A combined spatial and technological model for planning district energy systems

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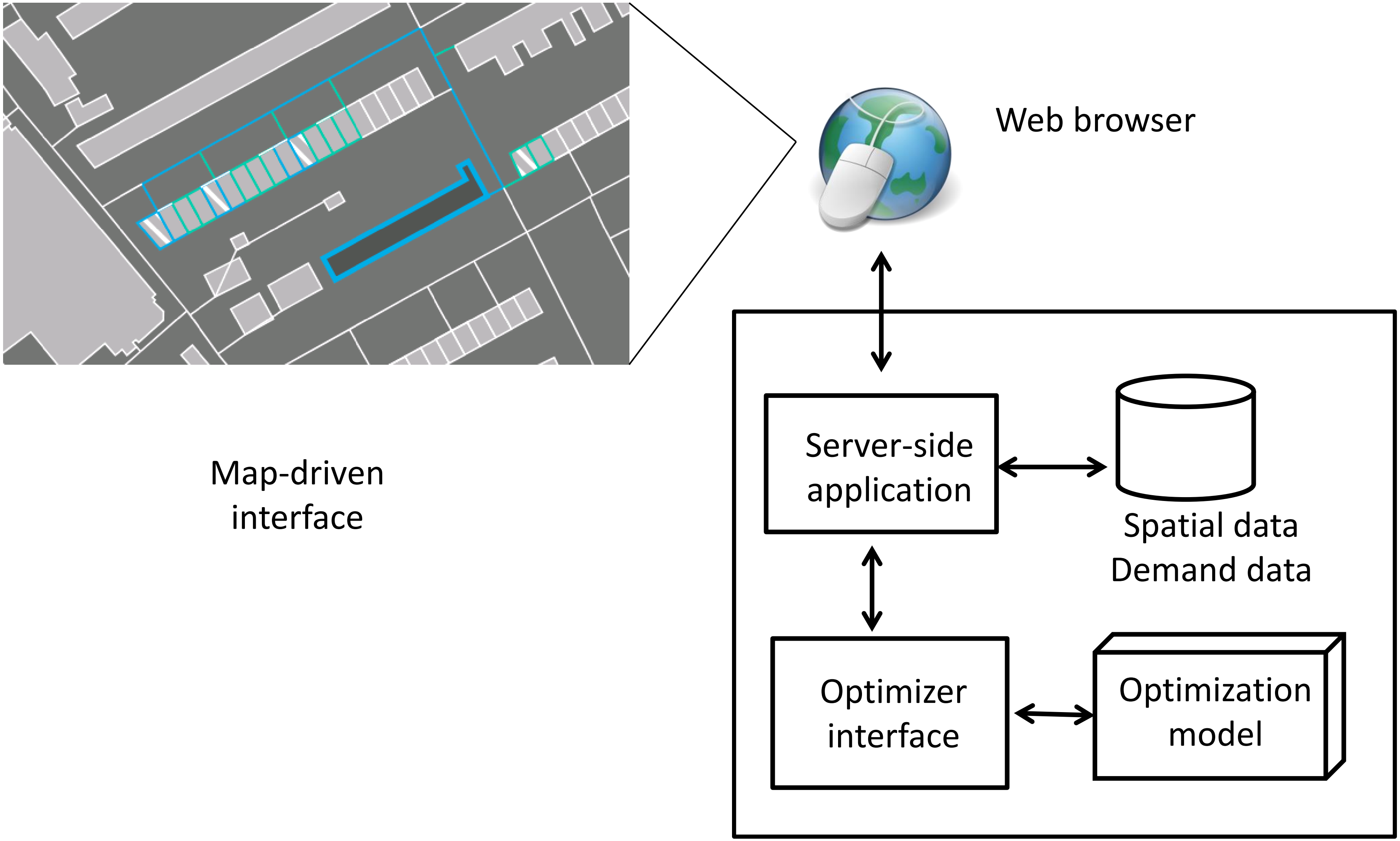
Introduction

- Map-driven modelling of district energy systems
  - Embed energy system model in a web-application
  - Thermal Energy Resource Modelling and Optimisation System (THERMOS)
- Model based decisions
  - Select connected heat loads, distribution route, location of energy source
  - Select technology type (e.g. heat pump, boiler, CHP), scale, fuel (biomass, gas)
    - Combined techs (e.g. local electricity generation + heat pumps)
    - Combined heat and electricity demands or exports
  - Objective: opex, capex, ghg



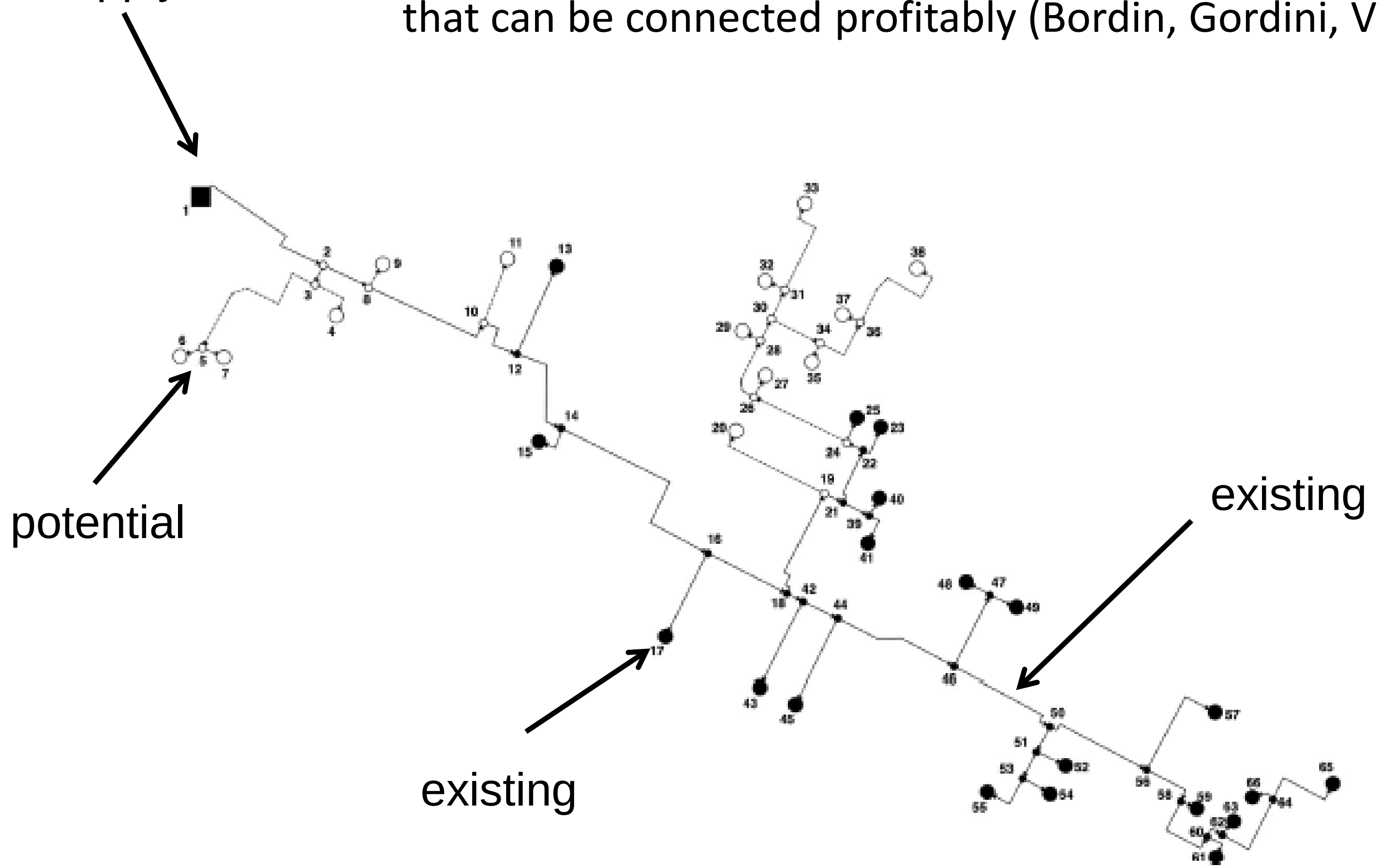
Application developed by CSE Bristol

District heating system models

- Model prototyping and development
  - Review → Specification → Testing → Application design/development
- Planning → Design → Operation → Control
  - Spatial, temporal and technological components
  - Aggregate models → Detailed models
- Planning and preliminary design models
  - MILP optimisation model (Bordin, Gordini, Vigo, 2016)
  - MINLP optimisation model (Weber, Favrat, Marechal, 2007)
  - Non-linear model with genetic algorithm (Li, Svendsen, 2013)
- Detailed design models (Pirouti, 2013)
  - Thermal and hydraulic model of distribution network
  - Estimate heat losses and pump energy requirements

District heating network design model

Select from set of potential new network connections the ones that can be connected profitably (Bordin, Gordini, Vigo, 2016)



Selection of supply technology

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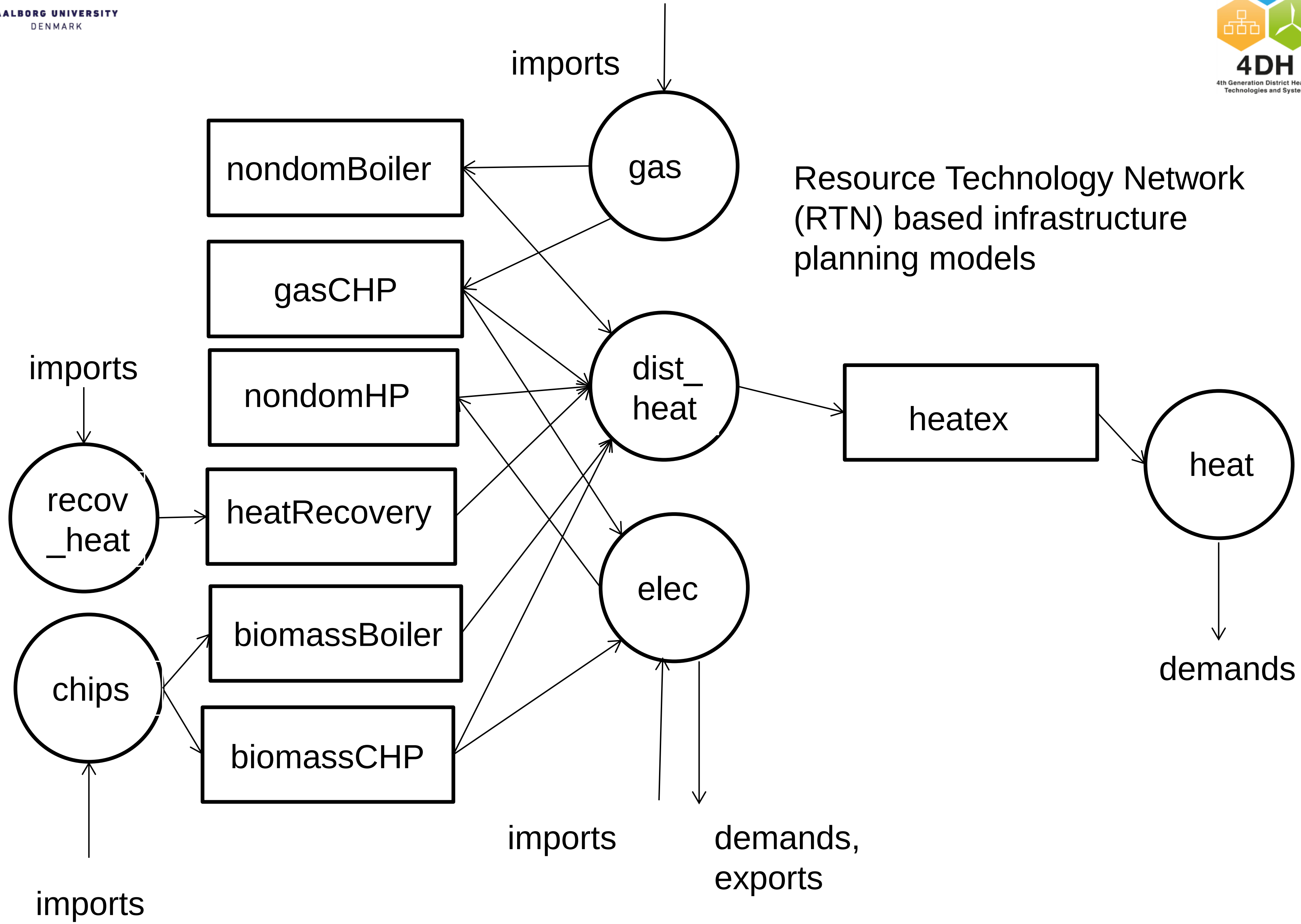
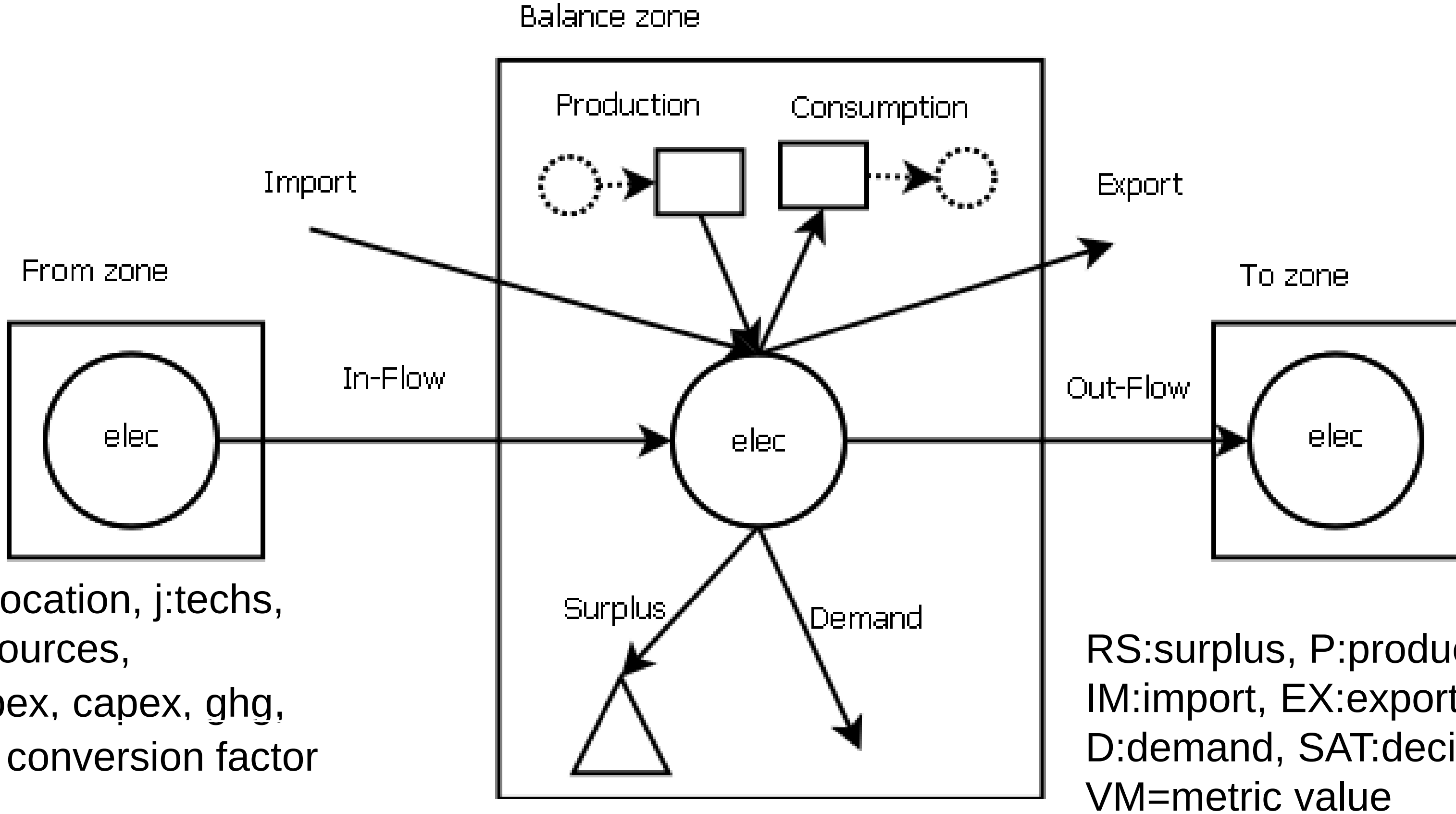
Resource Technology Network (RTN) based infrastructure planning models



RTN based infrastructure planning models

- Planning applications
  - Comparative analysis of urban energy governance (Morlet and Keirstead, 2013)
  - Chinese low-carbon eco-city case study (Liang et al., 2012)
  - Hydrogen network design and operation (Samsatli and Samsatli, 2015)
  - Infrastructure planning in Water, Sanitation, Hygiene sector (Triantafyllidis et al., 2018)
  - Sustainable planning of the energy, food, water nexus (Biebera et al., 2018)
- Varied level of spatial and temporal detail
  - Urban zones with periodic demands and storage (Samsatli and Jennings, 2013)
  - Regional zones with periodic demands and storage (Samsatli and Samsatli, 2015)
  - Urban zones with representative energy demands (Kuriyan and Shah, 2017)
- Alternative implementations (modelling language, algorithm, solver, tools)
  - AIMMS/CPLEX with decomposition algorithm (Samsatli and Samsatli, 2015)
  - Open implementation in Java/glpk, integrate with ABM (Triantafyllidis et al., 2018)
  - GAMS/CPLEX with Java tools (Kuriyan and Shah, 2016, 2017)
  - Python implementation for embedding in mapping applications (Kuriyan and Shah, 2016)
- Spatial Energy Model (SEM)
  - Address level district heating model with connection selection
  - Initial testing with GAMS/CPLEX, application development with Pyomo/CPLEX/glpk

Resource balance



i,i1: location, j:techs,
r:resources,
m:opex, capex, ghg,
μ(j,r): conversion factor

RS:surplus, P:production, IM:import, EX:export, Q:flow, D:demand, SAT:decision, VM=metric value

$$RS(r,i,t,tm) = \sum_j \mu(j,r)\, P(j,i,t,tm) + IM(r,i,t,tm) - EXP(r,i,t,tm) + \sum_{i1} Q(r,i1,i,t,tm) - \sum_{i1} Q(r,i,i1,t,tm) - D(r,i,t,tm)\, SAT(i)$$

$$OBJFN = \sum_{tm} \sum_m OBJWT(m,tm)\, VM(m,tm)$$

Map-driven model construction

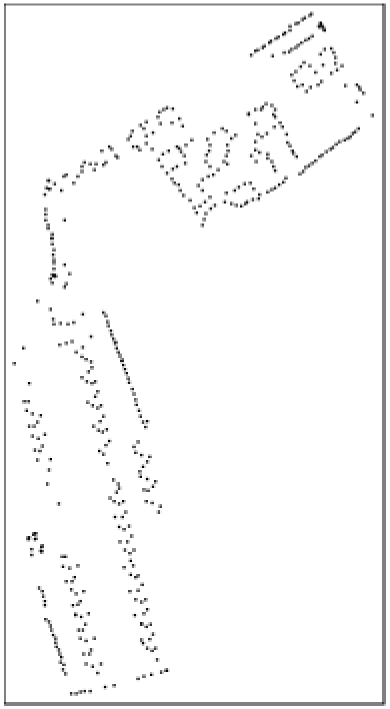
Image processing, mapping

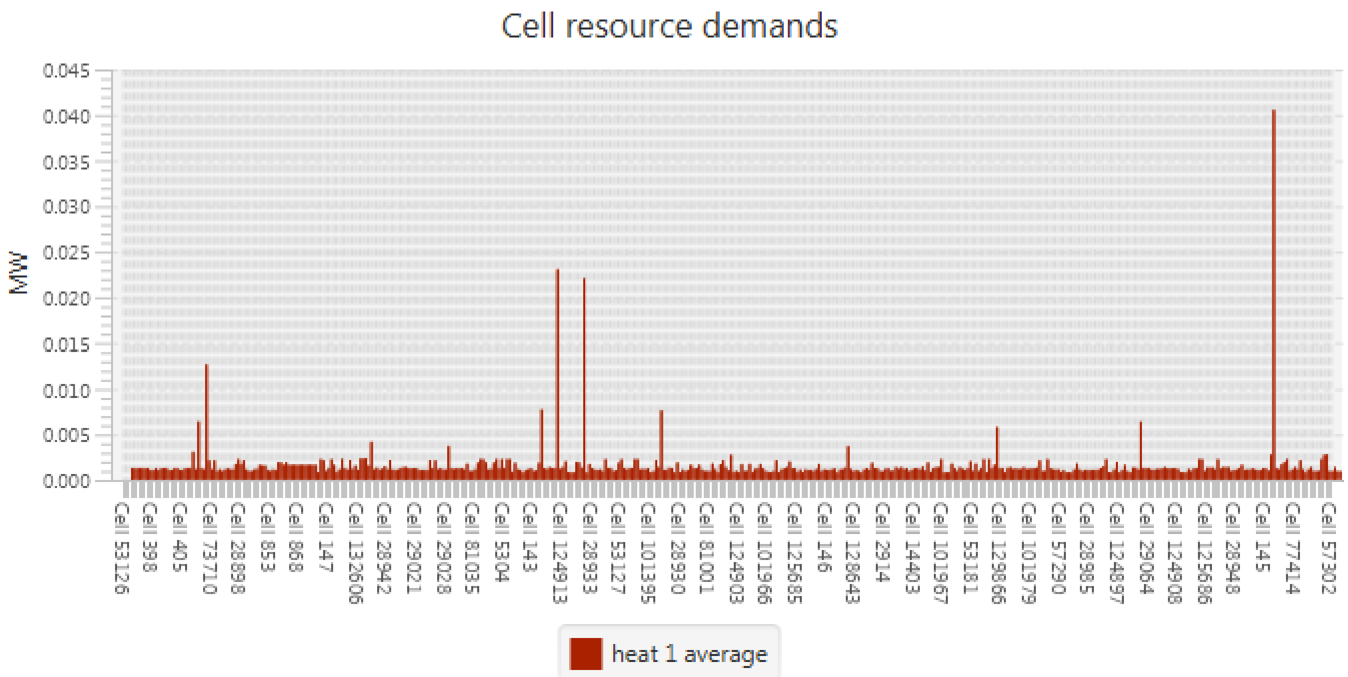
Building geometry, network paths

Abstract graph representation (vertices, arcs), with demands

Mapping and demand estimation methodology developed by CSE Bristol

Test data set





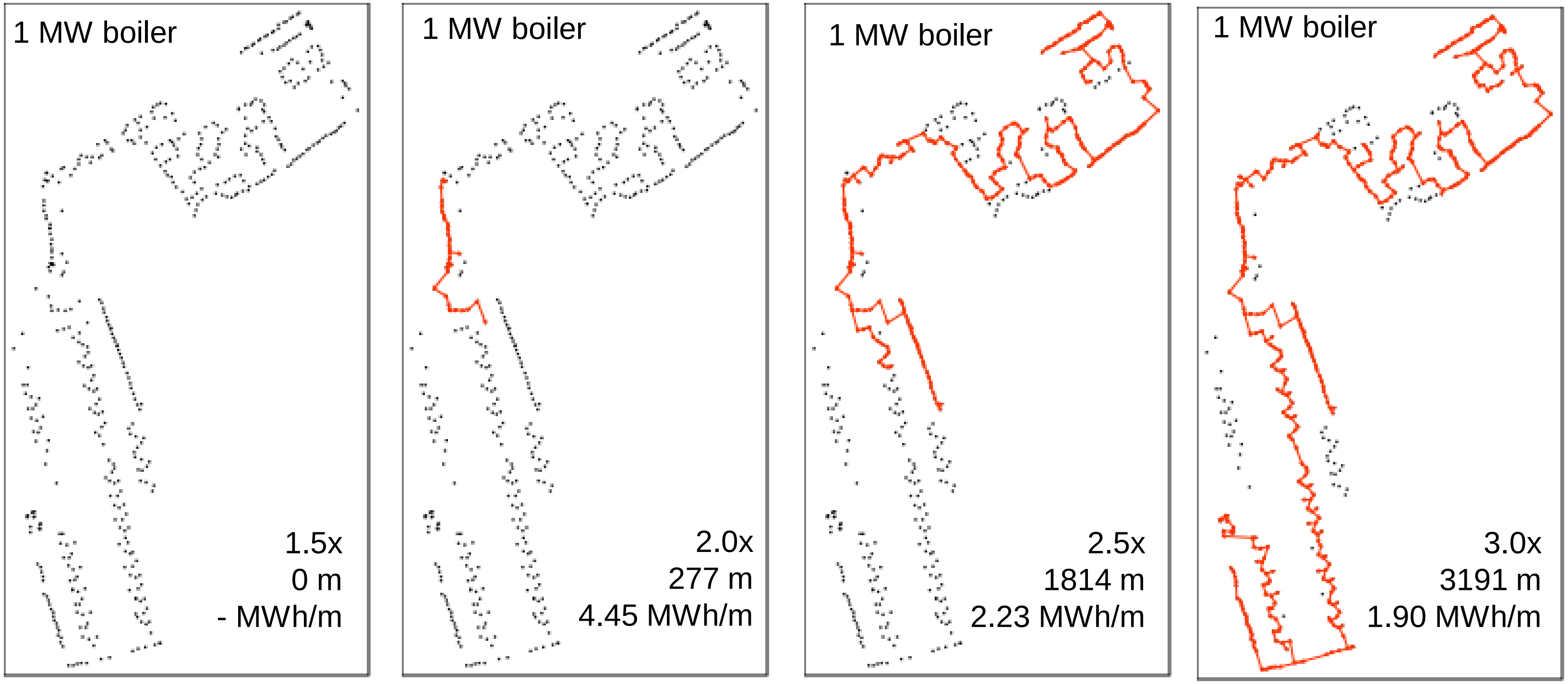
500 nodes with average demands

Test scenarios

- Non-domestic techs
  - CHP (small, medium, large), non-domestic boiler, heat pump, biomass boiler
- Select connections
  - Different heat tariffs
- Select technologies
  - Heat and electricity demands/exports
  - Emissions limit

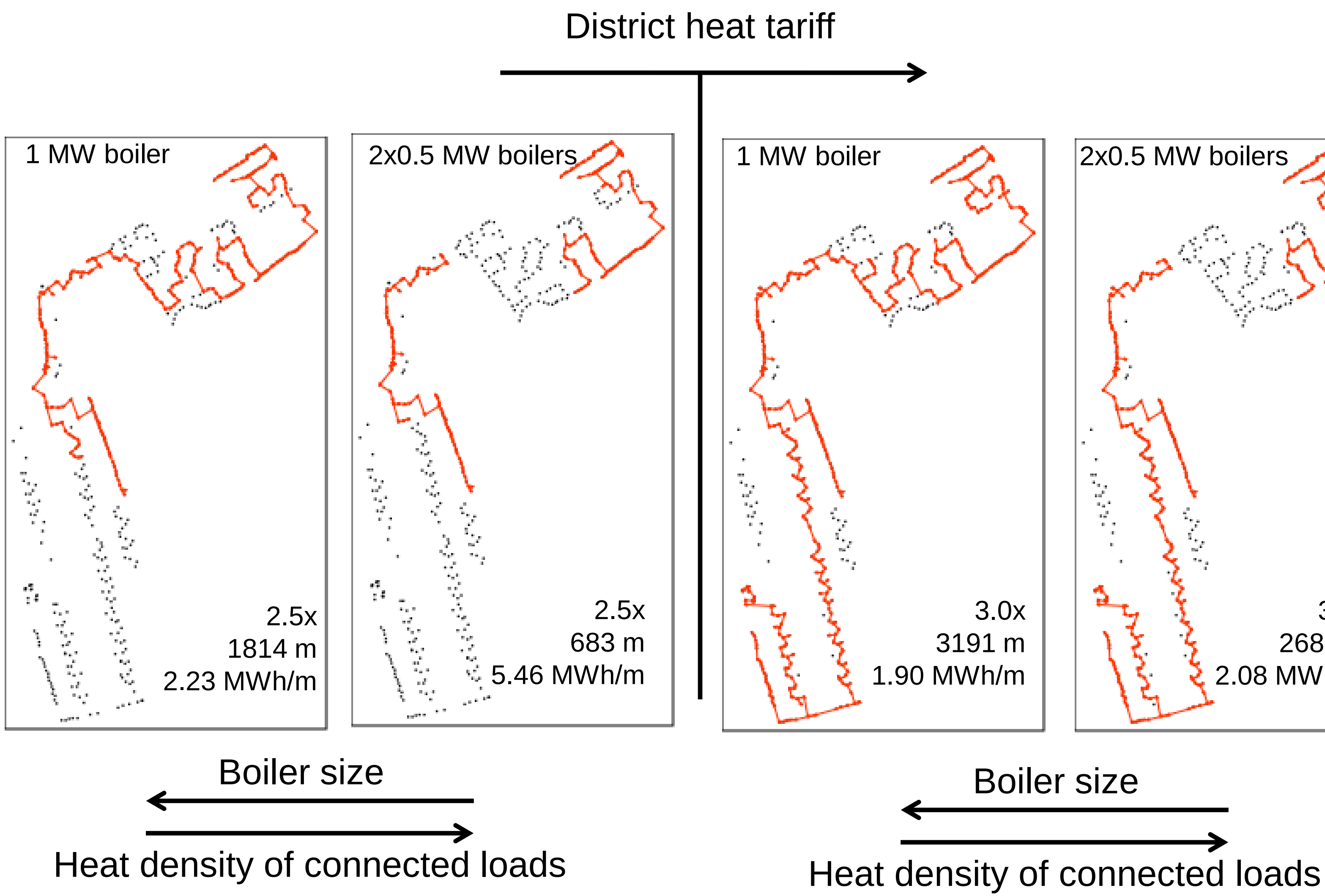
District heat tariff

Designed network length

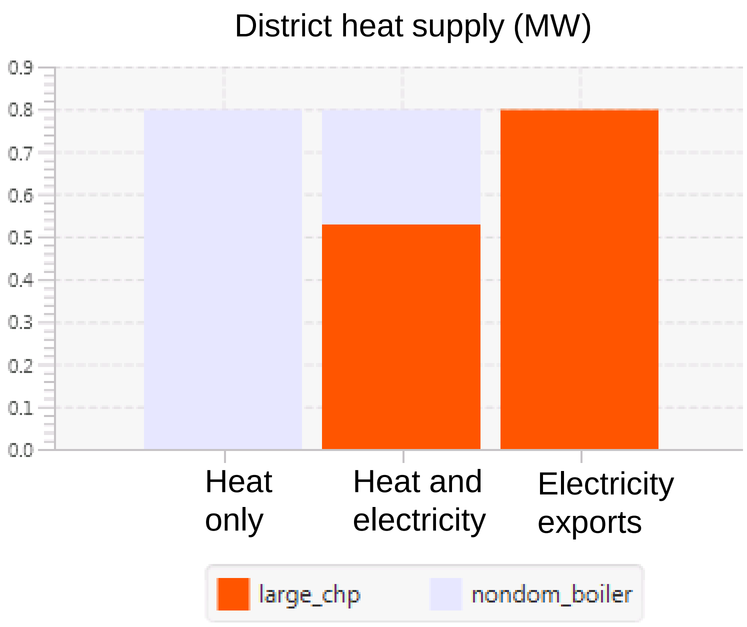


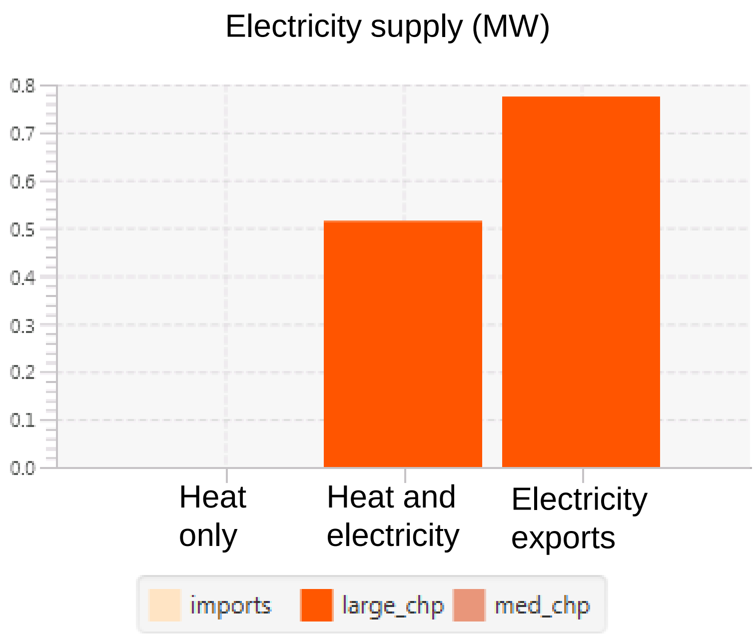
Linear heat density of connected loads

Tariff	Import	Maint.	Tariffs	Network	Equip.	Total	Length	MWh/m
2.0x	30	5	-59	7	15	-3	277 m	4.45
2.5x	99	19	-249	46	51	-33	1814 m	2.23
3.0x	146	31	-439	81	80	-100	3191 m	1.90


District heat tariff
1 MW boiler
2.5x
1814 m
2.23 MWh/m
2x0.5 MW boilers
2.5x
683 m
5.46 MWh/m
1 MW boiler
3.0x
3191 m
1.90 MWh/m
2x0.5 MW boilers
3.0x
2680 m
2.08 MWh/m
Boiler size
Heat density of connected loads
Boiler size
Heat density of connected loads

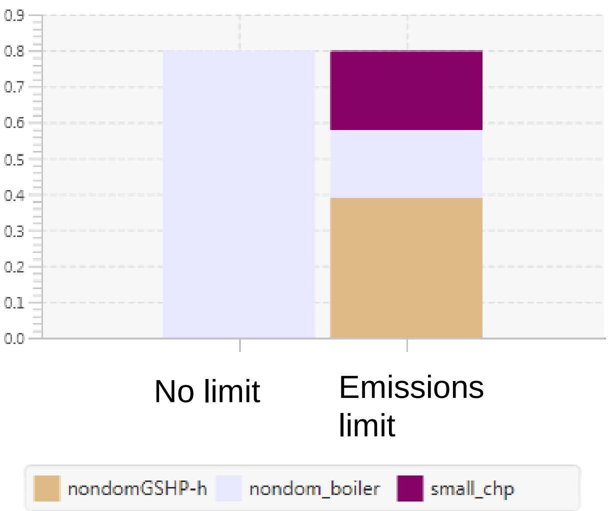
Technology selection for combined heat and power scenarios



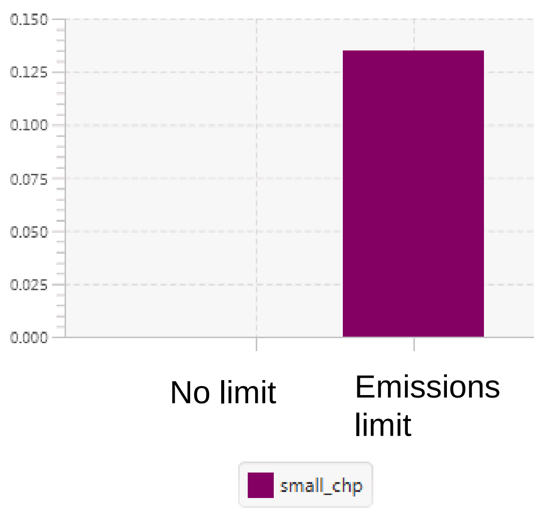


Technology selection with emissions limit

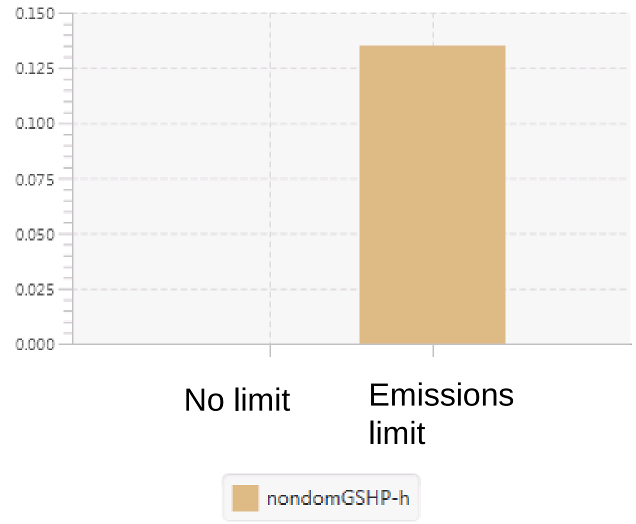
District heat supply (MW)



Electricity supply (MW)



Electricity usage (MW)



Summary

- Prototype model for screening network links, supply technology type and location
- Test cases to demonstrate main features of the model
- Python implementation embedded within the initial THERMOS application
- Further development
  - Trade-off in complexity and computation time
    - Aggregation, decomposition, parallelisation
    - Variable resolution modelling
  - Improved estimates of infrastructure costs
    - Pipe sizing (binary, discrete, binary/linear)
    - Electrical network costs
    - Diversity, coincidence factors

- Acknowledgments
  - EU Horizon 2020 grant agreement no. 723636 (THERMOS)
  - CSE Bristol
    - Mapping, application design and development, test data sets
  - CREARA, ICLEI, city partners
    - Application requirements, training, dissemination

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Data requirements

- Economic
  - Import/export prices, tariffs, operational costs
  - Investment costs, annuity factor (period, rate)
- Environmental factors
  - GHG, Other (NO_x, PM_{10}, $PM_{2.5}$)
- Technological
  - Conversion factors, minimum and maximum operating levels
- Spatial
  - Location constraints (allowed/disallowed)
- Temporal
  - Demand variations
  - Representative set of demand periods