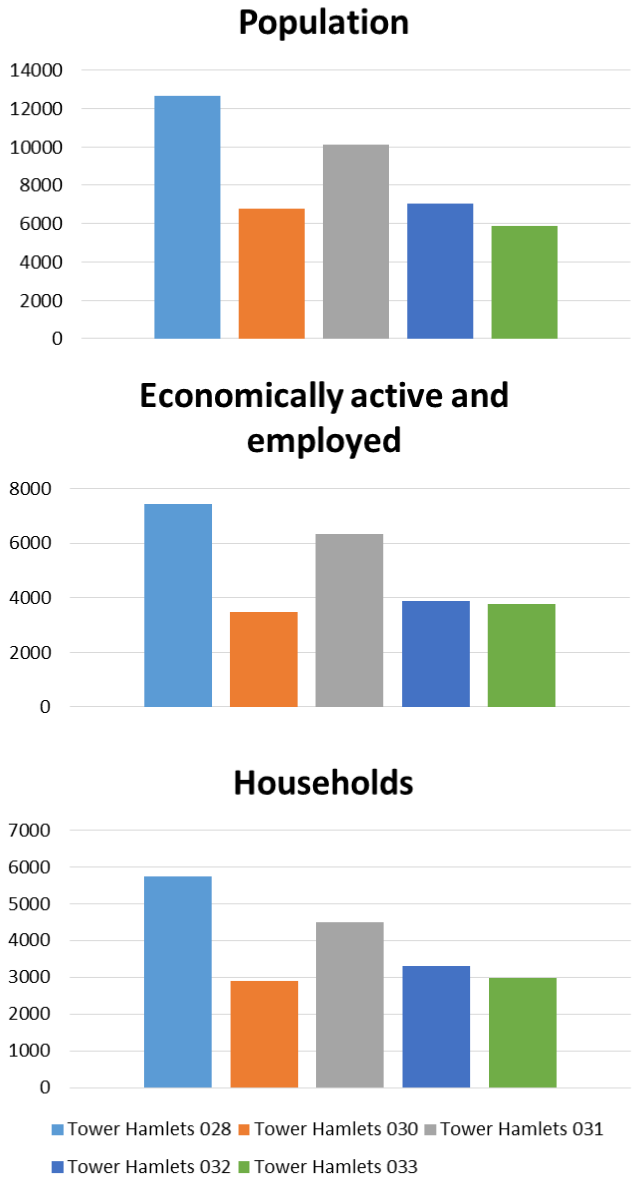
Case 2 – Isle of Dogs energy demands



(Land use consultants and the National Energy Foundation, July 2008)

Socio-demographics

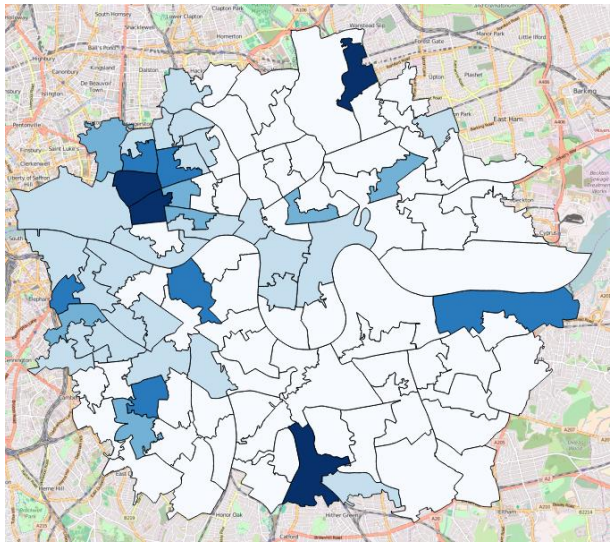




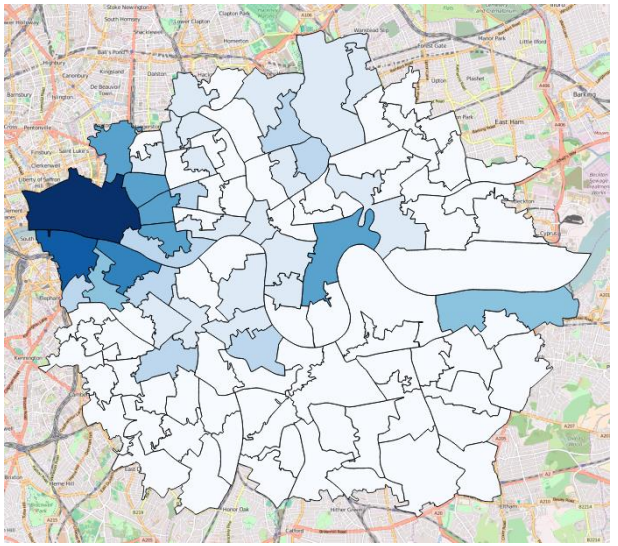
Source:ONS

Land use distribution

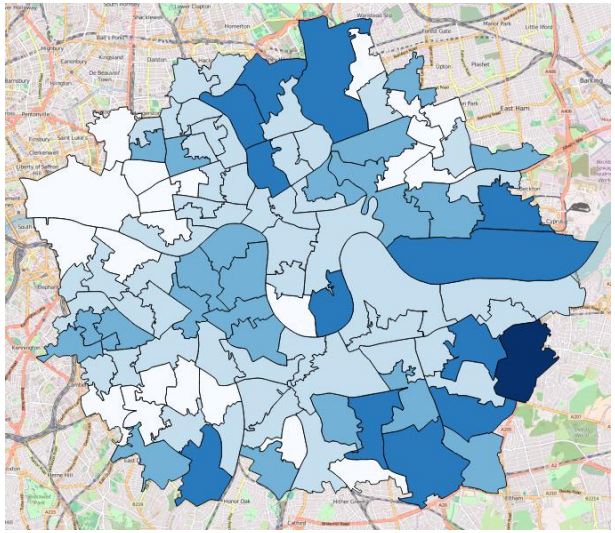
Retail area



Work area



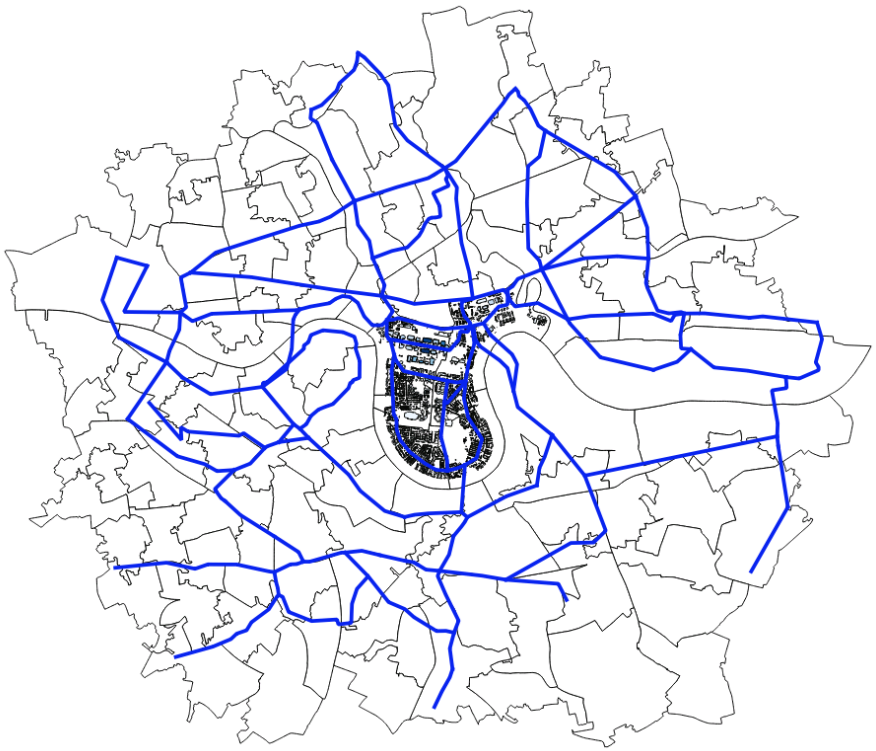
Leisure area



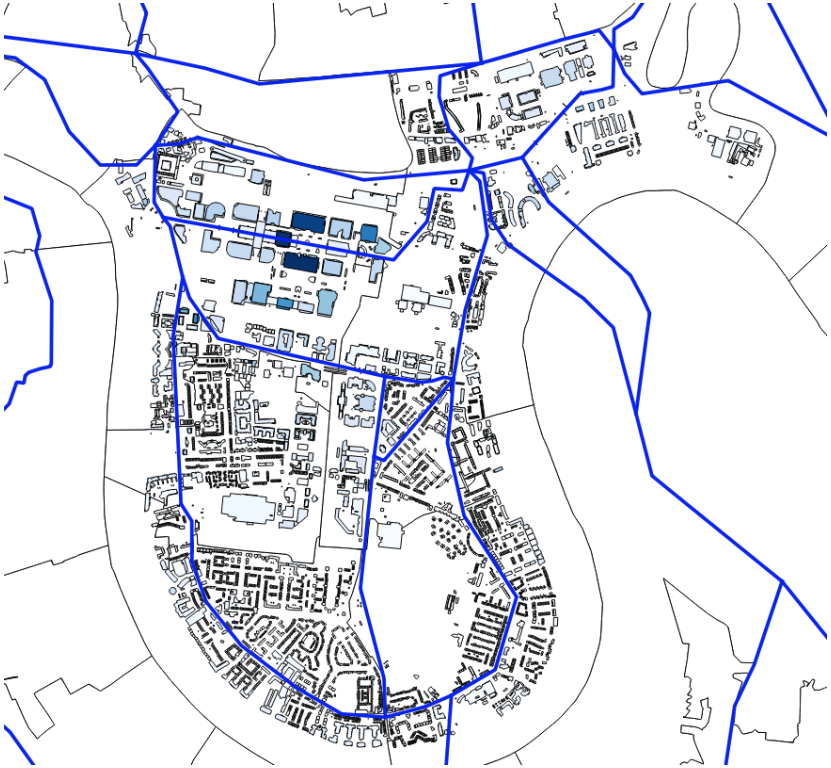
Source:ONS

Buildings and roads

Main roads

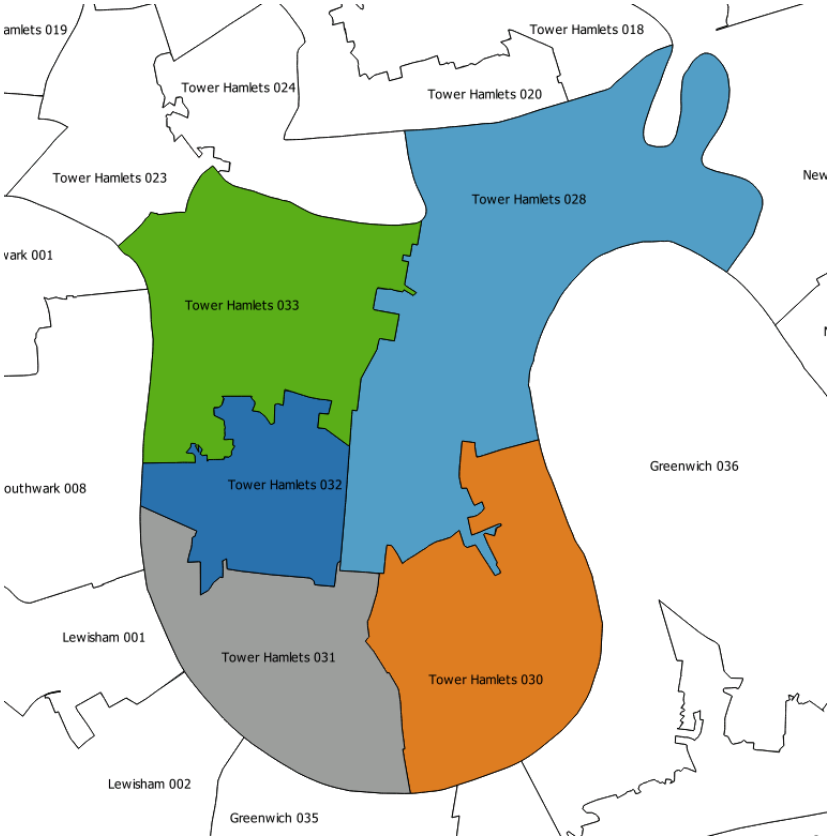


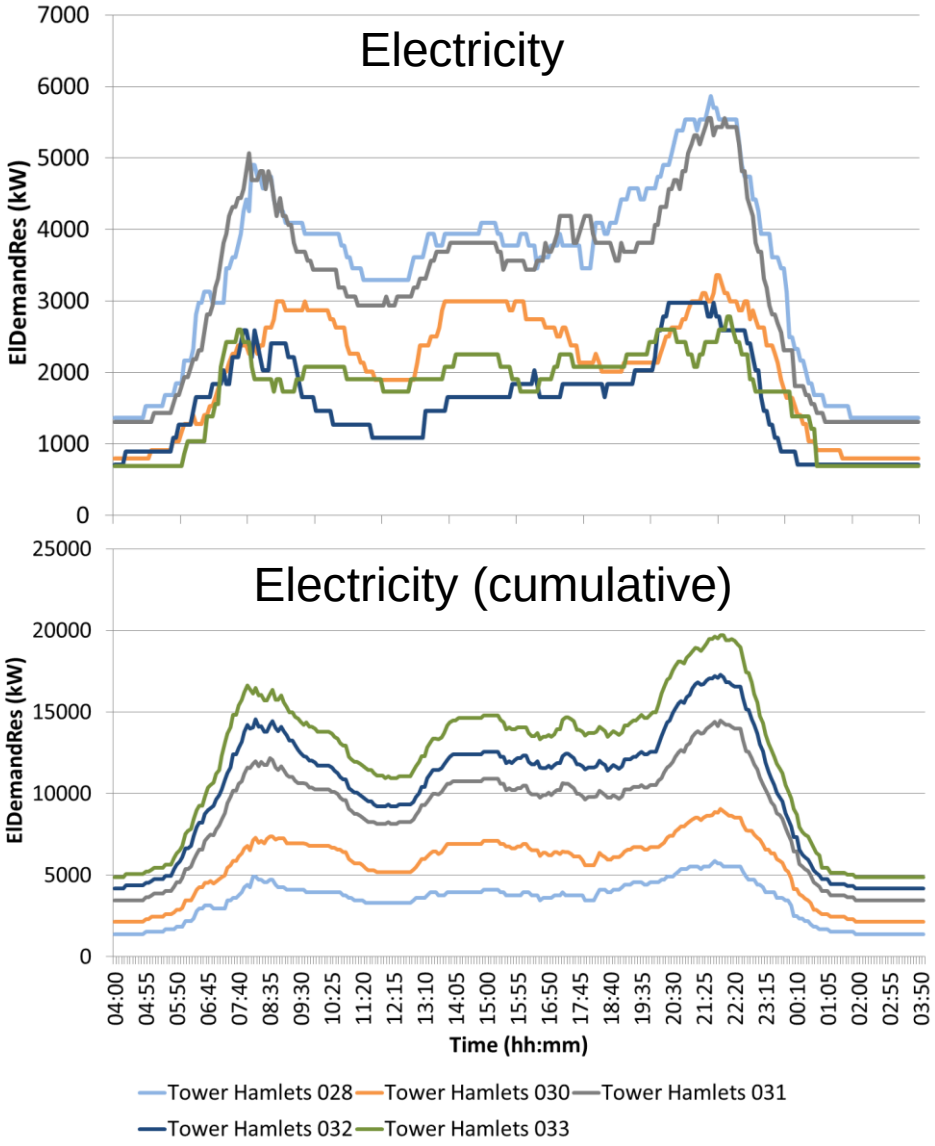
Buildings



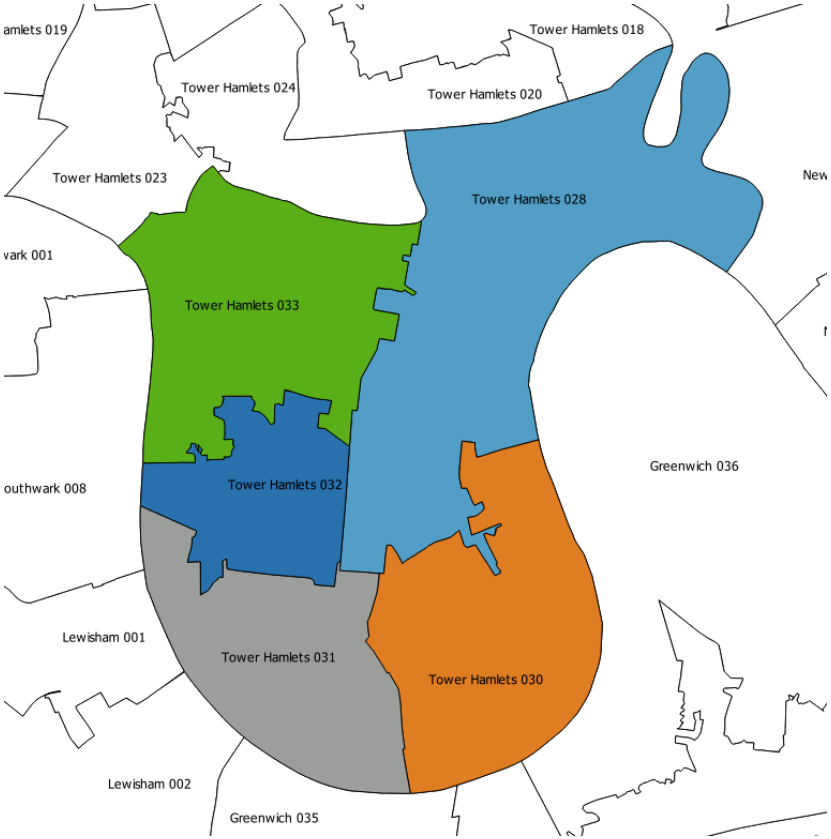
Source: Ordnance Survey, DigiMap, OpenStreetMap

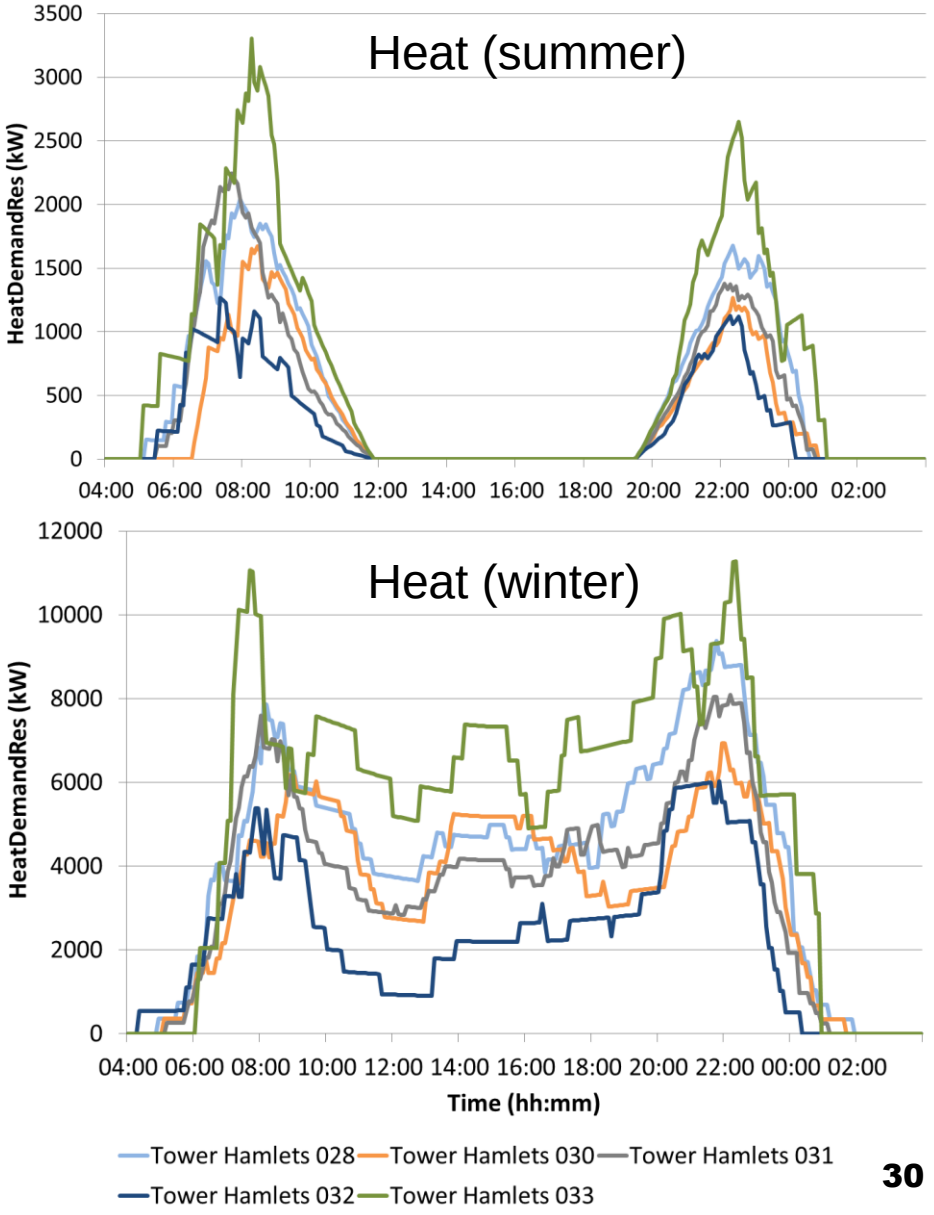
Preliminary outputs





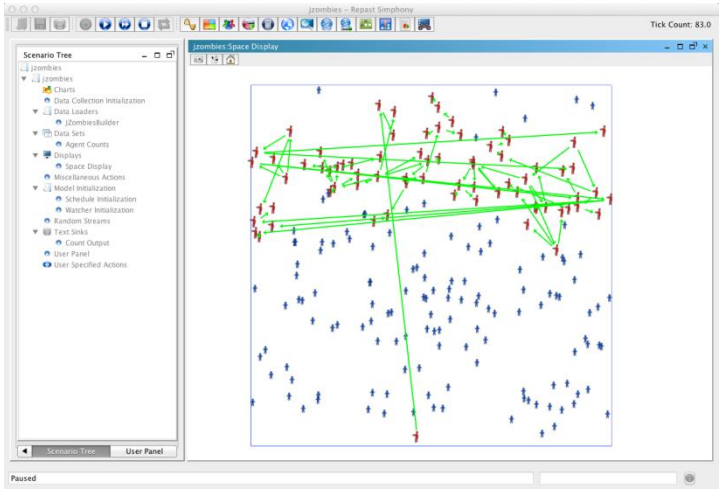
Preliminary outputs





Software tools

Repast Simphony

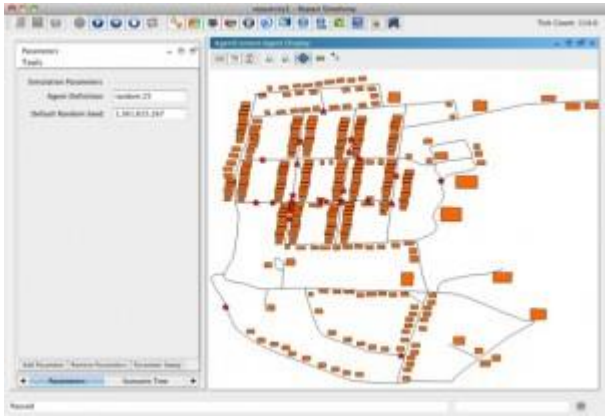


- Offers GUI for model launch, step and batch run, data collection, visualisation of agents and data
- Java implementation
  - Full connectivity with external software libraries and tools (e.g. optimisation, visualisation, data sets)
  - But…. that means you have to build most of your model from scratch
- Agents organised in (sub)contexts
- Model on grid, 2D or 3D space
- GIS integration
- Open-source software

repast.sourceforge.net

Repast Simphony – City modelling

- Can load ESRI shapefiles (.shp)
  - Polygon (e.g. buildings)
  - Lines (e.g. transport infrastructure)
  - Points (e.g. people)
- Instances of Java objects are created with properties set based on values in .dbf file
- All objects loaded can be seen as an agent, and thus can be scheduled to become active
- Load specific agents from file, or generate a synthetic population of *n* agents
- Tutorial/demo: Repast City
  https://github.com/nickmalleson/repastcity



Final remarks on Repast Simphony

- Suitable for complex projects where **interoperability** and **full control** are important…
- … but at a cost of **longer project development** and steep learning curve
- Easy to use with **spatial data** from OpenStreetMap, Ordnance Survey, etc.
- Works particularly well for when you want to make **changes to the spatial layout** of your agent-based simulation without changing your implementation
- Used successfully in **undergraduate and post-graduate thesis projects**, even without prior Java or object-oriented programming knowledge

Conclusions

Conclusions

- Model development to understand main factors in urban energy demand, with different levels of spatial (building—city) and temporal (minutes—annual) detail
- Bottom up approach enables us to experiment with different technologies, but also how they are used
- Models can be used to influence policies and technology decisions
- Collaborative decision making: using simulation as a design tool
- **Current and future work:** charging infrastructure (with TfL, GLA), heat networks (with EDF), water and sanitation (with Ghana Water Company and others), urban area redesign (with LLDC, Engie and others), etc.

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