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# Tools and workflows in the design of urban energy systems

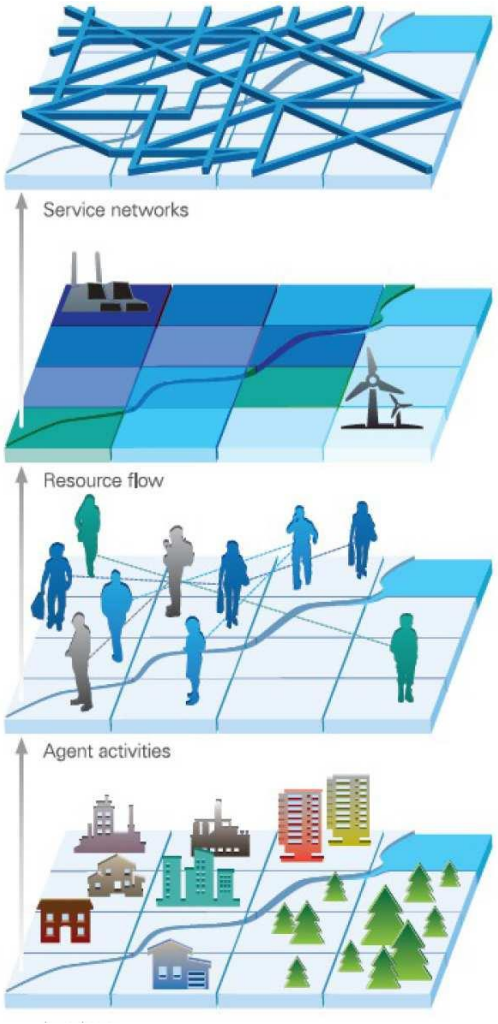
Kamal Kuriyan and Nilay Shah

AIChE Meeting, San Francisco, November 2016

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# Urban energy model

- SynCity prototype (Keirstead, Samsatli, Shah, 2009)
- Spans different modelling formalisms, aggregation levels, objectives for sub-systems
- Land use (Keirstead and Shah, 2011)
  - Given aggregate activity levels, building types and transport links, optimise building and transport costs (MILP)
- Agent activities
  - Simulate agent activities and movements to estimate energy demands (Keirstead and Sivakumar, 2012)
- Resource flow
  - Given spatial and temporal distribution of demands , optimise selection and location of processes to meet demands (MILP)



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# Implementation

UrbEn tool

Interactive scenario construction, analysis

User interface packages (JavaFX)

Forms/validation, visualisation, charts, scenario serialisation

Modelling framework packages(Java)

Cityspace, ontology, utility, manager, model

Protégé, JScience, SSHJ, Jung, Xstream

Ontology, units, networking, graphs, serialisation

GAMS

Algebraic optimisation model

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# Resource flow model

- Technological framework
  - Resource Technology Network (RTN)
  - Conversion, transport and storage processes
  - Similar to State Task Network for batch process scheduling
- Spatial framework
  - Process locations and resource transport network links
- Temporal framework
  - Hierarchical discretisation (Samsatli and Jennings, 2013)
    - H (hourly), D (daily), S (seasonal), Y (yearly)
  - Single temporal index (e.g. Morlet and Keirstead, 2013)

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# Model variants

- TURN (Samsatli and Jennings, 2013)
  - Detailed and reduced versions (GAMS)
- STeMES (Samsatli and Samsatli, 2015)
  - High level of detail with decomposition algorithm
- resilience.io RTN model (Wang et al., 2016)
  - Open implementation (Java/glpk/R) for WASH sector
- UrbEn resource flow model
  - Intermediate level of detail, convenient for interactive use and to connect with other tools
  - GAMS/CPLEX, Pyomo/Gurobi, Pyomo/glpk

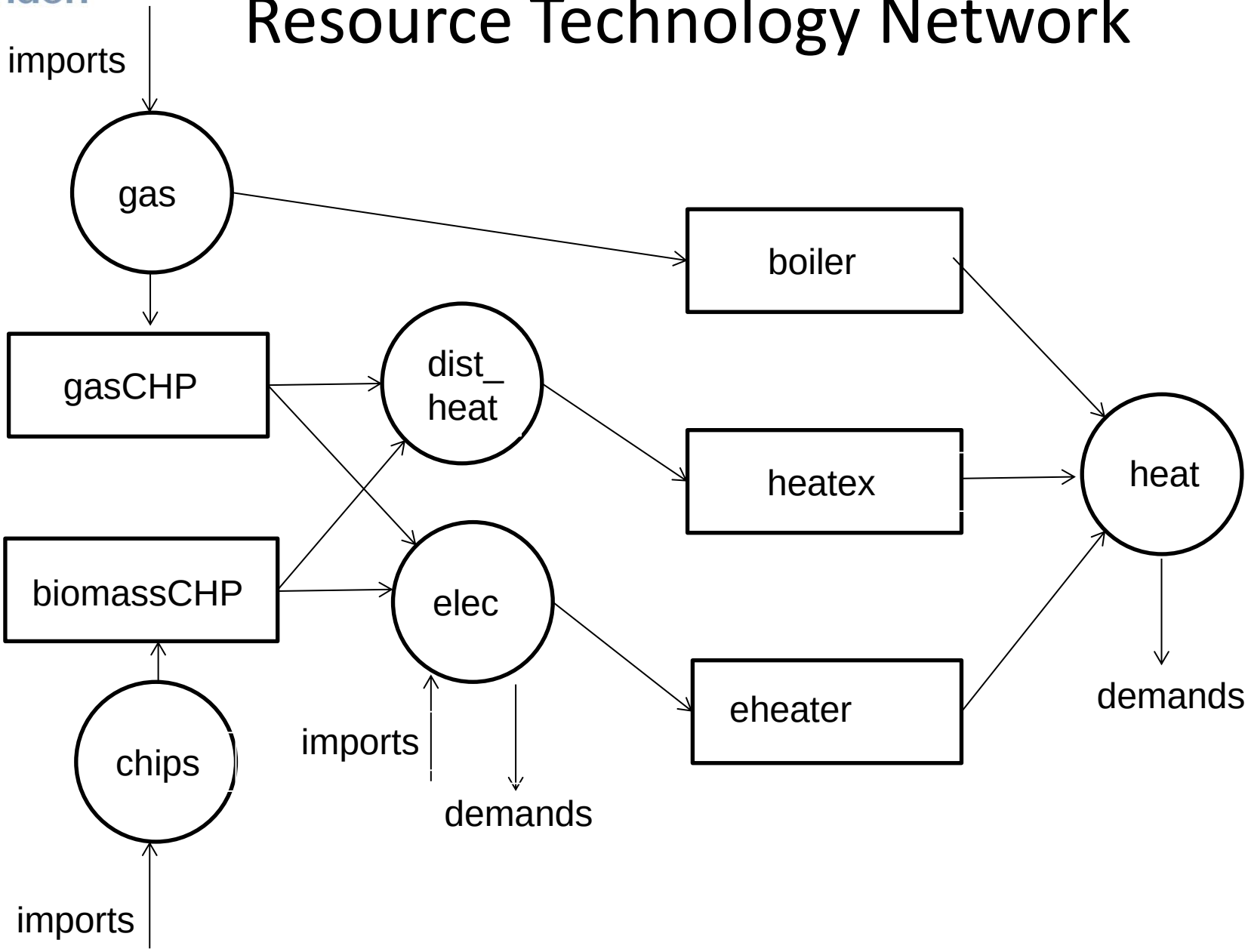
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# UES ontology

- Draw data from a generic database
  - Consistent framework for different model variants
  - Transfer information between projects
- Protégé ontology (Keirstead and van Dam, 2011)
- Resources
  - All materials and energy carriers
  - e.g. Coal, diesel, electricity, gas, heat, waste heat, wood chips
- Process type
  - Conversion, transportation, storage
  - e.g. Space C/H, Building C/H, CHP, Power generation
- Infrastructure (resource transport)
  - e.g. electricity, gas, heat network

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# Resource Technology Network



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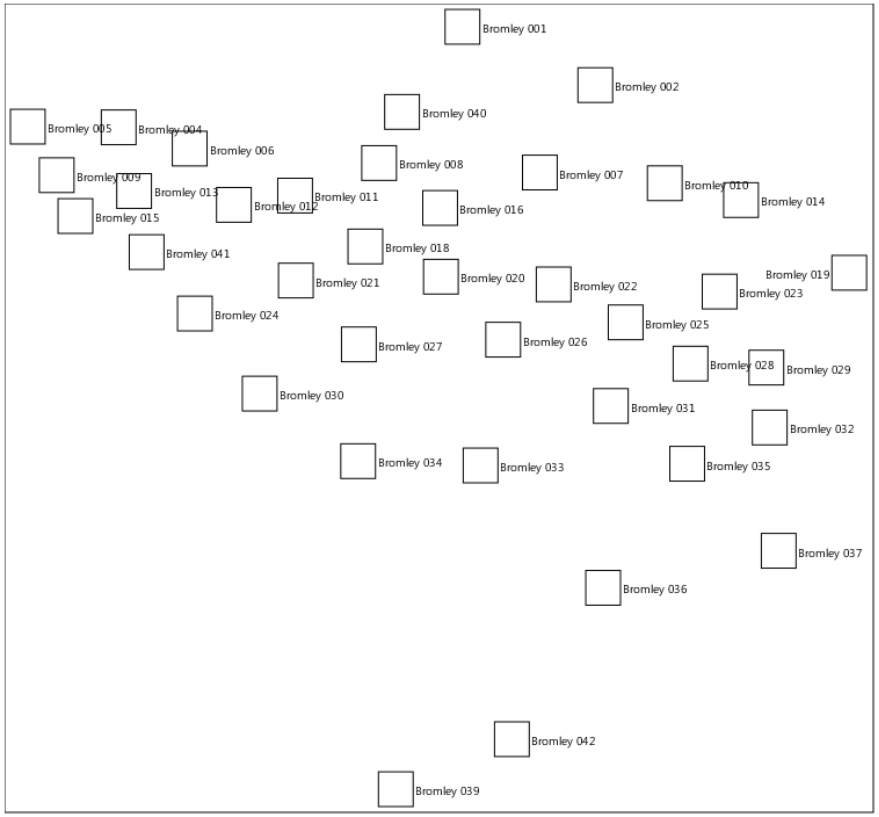
# Spatial and temporal framework

- Cells
  - Co-ordinates of centroid
  - Cell area
  - Neighbours (potential network connections)
  - Households
- Investment (major periods)
- Cell energy demands (minor periods)
  - Demand variations (peak/average)

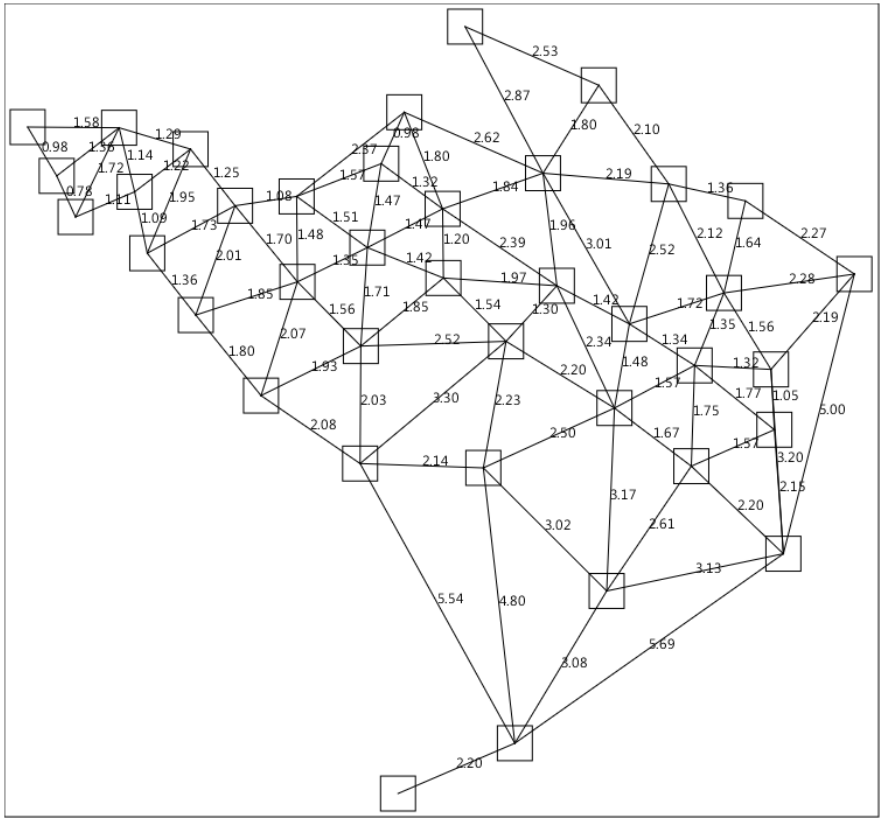
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# Spatial framework

District level, Bromley (Zavitsas and Keirstead, 2015)




Grid cells

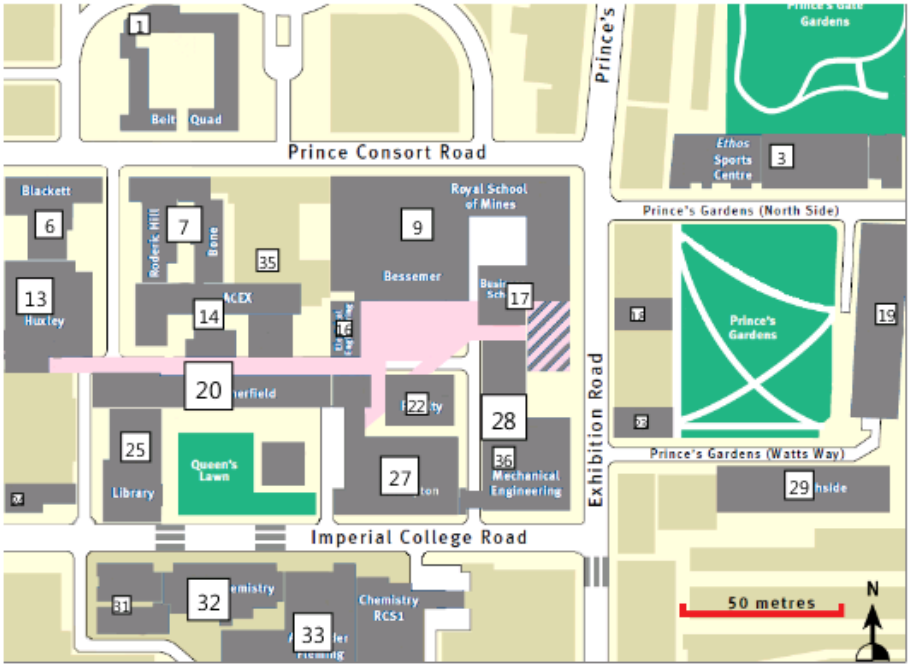


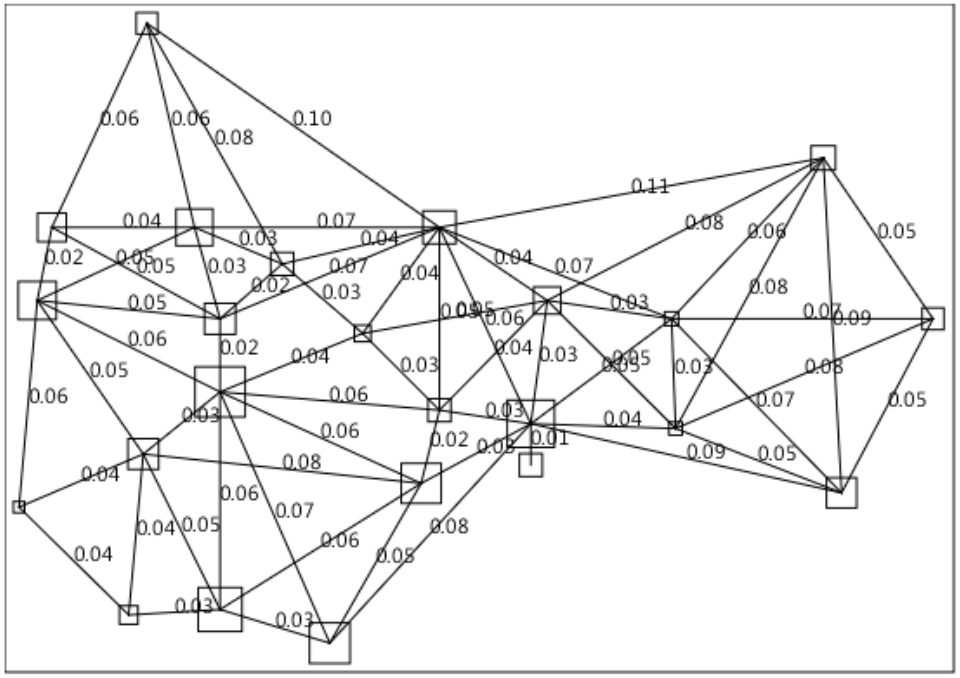
Neighbours

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# Spatial framework

Building level, South Kensington campus, Imperial College (Loeber, 2015)



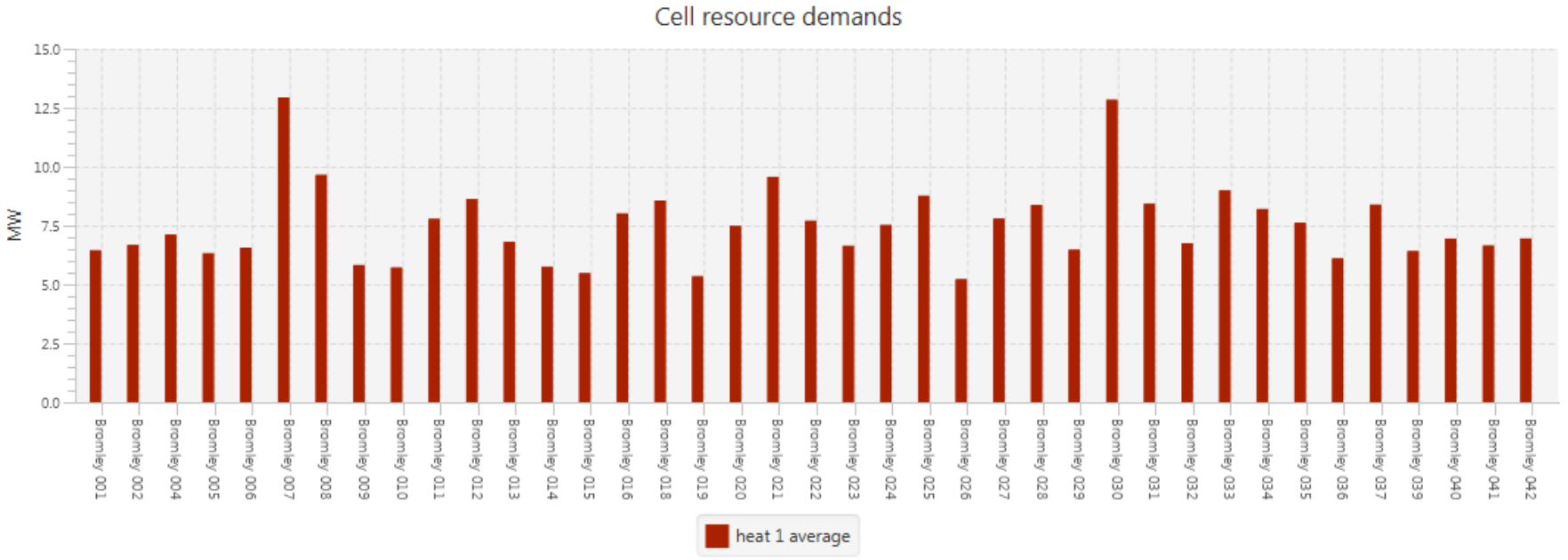
Grid cells

Neighbours

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# Temporal framework

## Demands for each cell, time period, resource




Average heat demands for Bromley

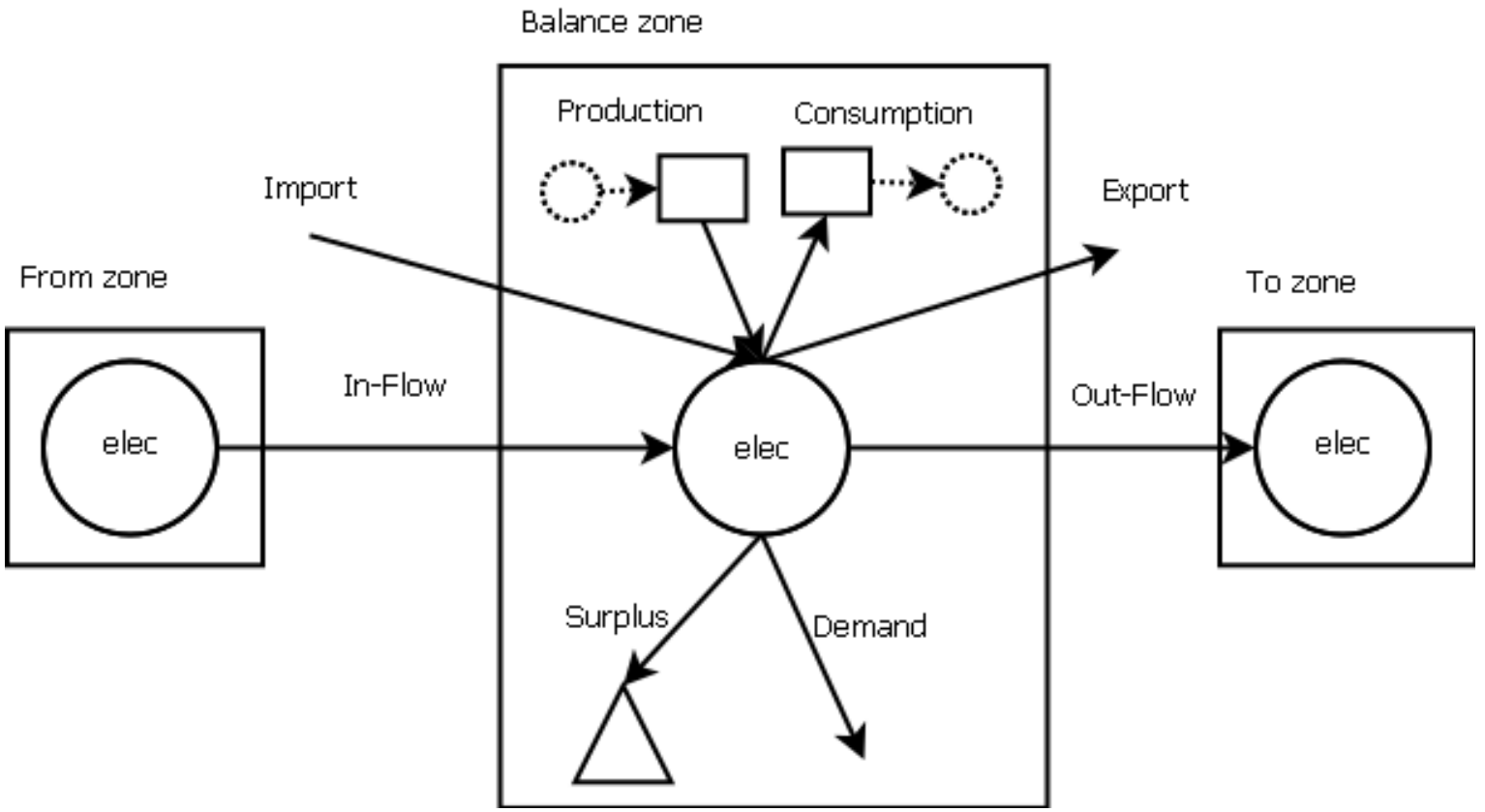
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# Resource flow model

- Resource balance
  - Consumption, production, import/export, transportation
- Technology selection
- Constraints
  - Import locations, amounts
  - Allowed connections, max rates
  - Max number of processes in cell, min, max rates
  - Emissions targets
- Objective
  - Min weighted metrics (capex, opex, ghg)

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# Resource balance



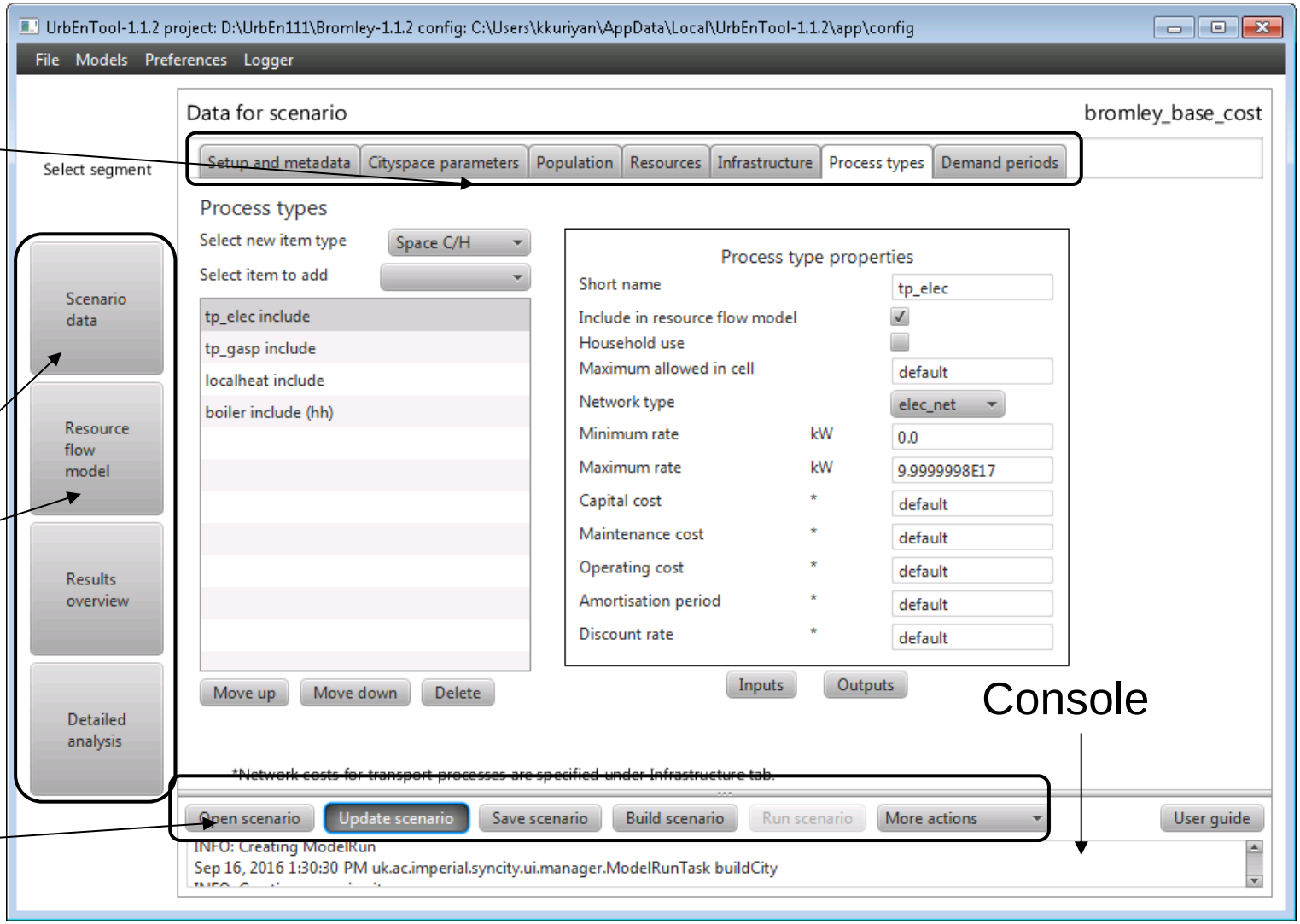
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# Tool features

- UrbEn tool (Kuriyan, 2015)
  - Interactive scenario construction and execution
  - Create scenario, assemble model, initiate and monitor execution
- Scenario data
  - Cityspace, resources, infrastructure, processes
- Resource flow model
  - Solver settings, model customisation, tariff based incentives
- Results analysis
  - Charts (demands, process  numbers, capital costs, resource supply)
  - Resource flows, conversion processes, import locations
  - Resource deficit for infeasible problems

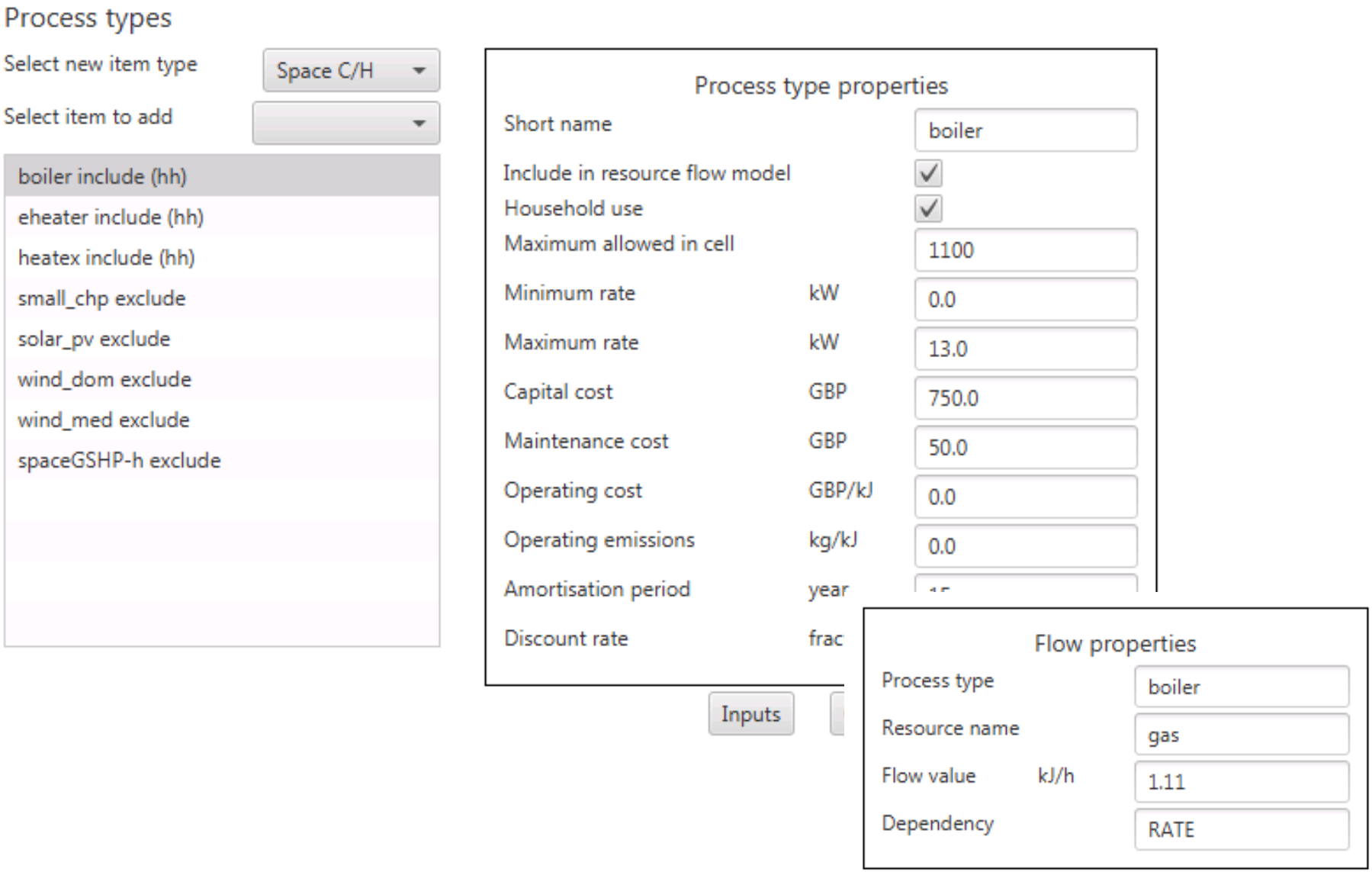
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# Scenario construction



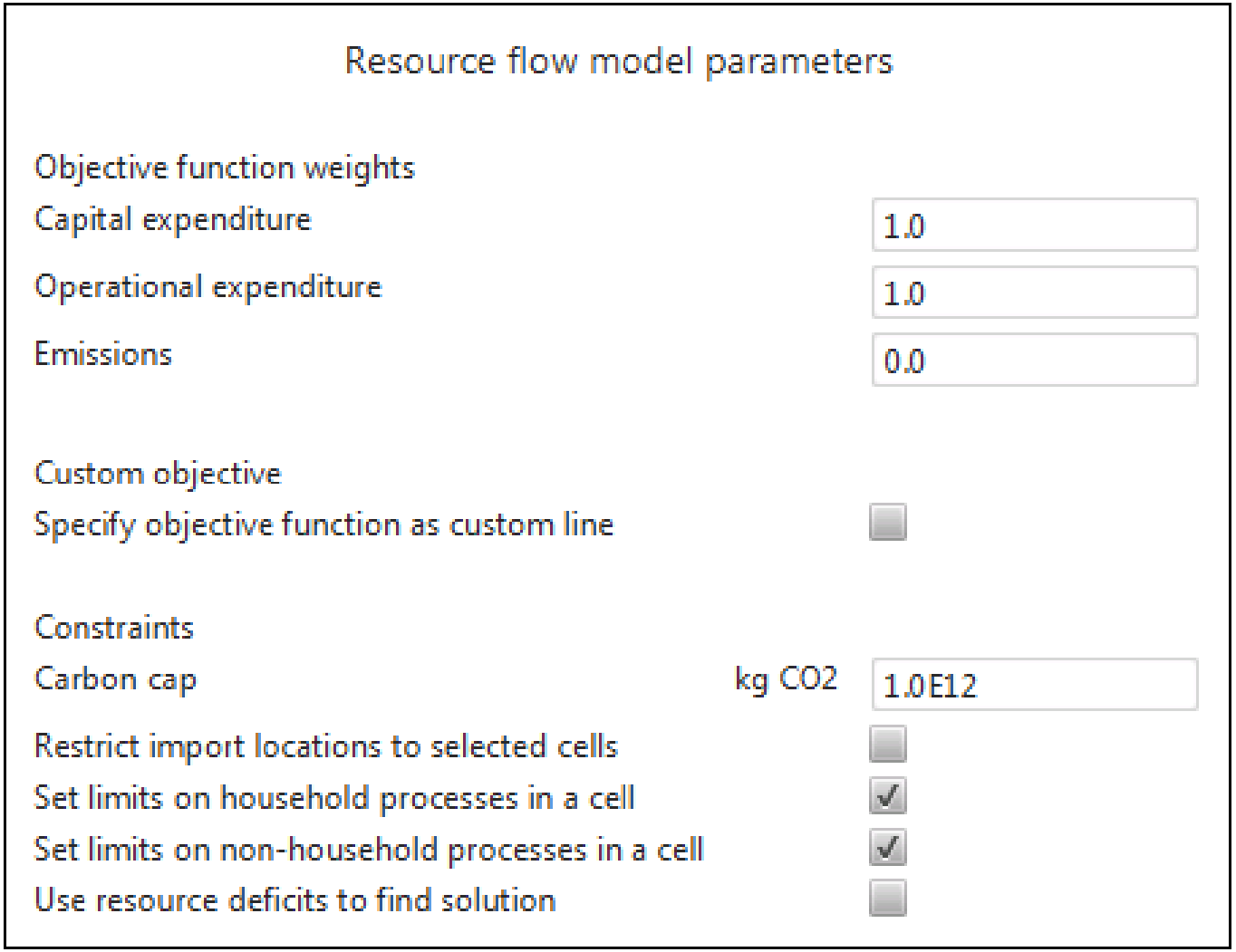
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# Process properties



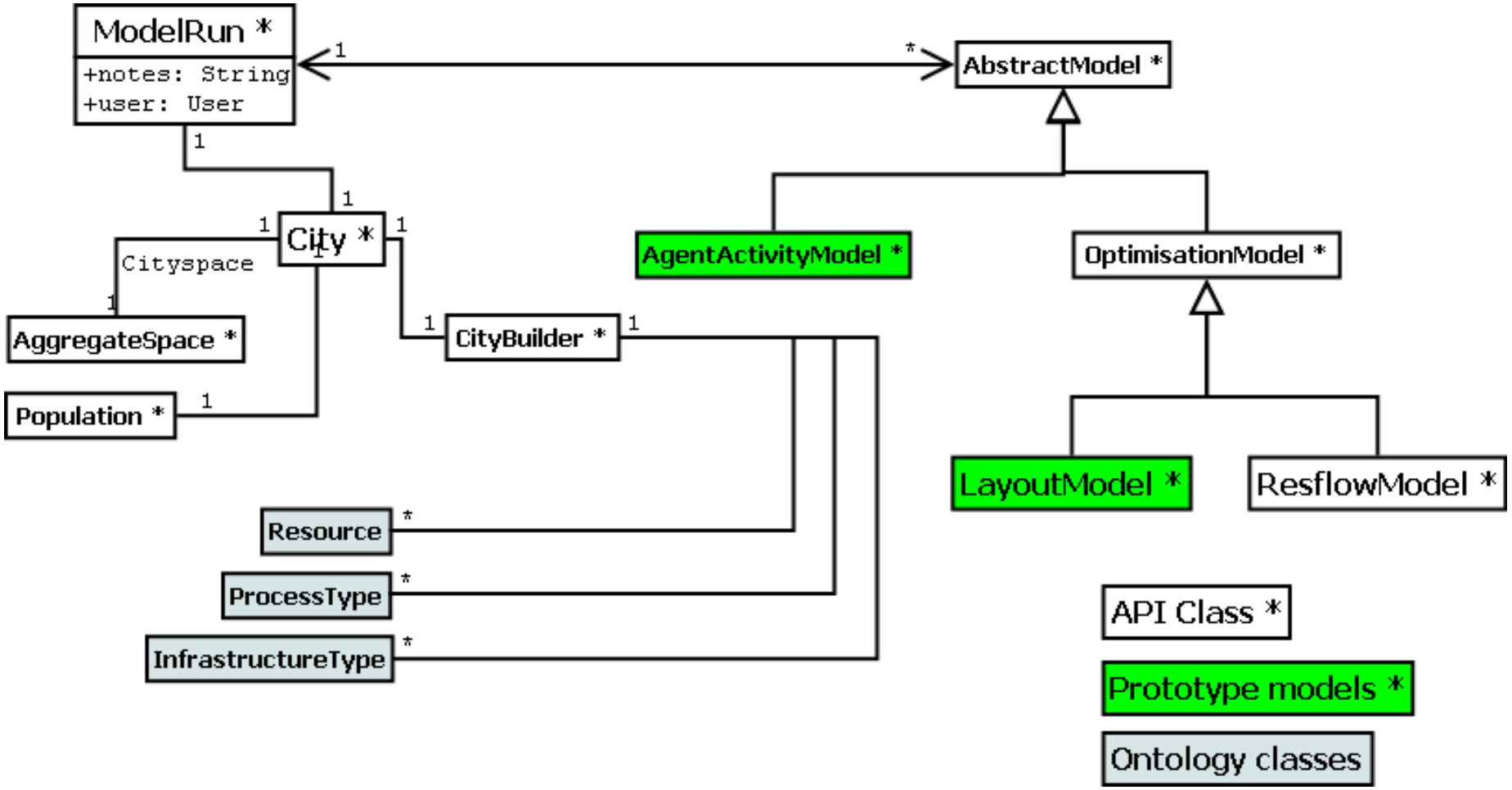
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# Resource flow model parameters



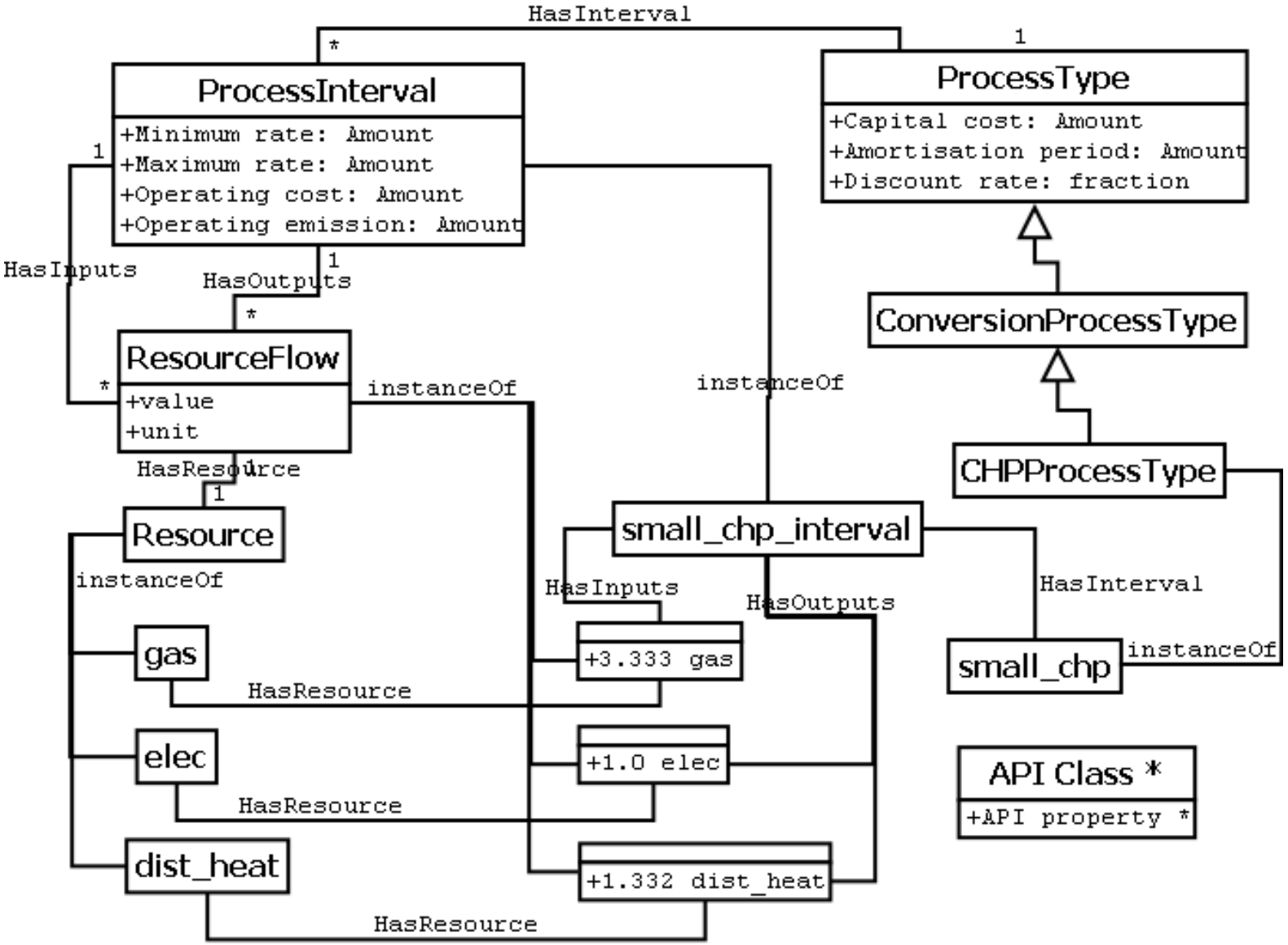
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# Scenario construction



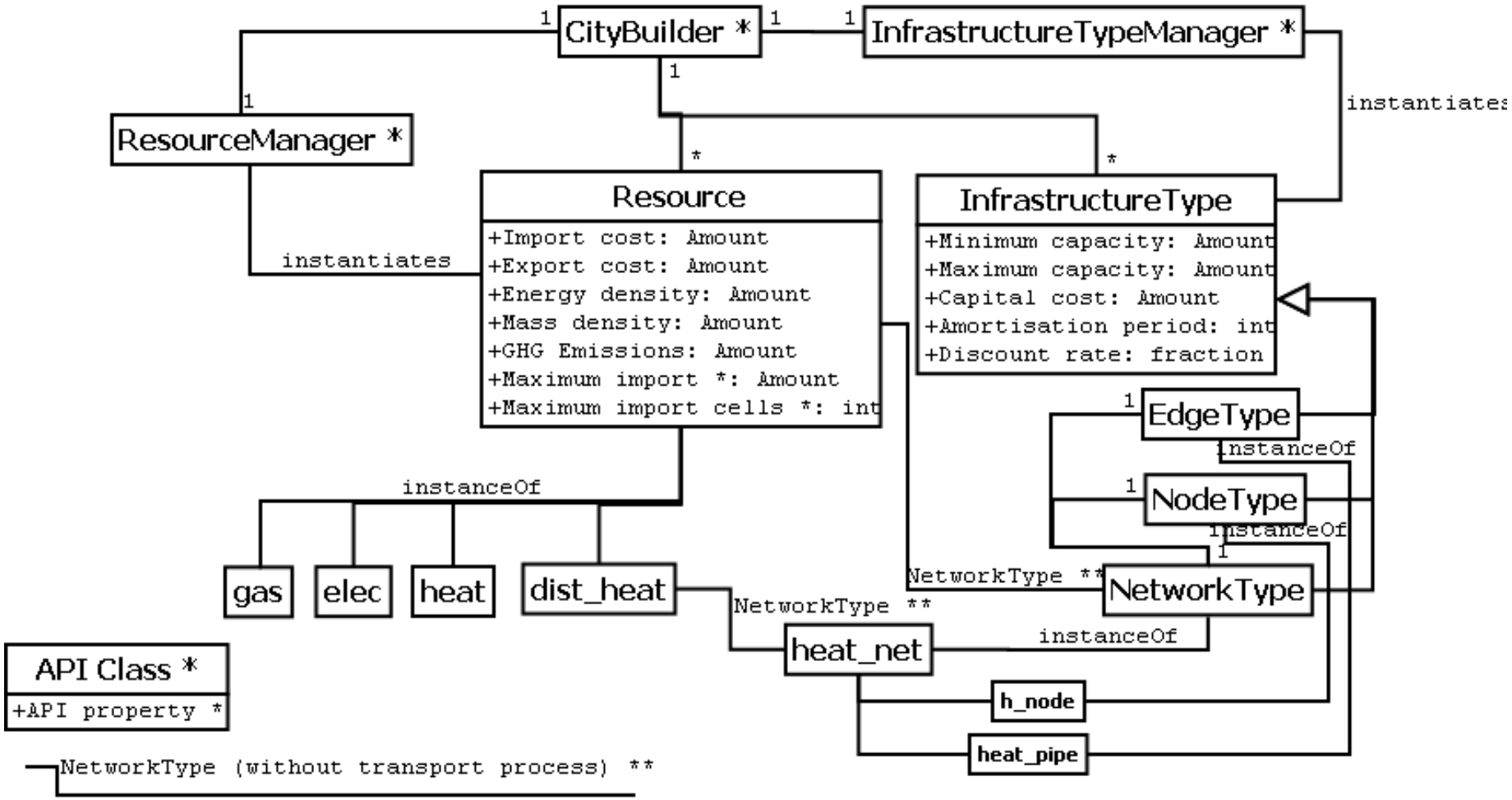
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# Processes



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# Resources and infrastructure



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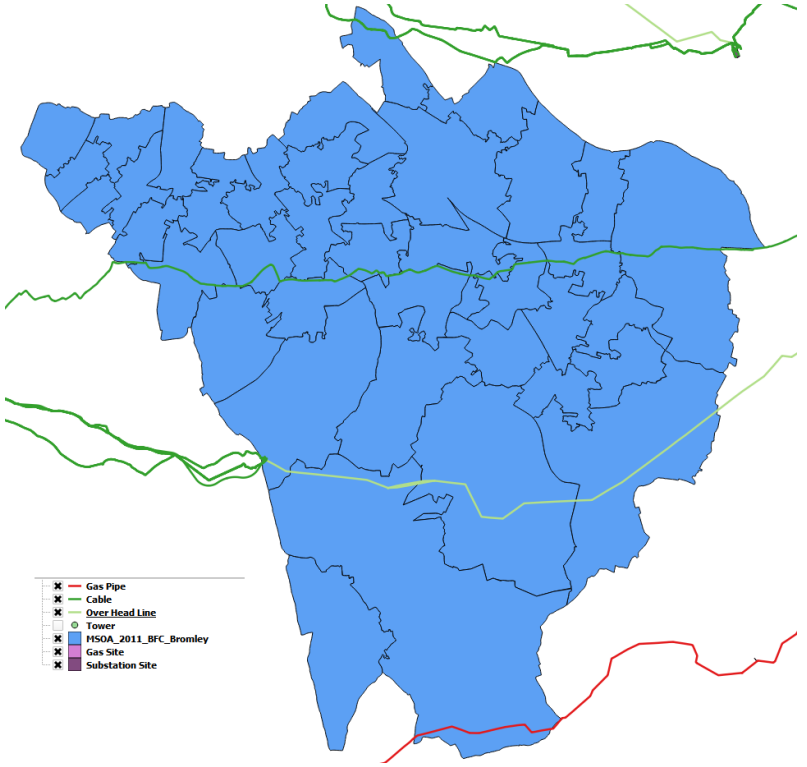
# Range of applications

- Different objectives (C02, cost, mixed)
- Spatial resolution (campus, district, city)
- Technology selection
  - Imports, local generation, heat pumps
- New cities, technology transitions
  - Lingang new city, China (Liang et al., 2012)
    - Cooling and heating network
  - European cities (Morlet and Keirstead, 2013)
    - London, Paris, Berlin, Copenhagen
    - Incentives, local policies, governance structure
    - Meeting CO2 targets

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# Example: Bromley

- The Department of Energy & Climate Change (DECC) collected sub-national electricity and gas consumption data from 2004 onwards
- Existing electricity and gas infrastructure information from national grid



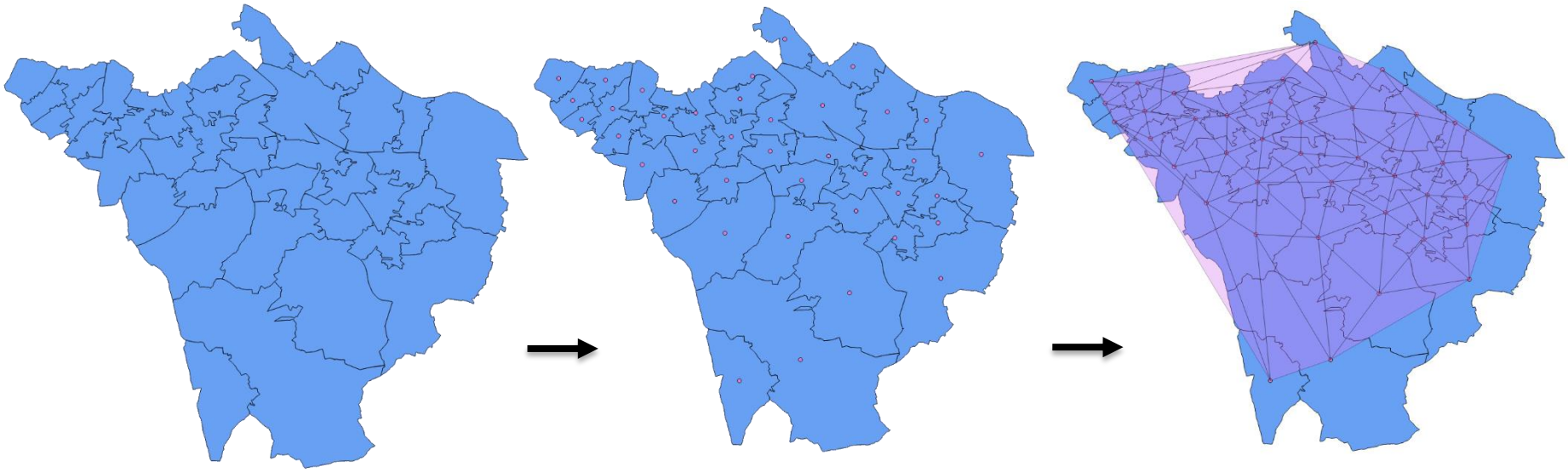

Bromley energy supply infrastructure

Zavitsas and Keirstead (2015)

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# Example: Bromley

- Centroid locations and distances are obtained from GIS shape files



Bromley cells

Centroids

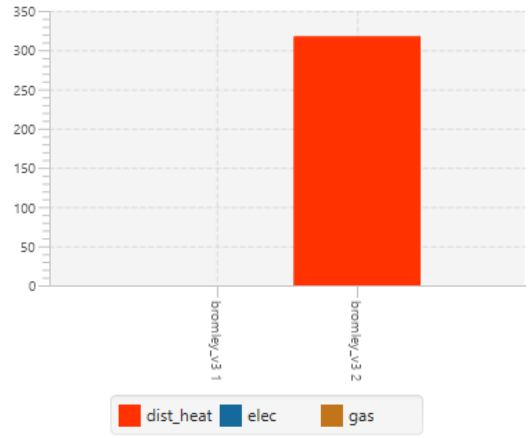
Distance matrix

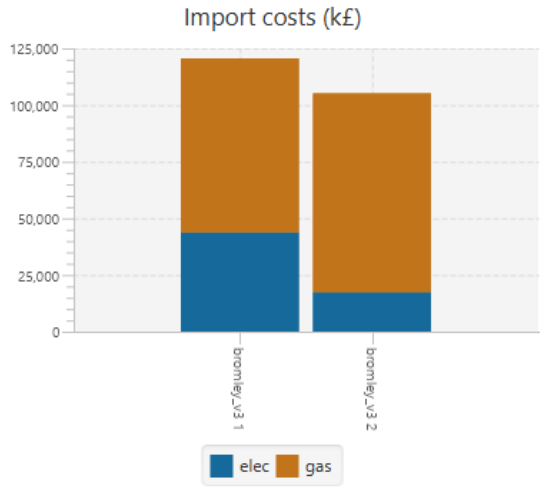
- First period: imports, boilers, existing gas/elec networks
- Second period: CHP, heat exchangers, heat network

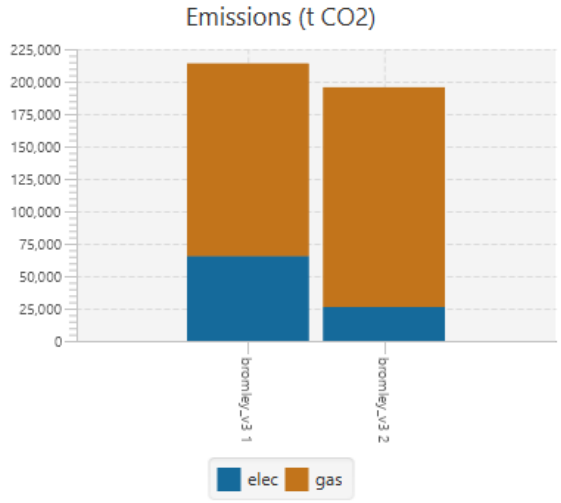
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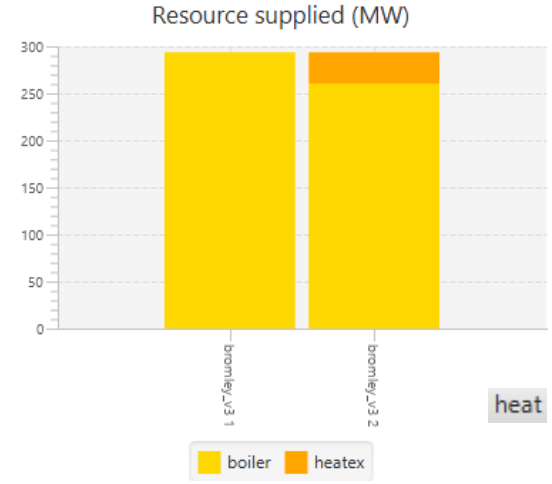
## Resource flow metrics

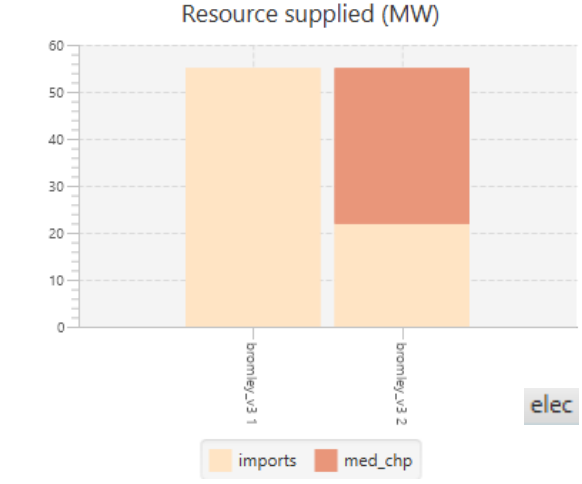
| Scenario | Objective value | Capital cost (k£) | Operating cost (k£) | Emissions (t CO2) |
|---|---|---|---|---|
| bromley_v3 1 | 127457 | 0 | 127457 | 213983 |
| bromley_v3 2 | 113840 | 6547 | 107292 | 195664 |

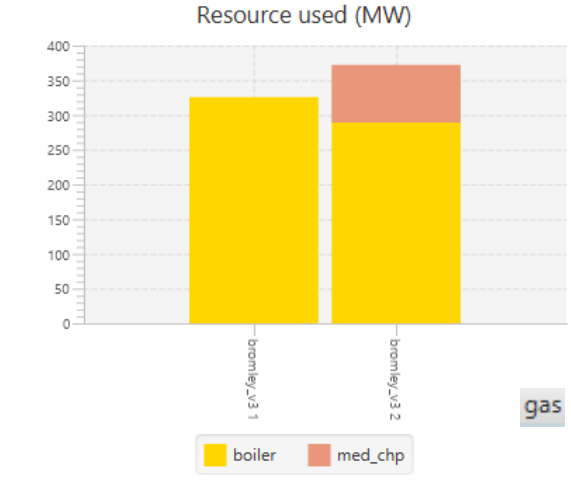


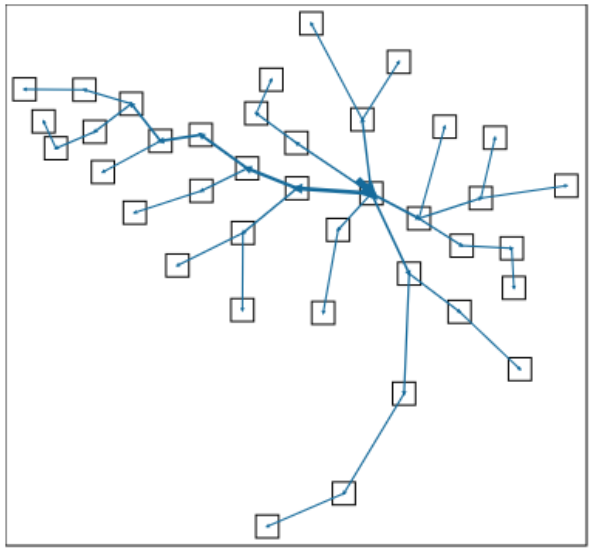



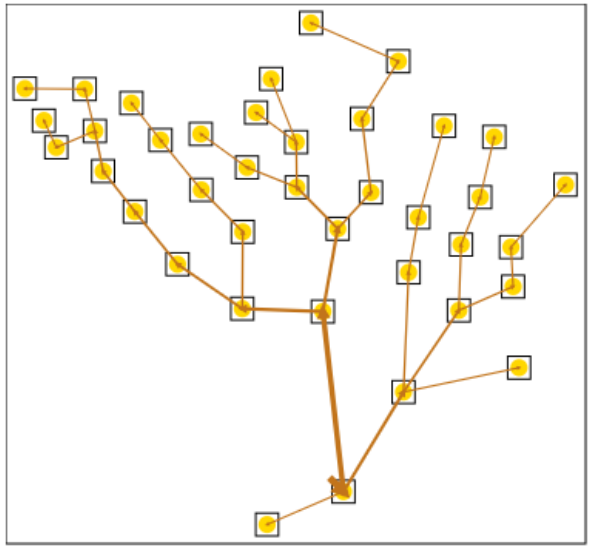



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electricity

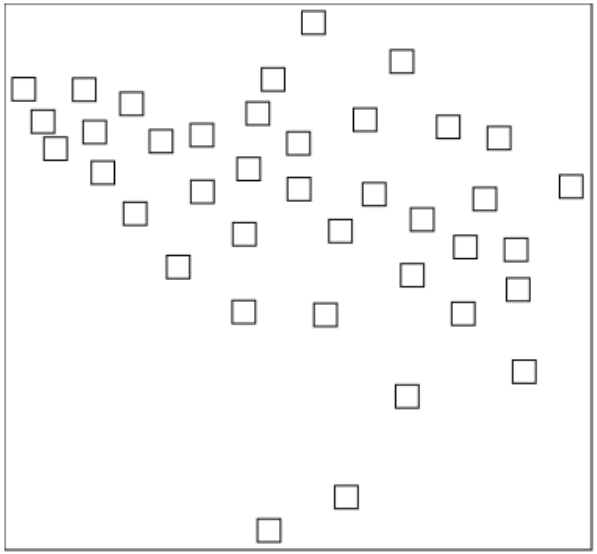
med_chp



gas

boiler

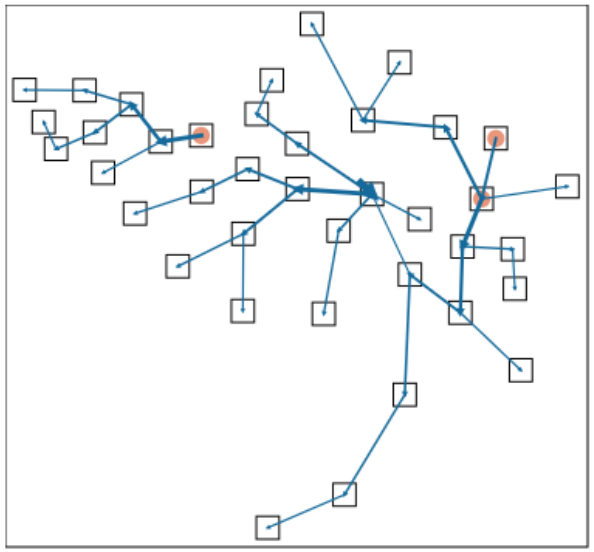
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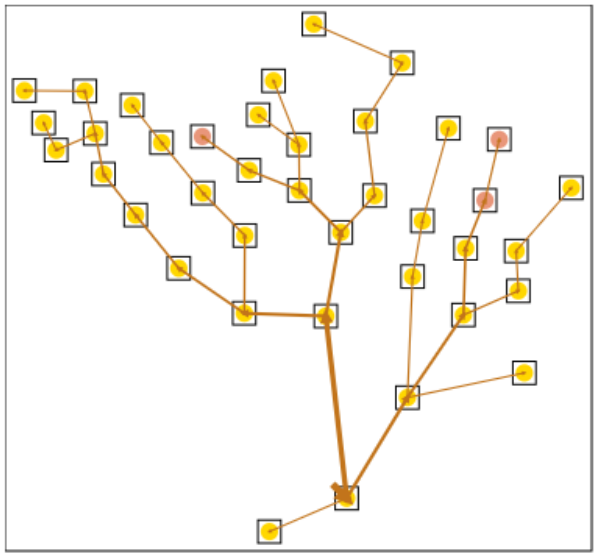


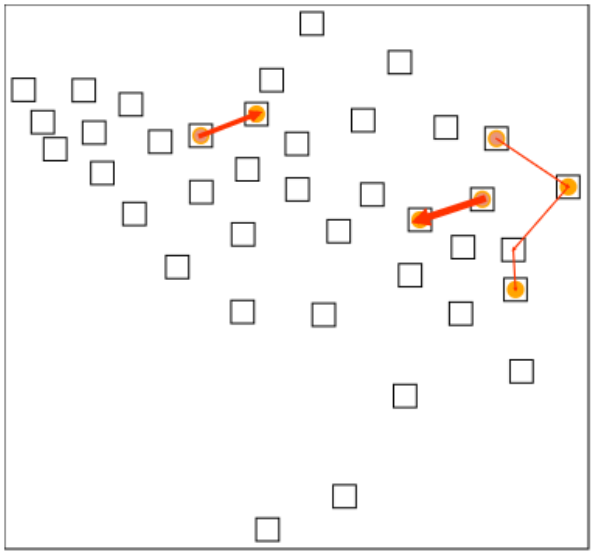
district heat

heatex

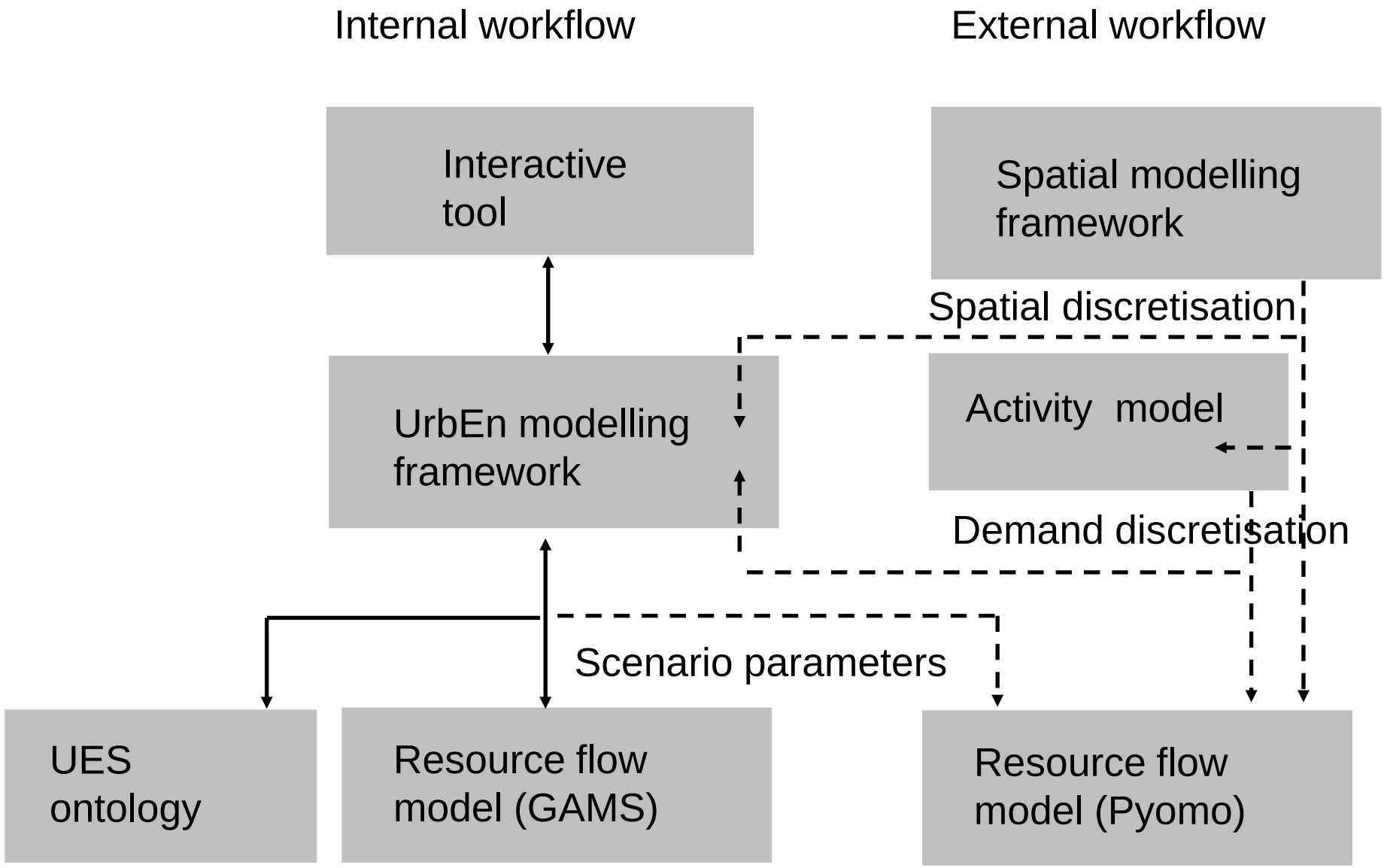
med_chp







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# External workflows

- Connect to activity models, geospatial information systems
- Smart city data infrastructure
- CityGML – Semantic 3d model
- Application domain extensions
  - Energy ADE
  - UitlityNetwork ADE
- Energy demands at the required temporal and spatial level of detail
- Web services protocols for sensors
- Combined visualisation of resource flows and city model
- Sensitivity analysis for distributed energy systems

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# Summary

- Tool, ontology and algebraic model (MILP) for optimal selection and location of energy conversion processes and transport links
- Assemble ontology and cityspace objects into optimisation scenarios with potential locations and technology choices
- Model output includes technology types, capacities, operating rates, locations and resource flows
- Models for land use and agent activities can be connected to form an integrated model
- Part of a broader range of tools for building models of urban systems (resilience.io; SmartCityModel)
  - Water sector; electric mobility

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