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
Server-side application

Map-driven interface

Spatial data

Demand data

Optimizer interface

Optimization model

Web browser

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

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

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

\[ OBJFN = \sum_{tm} \sum_m OBJWT(m, tm) VM(m, tm) \]
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
<table>
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<th>Import</th>
<th>Maint.</th>
<th>Tariffs</th>
<th>Network</th>
<th>Equip.</th>
<th>Total</th>
<th>Length</th>
<th>MWh/m</th>
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</table>
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

District heat supply (MW)

Electricity supply (MW)

Heat only  |  Heat and electricity  |  Electricity exports

Heat only  |  Heat and electricity  |  Electricity exports

large_chp  |  nondom_boiler  |  large_chp  |  med_chp

imports  |  large_chp  |  med_chp

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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
References


References


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