THERMOS

Accelerating the development of low-carbon heating & cooling networks

Capacity Building and Train-the-trainer programme

Module 2: Energy System Mapping and Modelling with THERMOS

Module 2 of the THERMOS Capacity and Training programme

This Module consists of three parts as follows:

2.1 Energy System Mapping

2.2 Energy System Modelling

2.3 Thermal Energy Resource Modelling and Optimisation System (THERMOS)

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1. Energy System Mapping

Content

The first part of the Module will focus on:

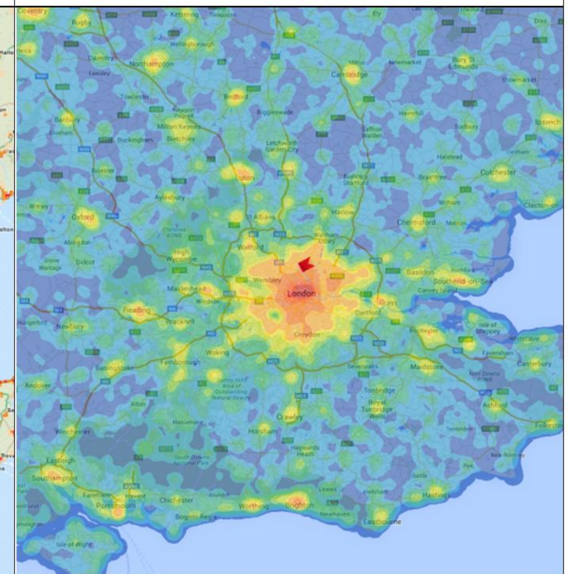
- Concept
- Methodology
- Data and resources needed
- Good practice examples

Introduction

- Robust energy system mapping is an essential requirement for local energy system analysis.
- Top-down mapping exists at continental and national levels but there is a lack of **specific local information** for energy system infrastructure development.

➢ THERMOS therefore aims to address this gap by developing and publishing a state-of-the-art methodology for developing **address-level energy system maps** for energy system analysis within the **THERMOS Application**.

2.1 Energy System Mapping

Location (on each row, the maps cover exactly the same area)	**Top down EU/National scale mapping (Stratego PETA, England)**	**Bottom up, address-level mapping (National Heat Map, England)**
Greater London Top-down and bottom up energy mapping produce comparable outputs, suggesting that whole-system analyses would produce consistent results.		

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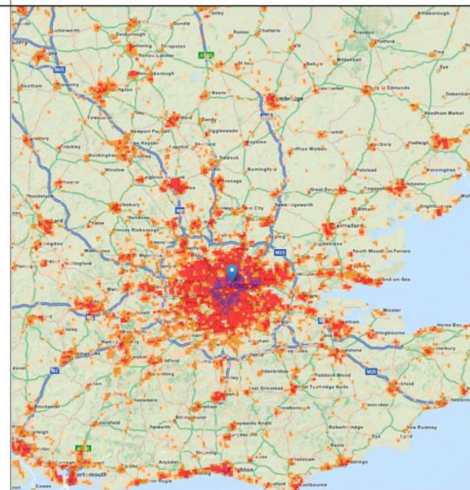
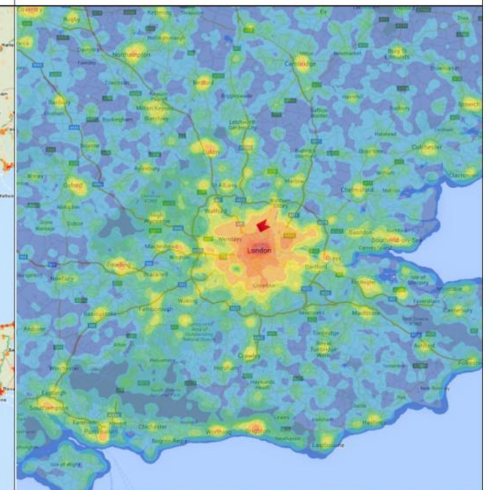
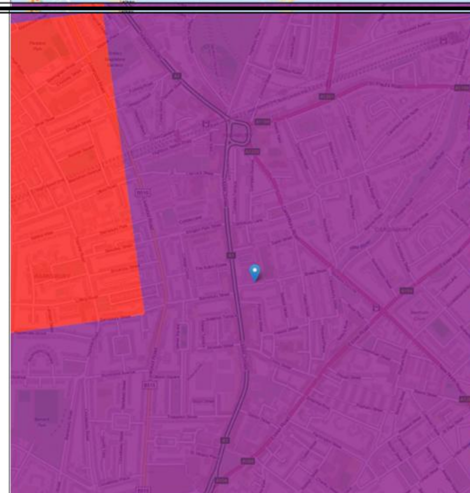
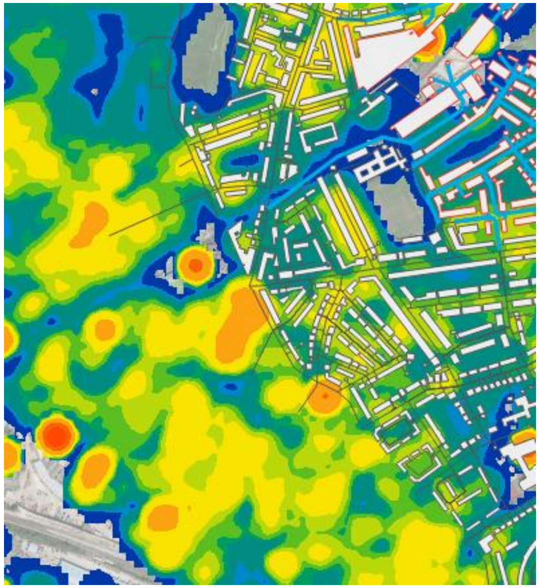
Greater London Top-down and bottom up energy mapping produce comparable outputs, suggesting that whole-system analyses would produce consistent results.		
Islington Top-down mapping lacks detail required for identification of specific options. Address-level mapping enables and analysis of potential networks (the image here can be viewed live at http://tinyurl.com/LBI-networks)		

Key features of THERMOS energy system mapping approach

- High resolution spatial representations of local energy systems
- Will create and publish a new 'standard' for thermal mapping to underpin local energy network planning
- Bottom-up address level heat demand using modelled building characteristics or empirical consumption data.



Key features of THERMOS energy system mapping approach

- High-resolution spatial energy system datasets e.g. energy supply (incl. secondary sources such as waste heat), power networks, building attributes, road/path network topology, etc…
- Replicable across borders using open data wherever possible
- Fully integrated within the THERMOS open-source web application tool for robust energy system mapping and modelling analysis.

Mapping methodology developed as part of four-stage process to produce THERMOS web-maps

1. Development of methodology for developing address-level energy demand maps
2. Collation of energy demand geodatasets, initially for Pilot 'Cities' of Islington (UK), Granollers (Spain), Warsaw (Poland) and Jelgava (Latvia)
3. Collation and management of additional energy system data
4. Visualisation and publication of energy demand and additional layers in web application to produce web-maps for each Pilot City.

We are familiar with this view of the world:

But for THERMOS we need to make something more like this:

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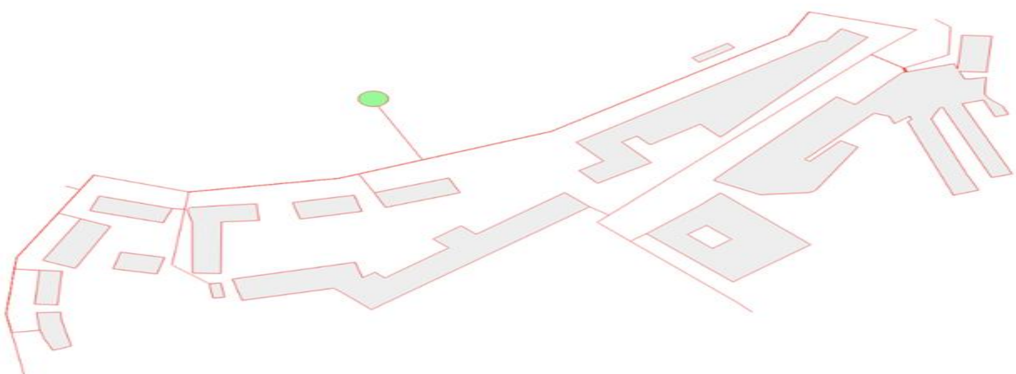
Points for locations and energy demands of buildings, and for the locations of energy supplies

Points for locations and energy demands of buildings, and for the locations of energy supplies

Lines for routes through which energy could be distributed

To make develop this model, we need:

1. Energy demand estimates for existing or new buildings (points)
2. Energy supply estimates for known actual/potential resources (points)
3. A representation of the road network (lines)



Estimating thermal demand of buildings (1/5)

The THERMOS method works by using some/all of the following:

- Three-dimensional building shape/size
- Internal and external temperatures
- Building thermal efficiency and space heating demand
- Other benchmark models

Estimating thermal demand of buildings (2/5)

a) Three-dimensional building shape/size is obtained using:

- **Floor area data** – e.g. from OpenStreetMap, often used as a reasonable predictor of heat demand
- **LIDAR (Light Detection and Ranging)** data
- **Building type/occupancy data** – e.g. where LIDAR is not available, used to estimate number of storeys in a residential tower block

Estimating thermal demand of buildings (3/5)

b) Internal and external temperatures are obtained using:

- **A variety of climatic archives for external temp data** – e.g. Wikidata contains monthly averages
- **Empirical survey data for internal temp data** – e.g. the EFUS dataset for the UK contains estimates of peak and average internal temperatures.

Estimating thermal demand of buildings (4/5)

c) Building thermal efficiency and space heating demand is obtained using:

- **Estimation of u-values** – obtained from building surface area and internal/external temps (where power requirement is known) or from reference tables/survey data of typical building construction elements.
- **Space heating demand** then calculated using internal/external temperature differential, rate of heat loss (from u-values) and estimated impacts of ventilation, thermal mass and solar gain.

Estimating thermal demand of buildings (5/5)

d) Other benchmark models

- **Water heating demand** – related to occupancy
- **Standard building energy benchmarks** – e.g. space heating demand (kWh/m^2) for new buildings
- **Area-based calibration** – use of empirical local energy data
- **Load profiles** – real or modelled data

Energy supply estimates for known actual/potential resources

Uses local data collection on existing potential energy sources and suggestions for new energy plant locations.

Sources may include:

- Existing thermal plant
- Waste heat from power plant
- Waste heat from other resources (water, air, industrial processes…)
- Solar thermal
- Waste-to-energy, etc

A representation of the road network

Starting assumption is that energy networks align with the road network. The approach uses:

- The layout of the road network
- The point-locations of energy supply (sources) and demand (sinks)
- Analysis of cost to connect pairs of points

Case study: UK data inputs

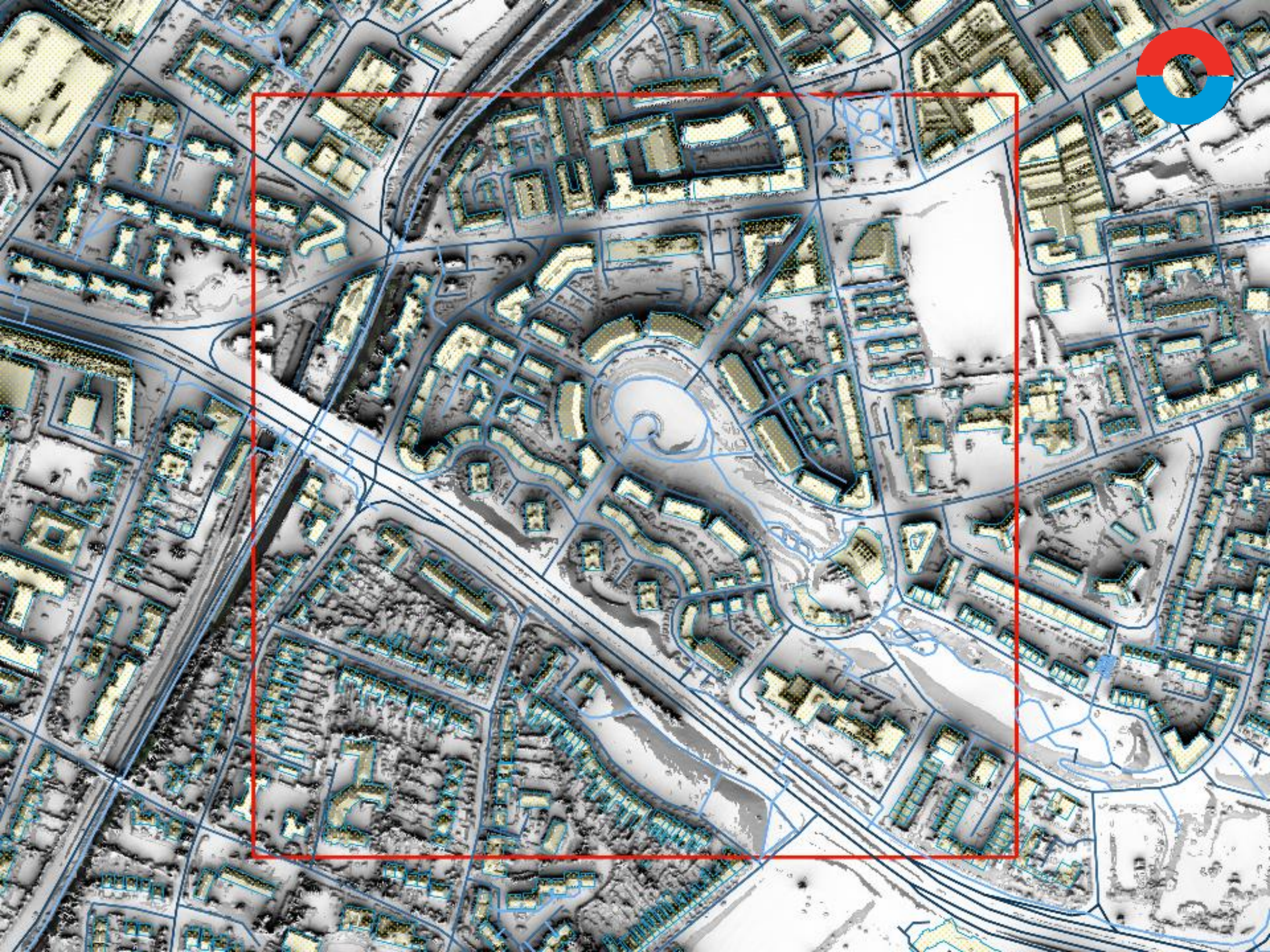
Estimating energy demand:

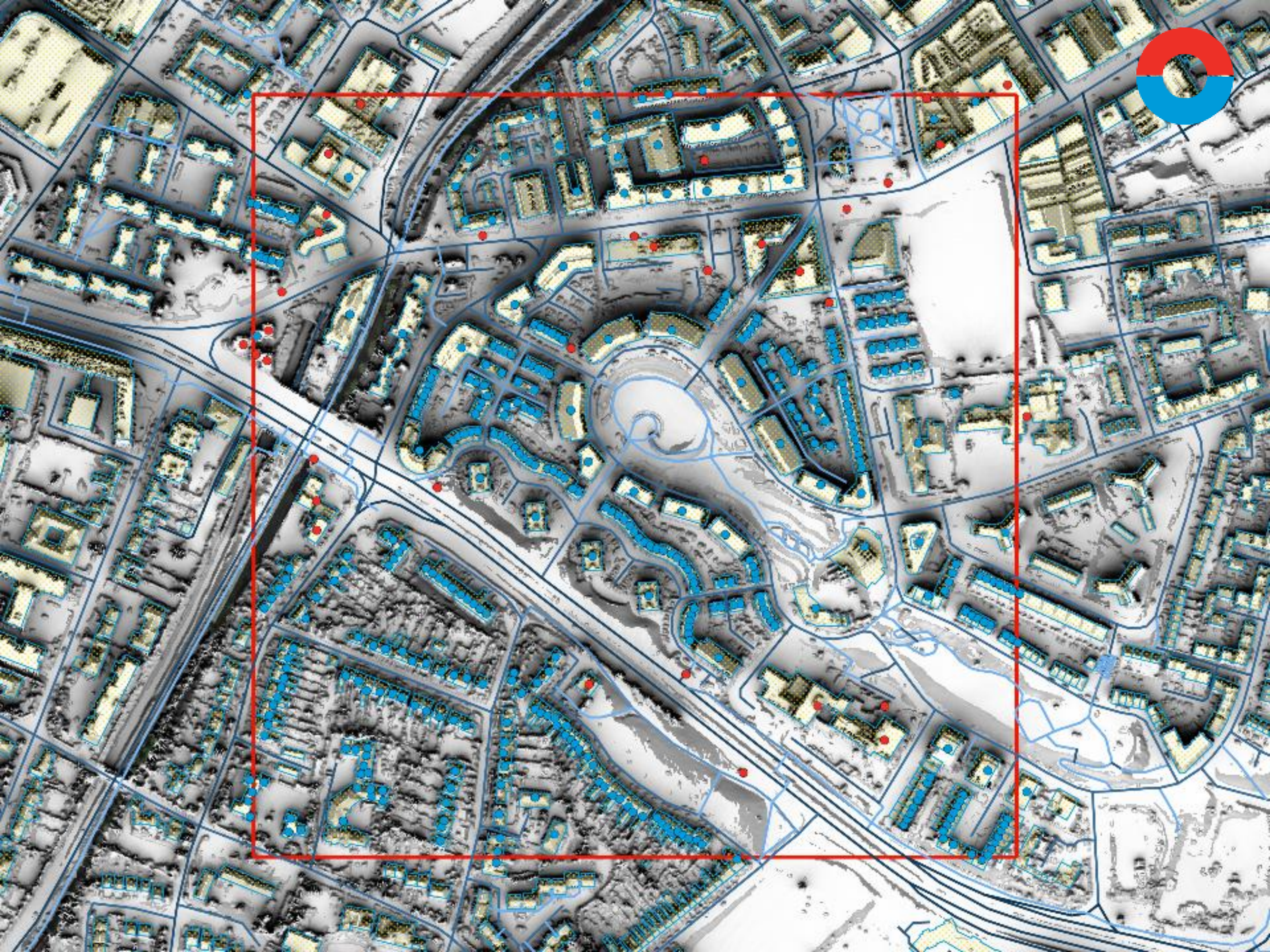
Parameter	Source
3D building models: • LIDAR • OpenStreetMap	• http://environment.data.gov.uk/ds/survey/#/survey • www.openstreetmap.org
Building typology: • Ordnance Survey • OpenStreetMap	• www.ordnancesurvey.co.uk/business-and-government/products/topography-layer.html • www.openstreetmap.org
Internal temps: • EFUS • BEES	• www.gov.uk/government/statistics/energy-follow-up-survey-efus-2011 • www.nist.gov/services-resources/software/bees

Case study: UK data inputs

Estimating energy demand:

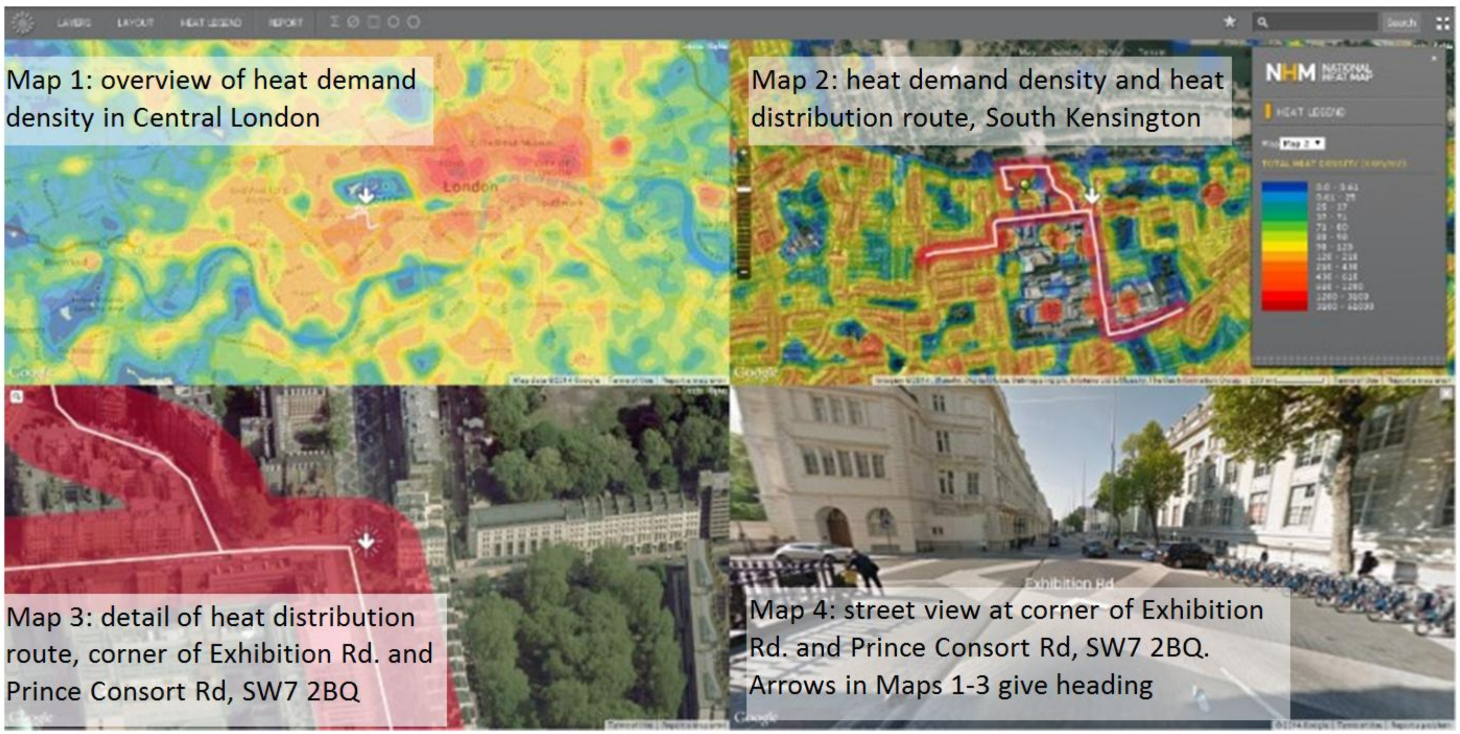
Parameter	Source
External temps	
Empirical consumption data: • Energy Performance Certificates (EPCs)	• www.epcregister.com/
Floor area energy benchmarks: • CIBSE guide F	• www.cibse.org/Knowledge/knowledge-items/detail?id=a0q20000008I7oTAAS
Small area fuel consumption: • Gov.uk energy statistics	• www.gov.uk/government/collections/sub-national-gas-consumption-data





English National Heat Map

An address-level energy demand model with web visualisation and analytical tools.



http://nationalheatmap.cse.org.uk/

Stratego Project / Heat Roadmap Europe

- http://stratego-project.eu/
- http://www.heatroadmap.eu/

Output includes development of a Pan-European Thermal Atlas which includes grid-based heat demand maps for the EU, which have helped to demonstrate the potential (within each nation and across the EU) for district heating and cooling networks

Stratego ENHANCED HEATING & COOLING PLANS

Co-funded by the Intelligent Energy Europe Programme of the European Union

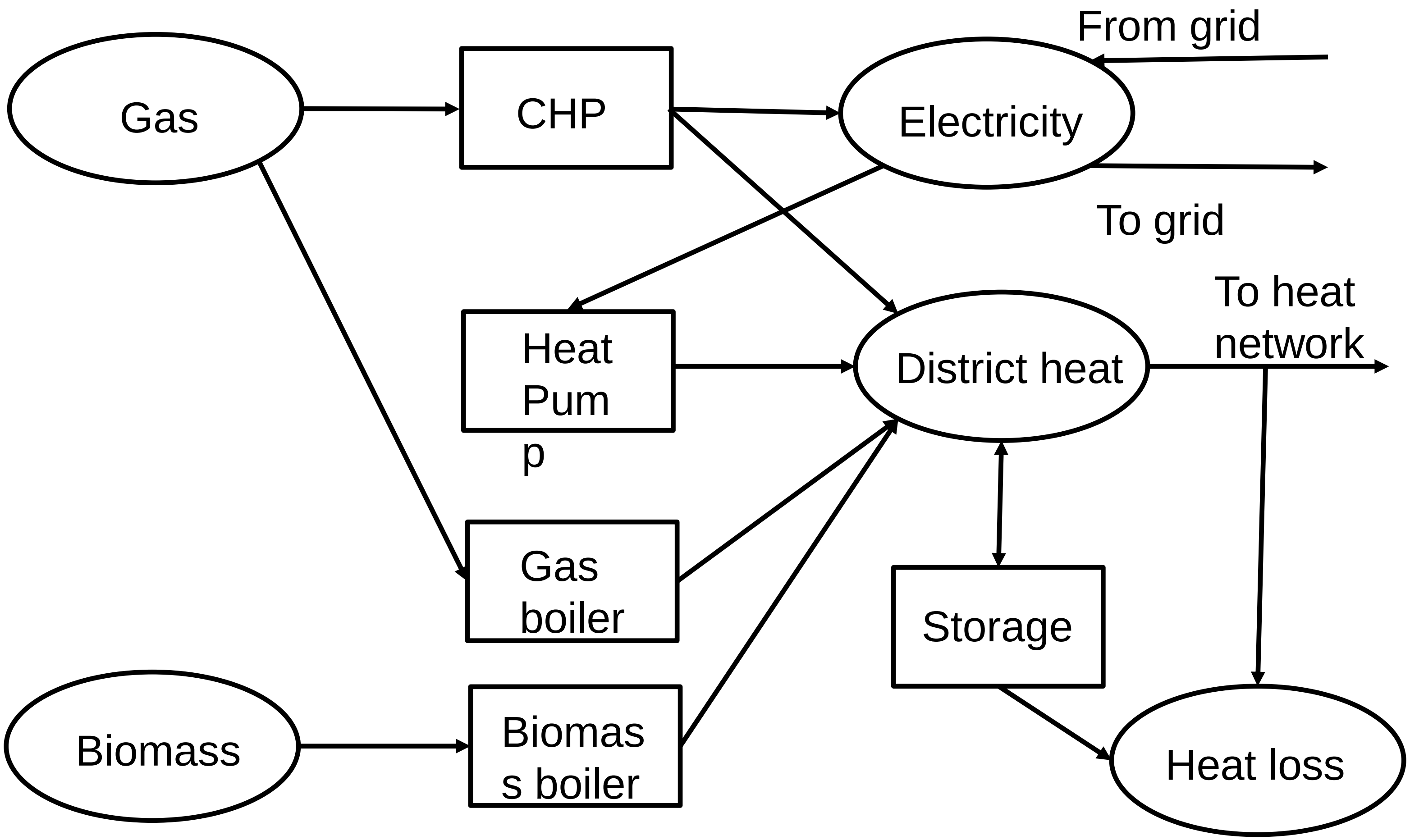
Heat Roadmap Europe 2050

4DH

Summary – Energy System Mapping

- **THERMOS** incorporates state-of-the-art heat mapping techniques using an address-level bottom-up approach
- Includes energy demands from buildings and sources of energy supply, including waste heat
- Representation of road network – used as a basis for planning energy distribution system
- Aims to be flexible regarding data input sources to allow for use of proxies and mixed data availability.
- Online heat maps produced for the four THERMOS Pilot Cities.

2.2 Energy System Modelling



Content

The second part of the Module will focus on:

- Concept
- Methodology
- Data and resources needed
- Good practice examples

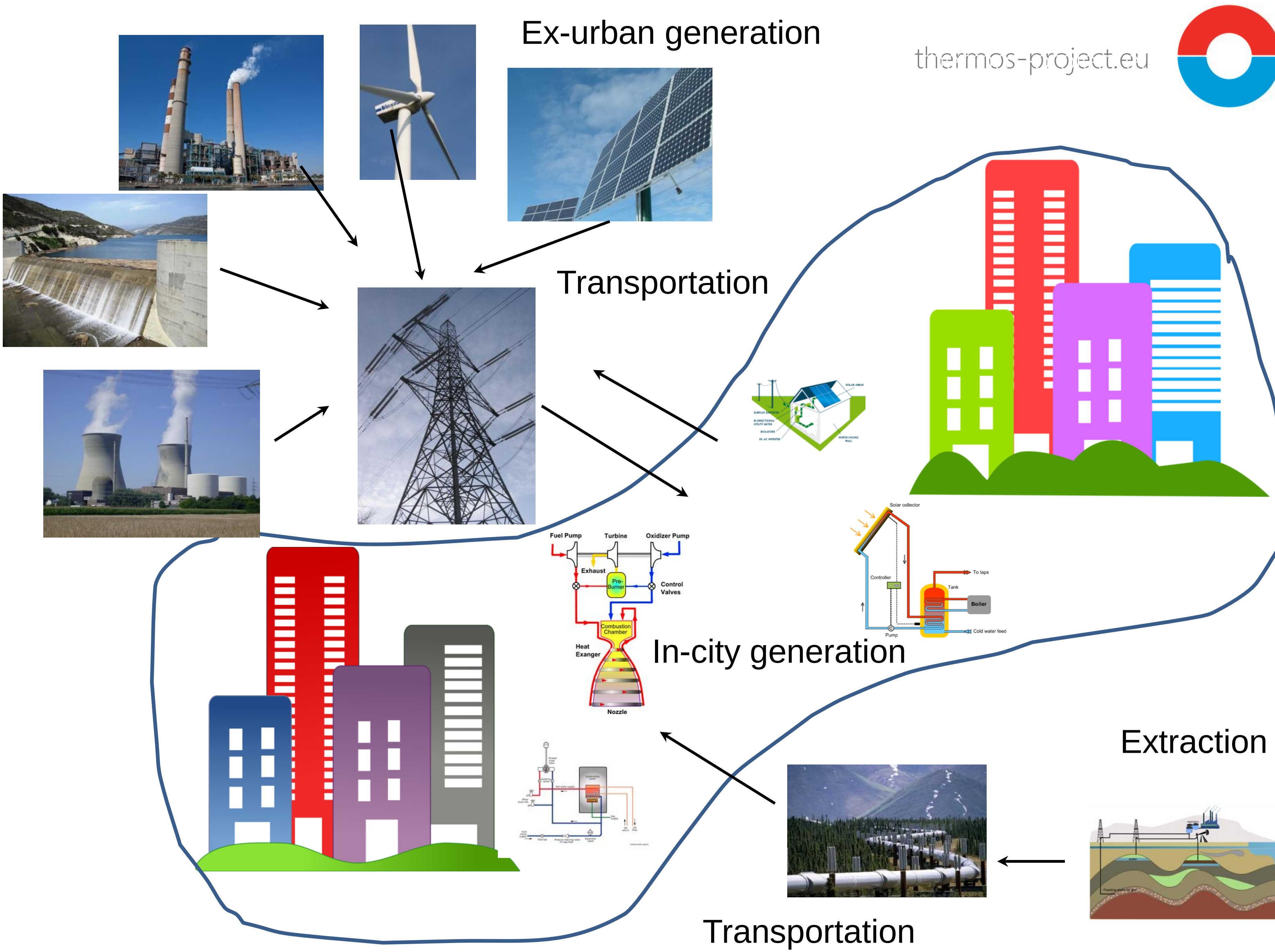
Introduction

- Increasing urbanisation (UN DESA, 2014)
  - 54% of world's population lives in urban areas.
  - Projected to rise to 66% by 2050.
- Global energy assessment (GEA, 2012)
  - 56-78% of final energy usage is urban.
- Urban energy system models
  - Improve understanding of urban energy use.
  - Analyse policy initiatives, infrastructure investments.

Urban energy system

A formal system that represents the combined processes of acquiring and using energy to satisfy the energy service demands of a given urban area:

- Ex-urban processes for resource extraction, energy generation and transportation
- Associated costs and greenhouse gas emissions
- Potential processes for in-city energy generation and conversion


Ex-urban generation
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Transportation
Fuel Pump
Turbine
Oxidizer Pump
Exhaust
Pre-Burner
Control Valves
Combustion Chamber
Heat Exanger
Nozzle
Solar collector
Controller
To taps
Tank
Boiler
Cold water feed
Pump
In-city generation
Extraction
Transportation

Urban energy system models

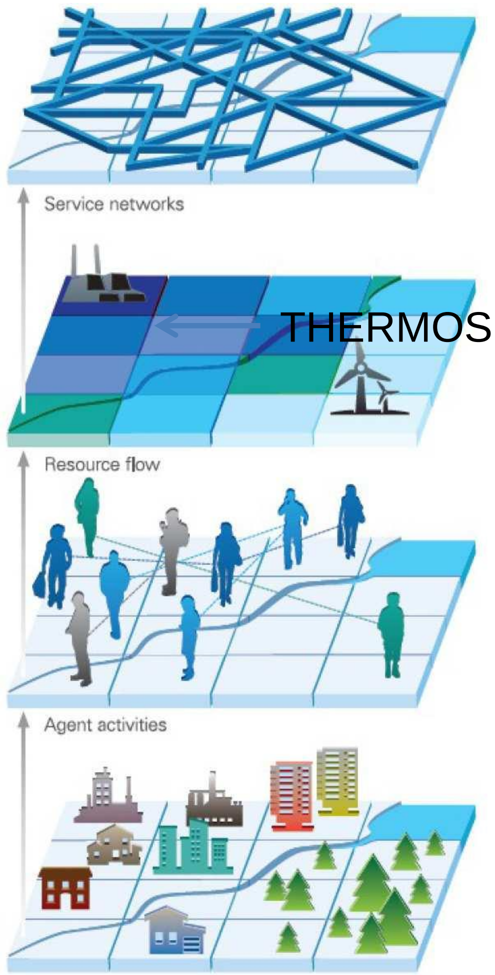
- Technology design
  - E.g. wind, solar, vehicle performance, waste-to-energy
- Building design
- Urban climate
- Policy assessment models
- System design models
  - Optimisation based models
  - Trade-offs between multiple technologies
  - Specific goals (e.g. carbon reduction target)

System models

- Holistic view
  - Technology, economics, environmental impacts
  - Include all relevant interactions
- Urban systems are complex systems
  - Decomposition to manage complexity
  - Abstraction to create formal network-based models
  - Adjust level of detail to scale of model
    - City ↔ District ↔ Neighbourhood

Decomposition

- Land use model
  - Given aggregate activity levels, building types and transport links, optimise building and transport costs
- Agent activity model
  - Simulate agent activities and movements to estimate energy demands
- Resource flow model
  - Given spatial and temporal distribution of demands , optimise selection and location of processes to meet demands
- Service network model
  - Design network to transport energy flows



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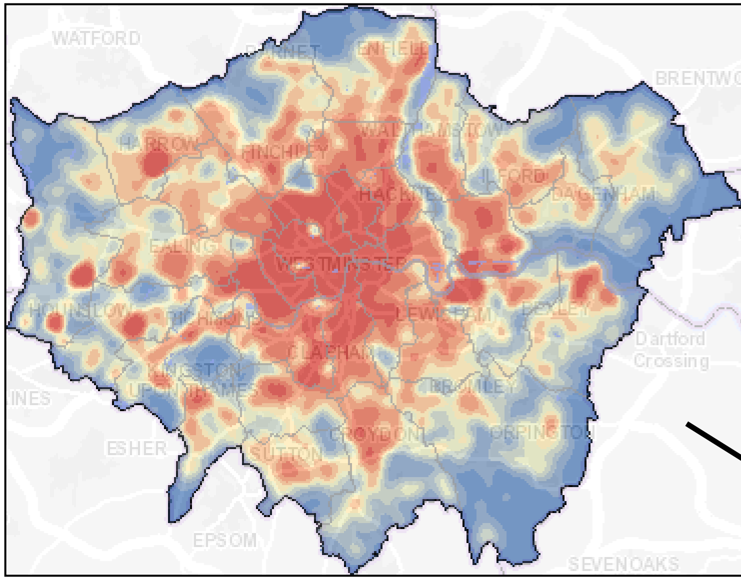

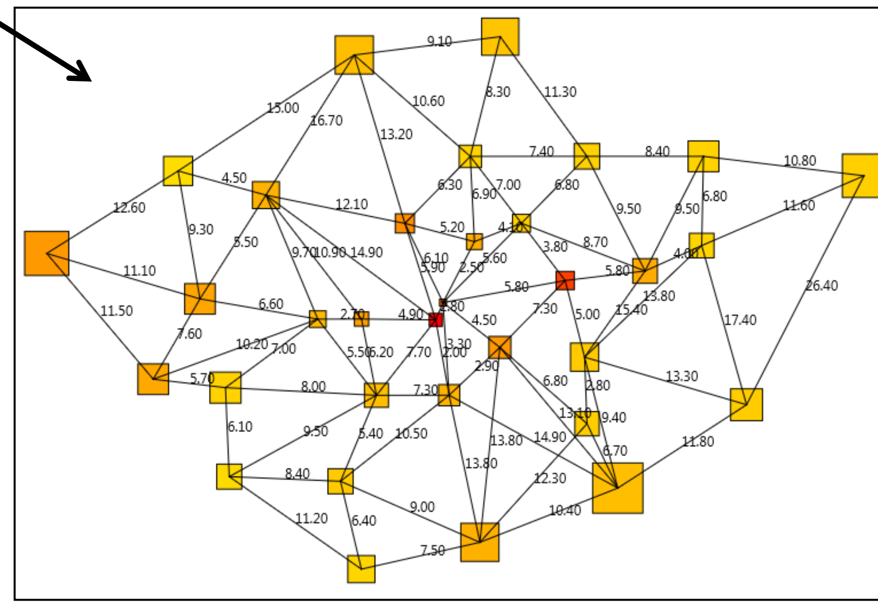

Abstraction to create formal network model

2.2 Energy System Modelling - Concept

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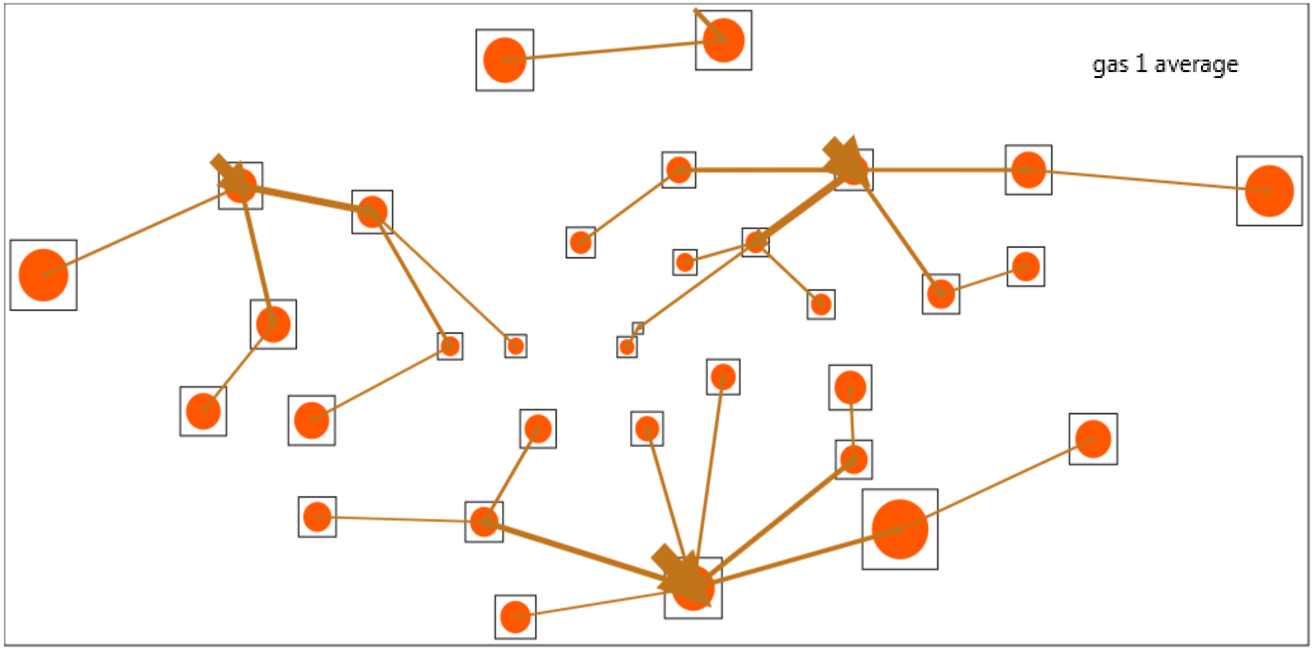
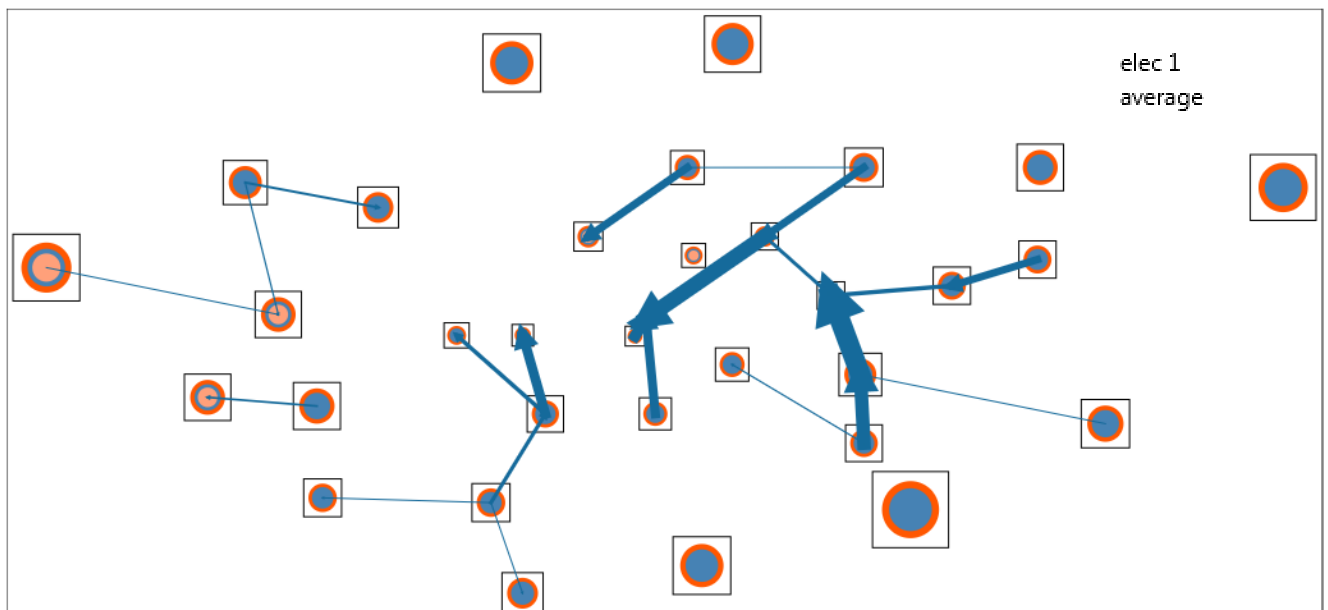


Gas import and distribution for CHP

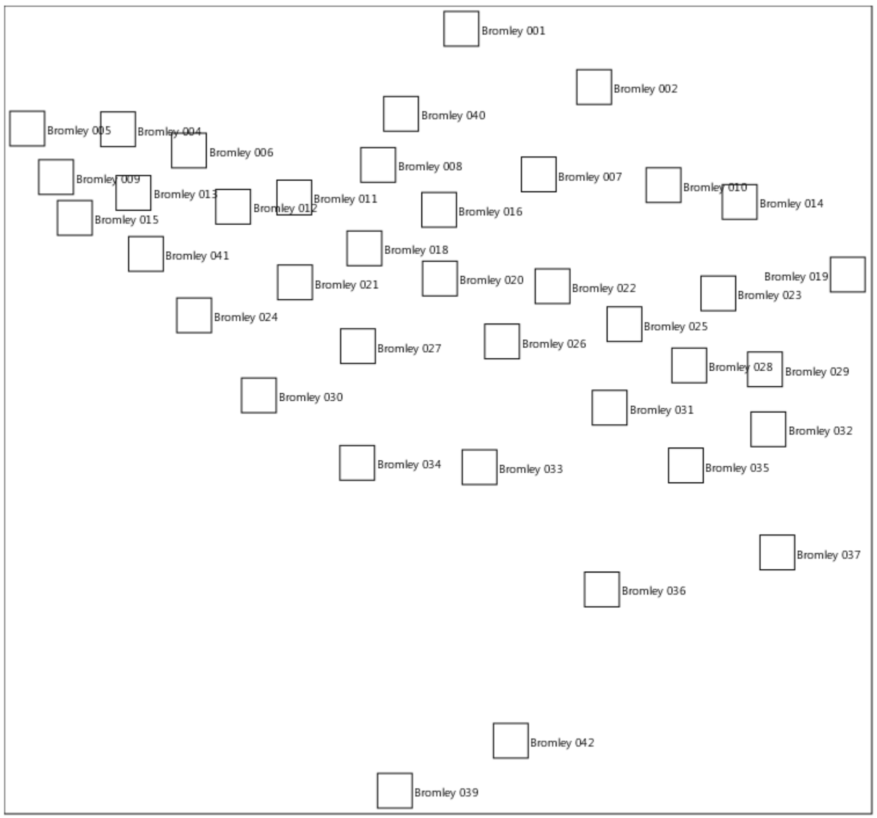
Network interactions



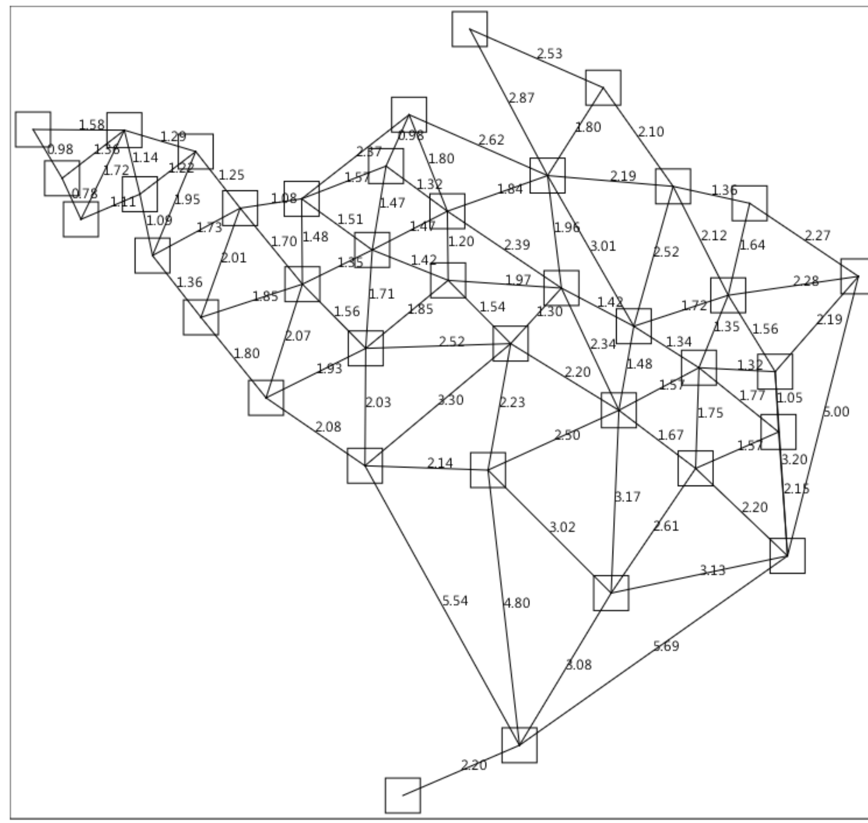
Distribution of electricity generated locally

District level model

Bromley



Grid cells



Network

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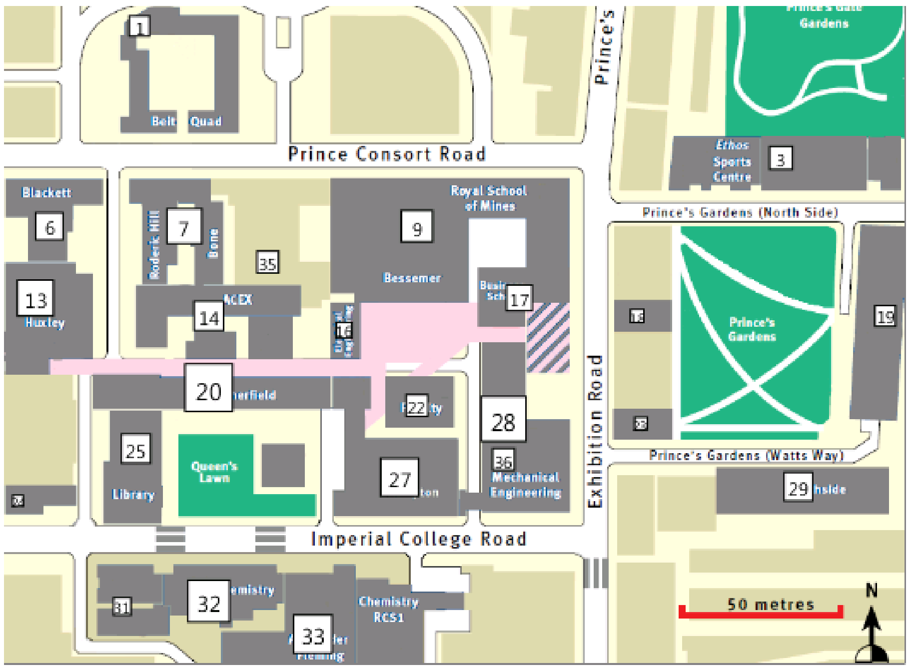
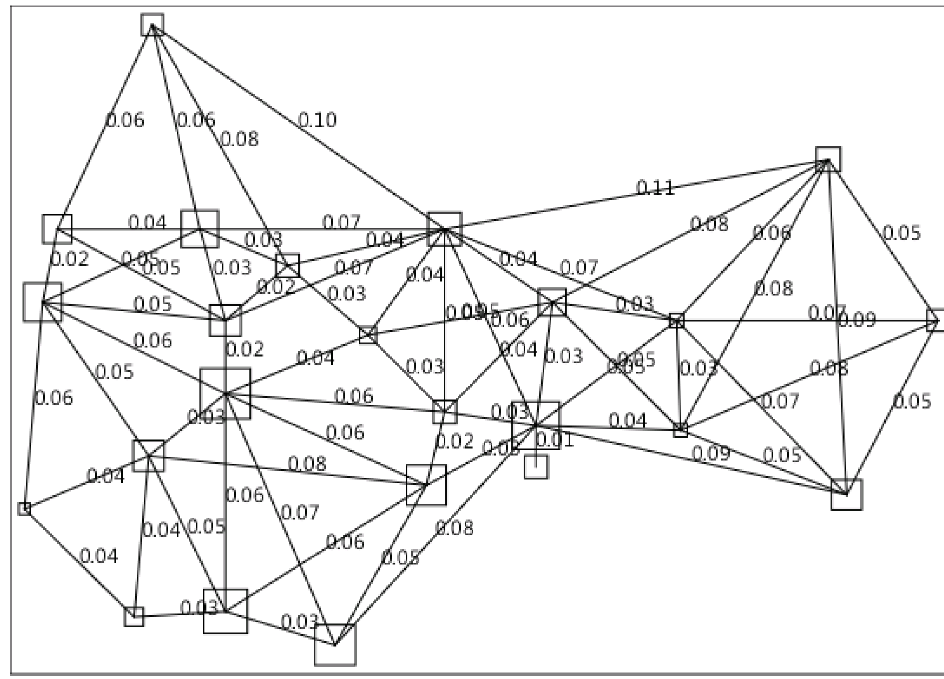
Neighbourhood level model

Imperial College, South Kensington Campus



Grid cells



Network

Systems methods and outcomes

- Holistic model
  - Incorporates economic, environmental and technological concerns
- Assessment of supply options
  - Renewables, poly-generation, cascading, heat-recovery
  - Learning and technology improvement
- Quantified metrics
  - Economics
  - Environmental impact
- Business models and policy options
  - Tariffs, rebates, emissions targets

Model-based decisions

- Selection of technology type, scale, location
- Technology size
  - Meet peak loads, part load operation outside peak periods
  - Large techs: Build out heat network from primary demand location
  - Small techs: Close to multiple demand locations
- Emissions targets
  - Biomass vs natural gas, renewables
- Combined heat, power, cooling
  - Electricity imports vs local generation
  - Revenues from electricity exports
  - Heat pump electricity requirements

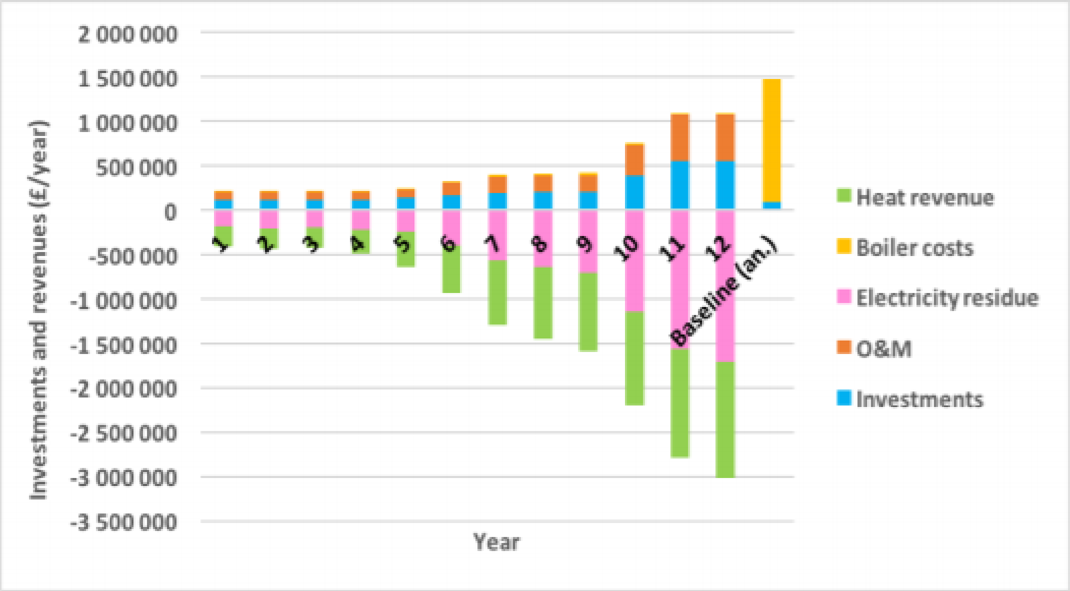
Model-based decisions (contd.)

- Ensure feasibility
  - Sufficient generation and transport capacity
  - Satisfy energy demands at all locations, in all time periods
  - Select operating level for each supply technology in every time period
  - Meet emissions targets
- Optimisation
  - Minimise costs (operating costs, carbon costs, incentives, investment costs)
  - Maximise revenues

Temporal Framework: Minor periods

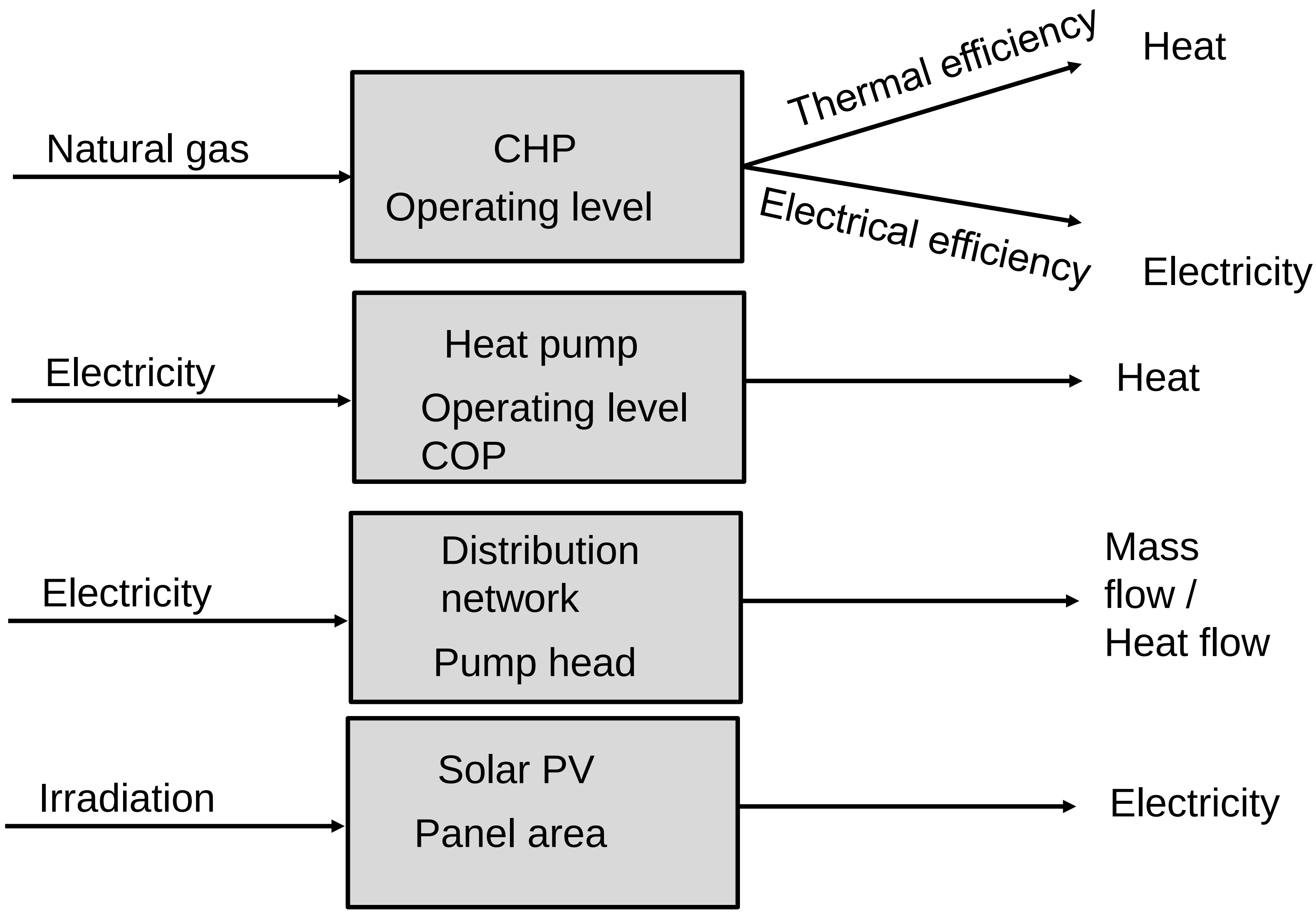
- Minor periods can be used to capture the impact of temporal variations in model parameters
  - Hourly, daily, and seasonal variations in energy demands
  - Hourly variations in electricity prices
  - Seasonal variations in natural gas/biomass prices
  - Variations in grid emissions factors with load
- Simplification for initial model
  - Limited number of representative time periods
    - Peak loads ↔ Investment costs
    - Average loads ↔ Operation costs
  - Average prices, emission factors valid for duration of planning horizon

Temporal Framework: Major periods



- Major periods (e.g. year or decade) can be used to define staged investments and capture long term variations in gas price, heat demand and grid emissions factors
- Single investment period with annualised investment costs

Individual process models



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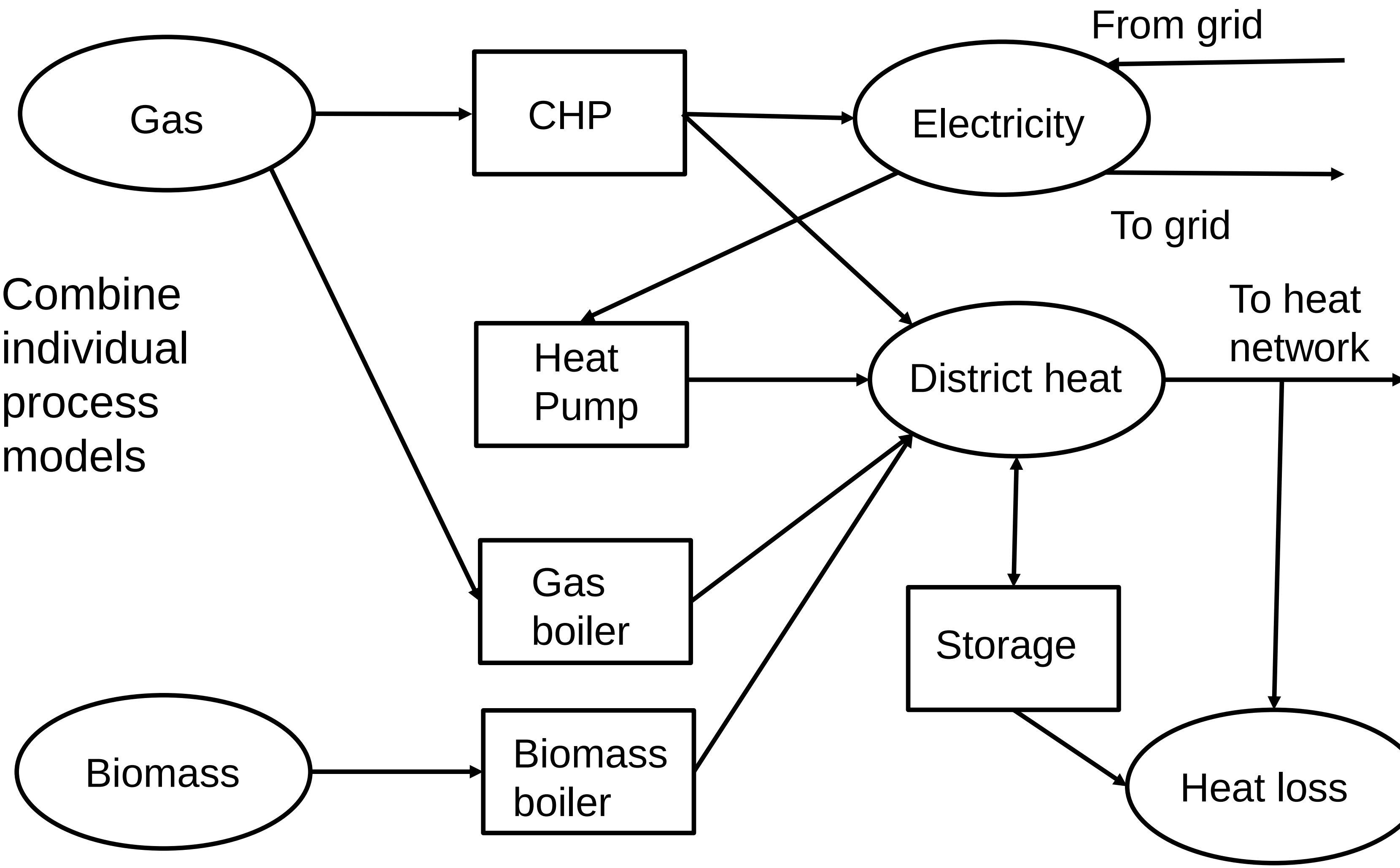
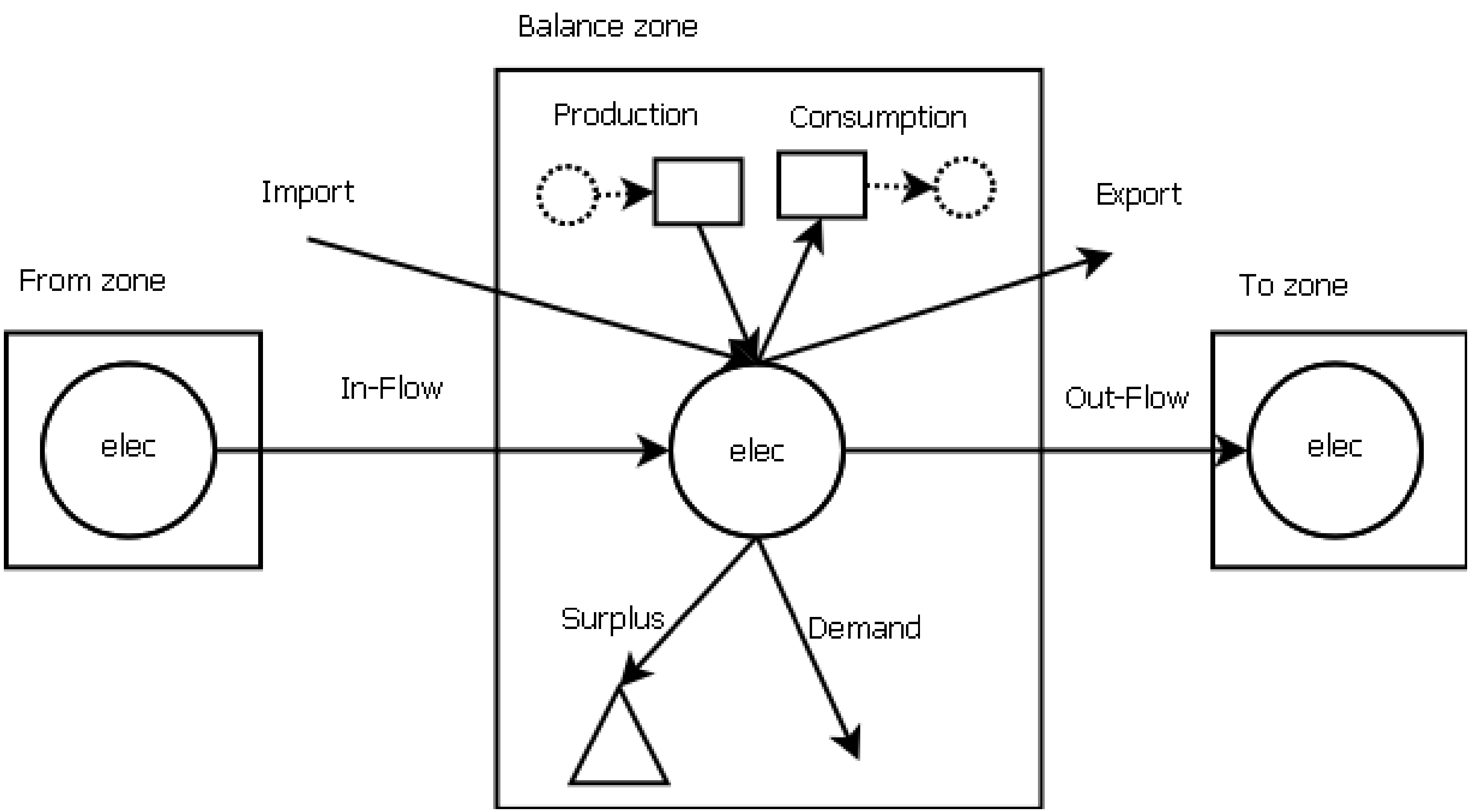
Overall process model

Combine individual process models



Energy Centre, Barkantine District Heating Network

Combined process and spatial model



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)
  - Existing links, plants

Data requirements - Resources

Property	Value
Resource	gas
Import cost	0.0269 kGBP/MWh
Export price	-
Max import locations	2
Max export locations	0
Maximum import	10 MW
Maximum export	-
GHG emissions	0.18455 t CO2e/MWh
Requires new network	no
Include in model	yes

Data requirements - Infrastructure

Property	Value
Network type	heat_net
Transported resource	dist_heat
Capital cost	0.35 kGBP/m
Maintenance cost	0.011 kGBP/m
Amortisation period	15 years
Discount rate	6 %
Minimum transport rate	0 MW
Maximum transport rate	10 MW
Transport cost	1.1e-8 kGBP/(m MWh)
Transport emissions	0 t CO2e/m MWh)

Data requirements – Technology types

Property	Value
Technology type	small_chp
Capital cost	173 kGBP
Maintenance cost	21 kGBP
Amortisation period	15 years
Discount rate	6 %
Minimum operating rate	0.040 MW
Maximum operating rate	0.135 MW
Operating cost	0 kGBP/MWh
Operating emissions	0 tCO2e/MWh

Inputs		Outputs	
Type	Rate	Type	Rate
gas	2.933	elec	1.0
		dist_heat	1.619
		heat_loss	0.314

Heat-map based models

Map-driven construction of spatial network with estimates of demand data for energy system model

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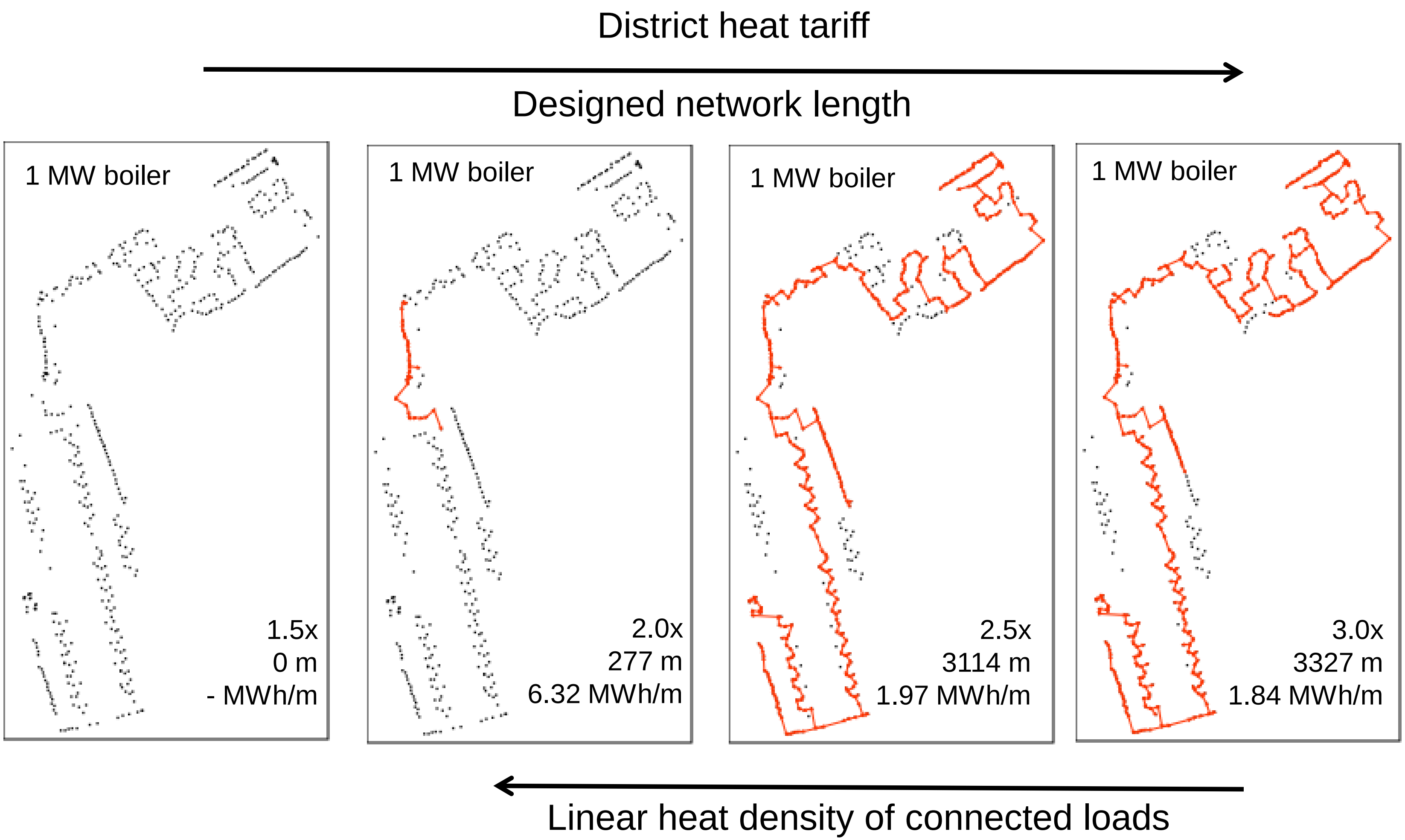
Heat-map based models

Identify favourable areas for heat network development
Interactively select sub-areas for detailed analysis

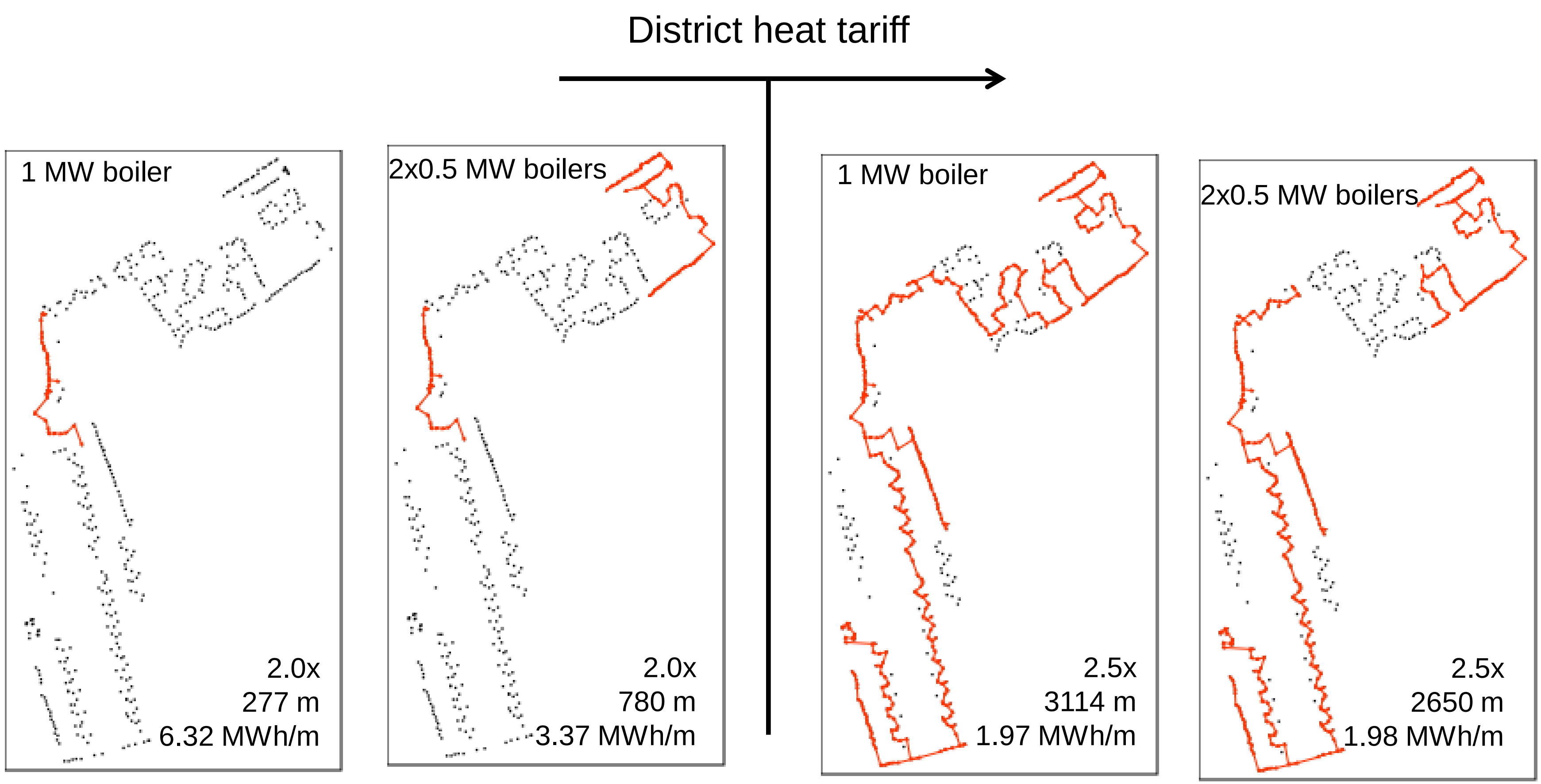
Scenarios

- Compare scenarios with different assumptions
- Purchase price for fuels
- Sales price for heat and electricity
- Alternative supply technologies
  - Technology type
    - E.g. boiler, heat pump, combined heat and power
  - Technology scale
  - Fuel selection
    - E.g. natural gas, biomass

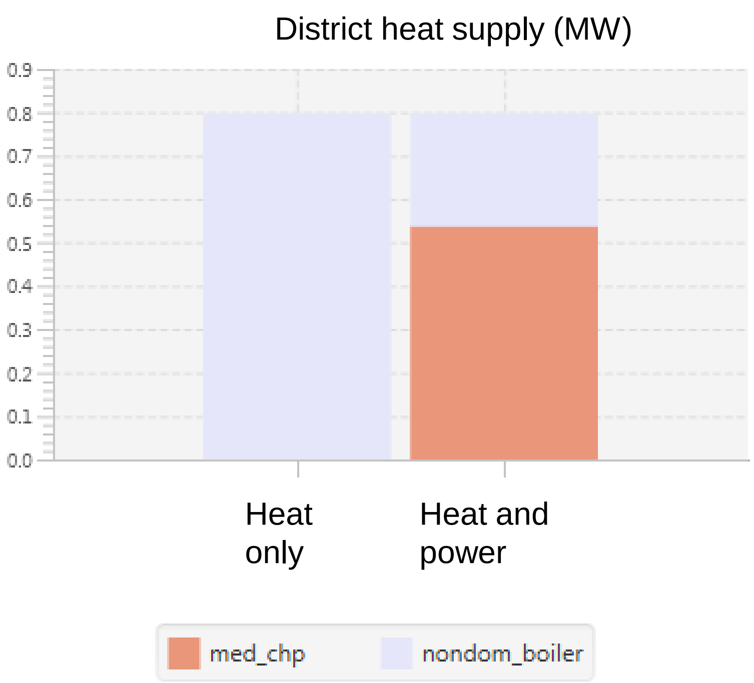
Heat price scenarios

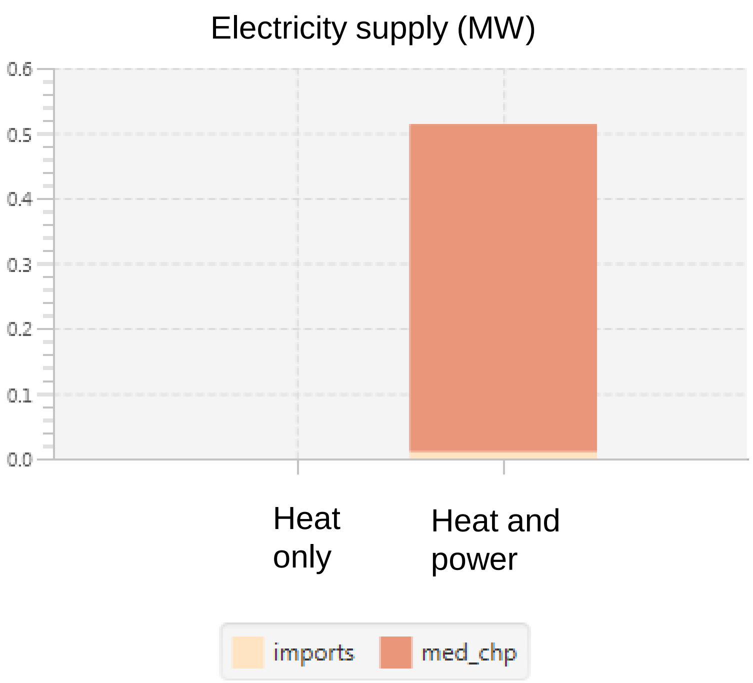


Boiler size scenarios



Heat and power scenario





Summary

- Transferable network-based model
  - Can be applied to cities with varying technology mix, economic and environmental concerns
  - Model data should be calibrated to reflect local conditions
  - Adjust level of detail to scale of system
    - City ↔ District ↔ Neighbourhood
- Heat-map based models
  - Interactive generation of spatial network
  - Estimates of heat demand
  - Potential plant locations

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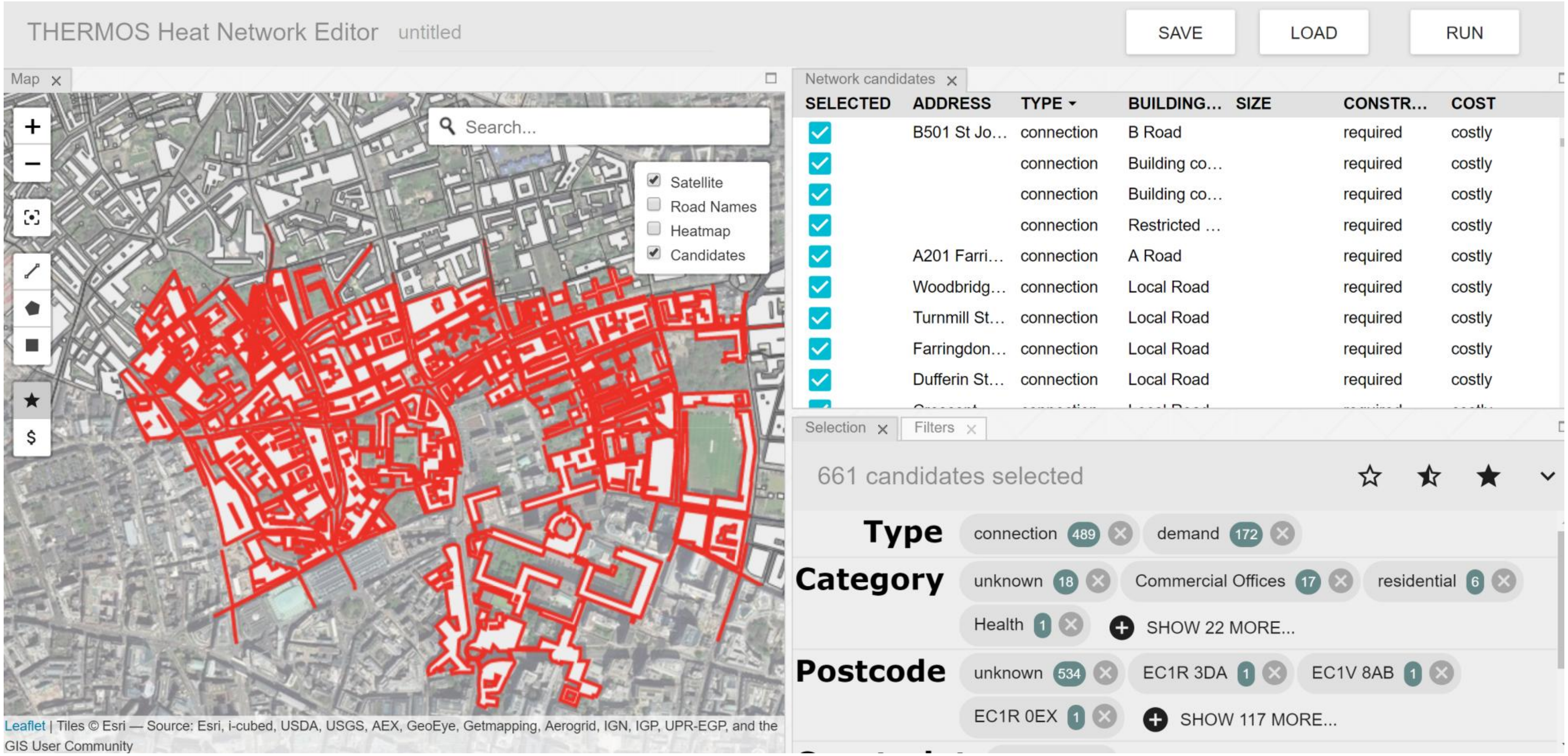
2.3 Thermal Energy Resource Modelling and Optimisation System



Content

The third part of the Module will focus on:

- Concept
- Methodology
- Application features
- Data, resources and skills needed

A problem…

The identification, analysis, and comparison of ***specific thermal energy system options*** **in** ***real local geographies…***

- Tends to be done manually using bespoke tools
- Studies are very expensive
- Limited capacity to undertake studies
- Lack of transparency and consistency in the methods used
- Little or no capacity-building in the public authorities.

A solution… ?

THERMOS

- Acts as a **decision support tool for energy planners**, combining state-of-the-art energy system data and models in a user-friendly map-driven open-source web-based application.
- Tailored to the real-world requirements of energy planners to make heat network planning faster, more efficient and more cost effective.

A solution… ?

THERMOS

Key features:

- Considers a wide range of energy sources (including waste heat from transport infrastructure).
- Incorporates state-of-the-art demand modelling to produce address-level energy system maps (considers heating, cooling and electricity).
- Applies advanced modelling algorithms to analyse energy supply and distribution options.
- Tested in eight THERMOS Pilot and Replication Cities.

Design approach

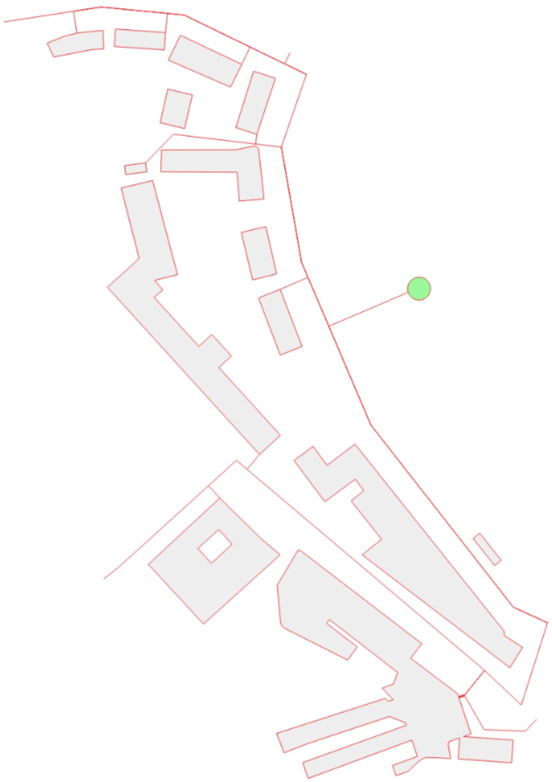
The interests of the THERMOS Pilot and Replication City users imply a need to support the following activities, and this is how the tool is designed:

1. Adding new sites and connections to an existing network
2. Designing a new network based on an existing energy source
3. Designing a new network to supply a given set of buildings, with one or more potential energy sources
4. Assessing / comparing the performance of specific networks and non-networked solutions

What does THERMOS actually do?

The THERMOS application identifies the *best solution*, given a set of available energy supplies, demands, and distribution routes:

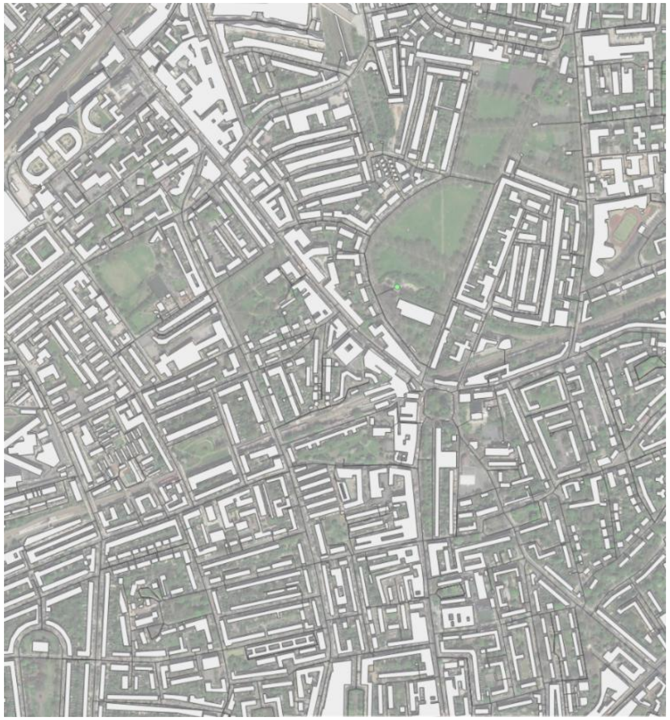
Here, a solution is a set of energy supplies connected to the set of demands they satisfy.



Asking a question

There are often lots of possibilities. The question is which supplies and demands to include, and how to join them up to get a viable system?

This is the set of decisions that the tool supports the user in making.



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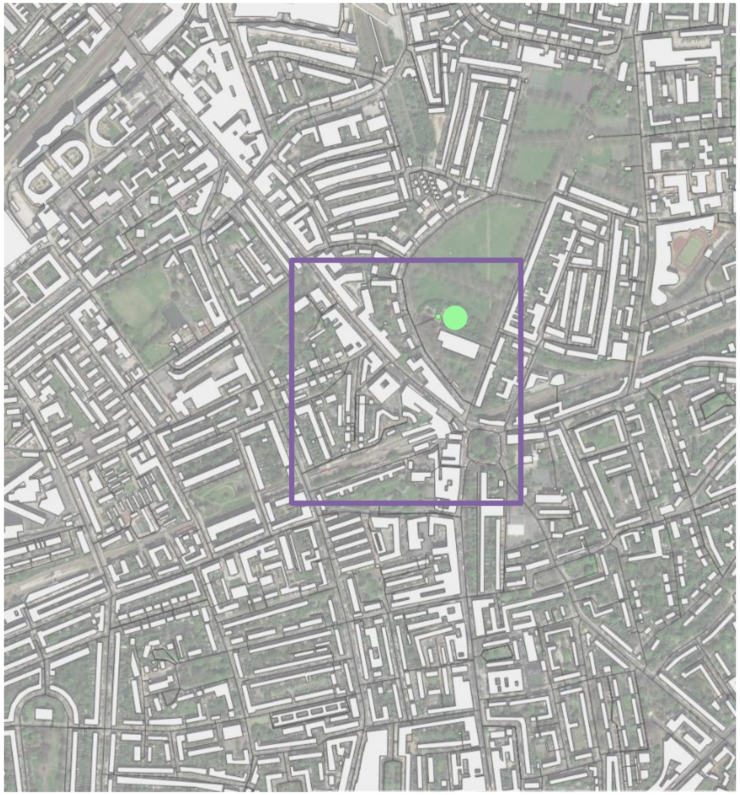

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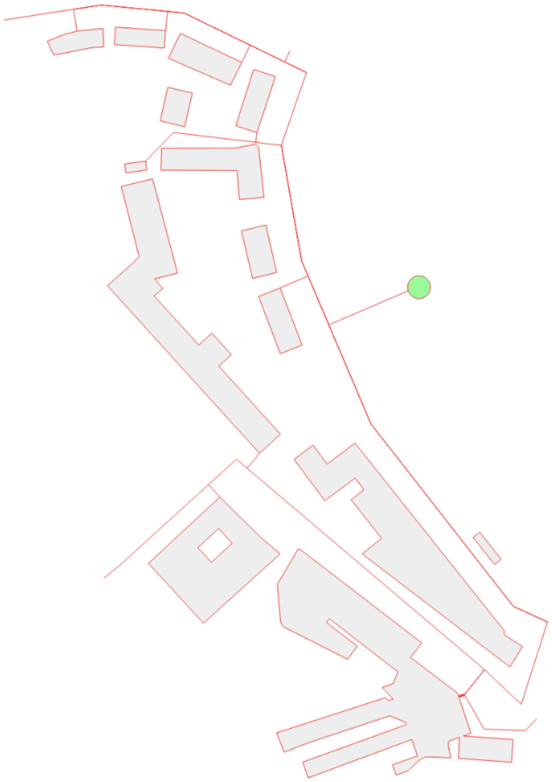
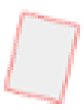


Question structure

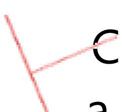
In THERMOS, a question comprises a set of elements which either could, or alternatively must, be in the resulting solution.

The elements are:

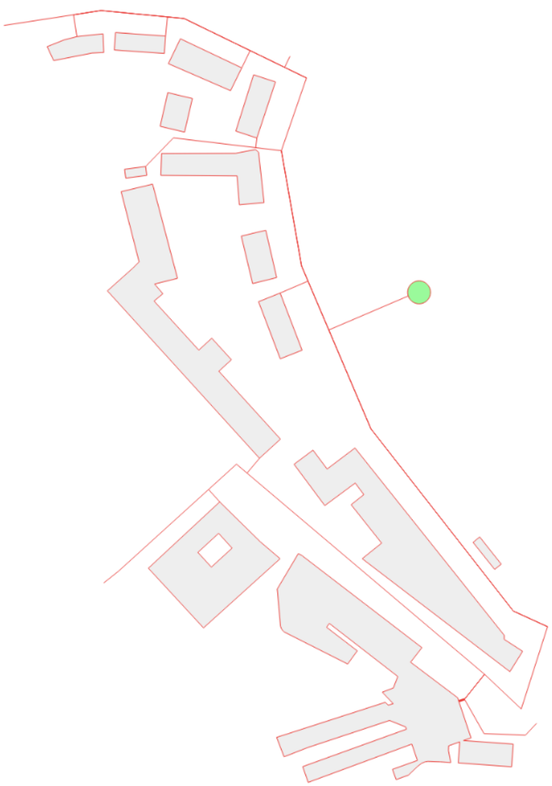


nergy demands - usually buildings

Energy supplies - e.g. CHP, boiler, heat pump



Connections – these combine to form a distribution network



And importantly: we also have to say what we mean by the "**best**" solution

Question structure

“Best” defines what quantity the energy system model is trying to optimise. For example, we might want as our answer the solution with the:

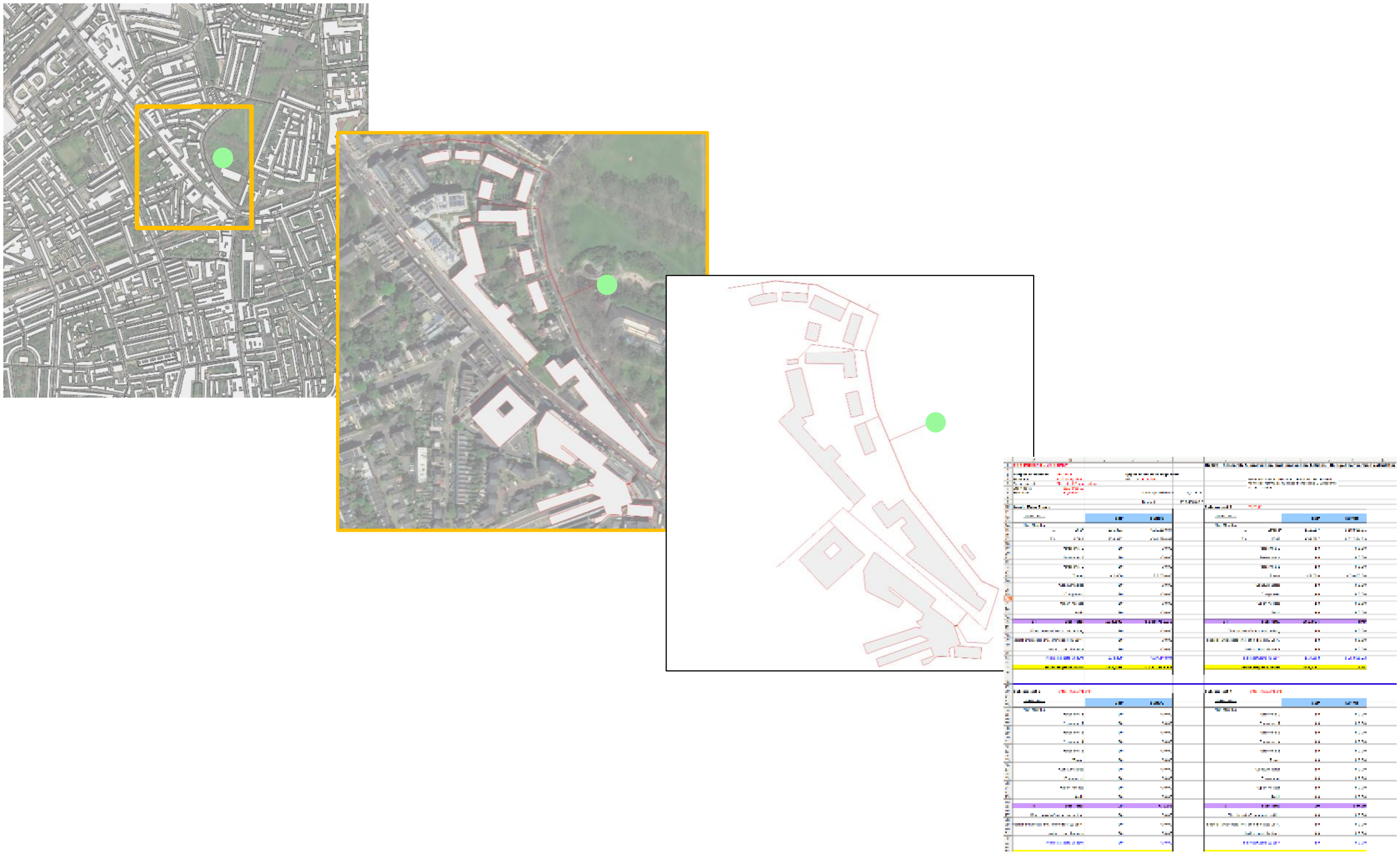
- Highest net present value (NPV)
- Lowest capital expenditure
- Lowest emissions
- Highest total demand met
- (other criteria are possible)

Getting an answer

When presented with a question in this way, the application will return a description of the solution. This will include things like:

- Costs (capital, fuel, NPV)
- Fuel inputs and heat outputs
- Emissions
- A list and a map of the sites (supplies and demands) and connections
- Some detail on the properties of each of the sites and connections.

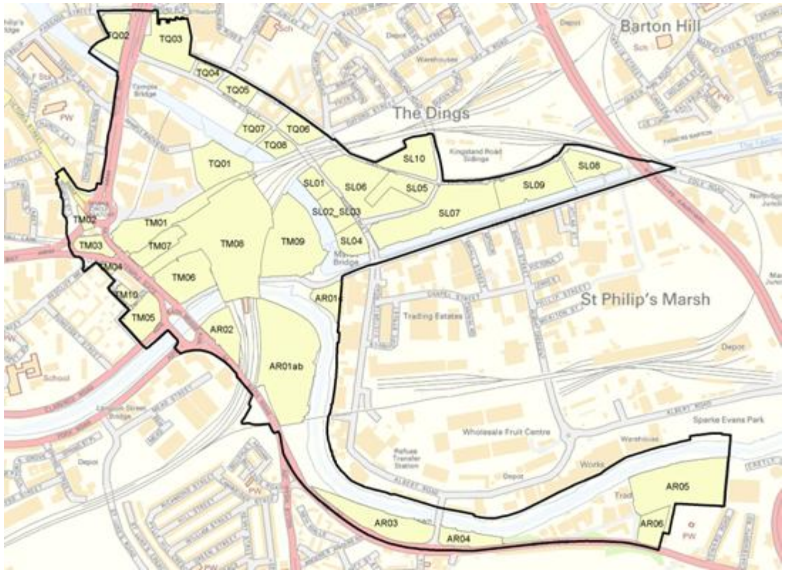
Recap



Required ingredients

For this to work, the application needs a good underlying energy system model, and a lot of data. Much of the project is about building, collating and synthesising these:

- A thermal energy system optimisation model
- Spatial data on the locations of roads and buildings
- Estimates of energy demand for all buildings…



Required ingredients

For this to work, the application needs a good underlying energy system model, and a lot of data. Much of the project is about building, collating and synthesising these:

- Estimates of the cost of making the individual connections
- Estimates of the costs of different technologies
- An application that brings this all together, and allows users to alter the assumptions when they know better than our estimates

Sector & phase		CO_2 saving from RE installed [tonnes/yr]	Biomass boiler CAPEX	Heat pump CAPEX	Solar PV CAPEX	Solar hot water CAPEX	Gas CHP Capex
Existing domestic		147	£0	£268,200	£197,864	£30,127	–
Existing non-domestic		2,242	£1,803,425	£1,567,548	£1,080,728	£1,193,634	£1,273,546
Phase 1 (2013-2018)	Domestic	334	£115,605	£100,007	£444,571	£15,069	–
	Non-domestic	733	£240,671	£285,156	£1,097,129	£74,191	–
Phase 2 (2018-2023)	Domestic	1,189	£271,502	£111,538	£1,340,040	£28,311	–
	Non-domestic	1,529	£242,631	£859,980	£1,969,209	£187,283	–
Phase 3 (2023-2036)	Domestic	506	£97,217	£57,116	£434,501	£9,049	–
	Non-domestic	55	£0	£74,656	£82,189	£22,313	–
	Total	6,735	£2,771,051	£3,324,201	£6,646,231	£1,559,977	£1,273,546

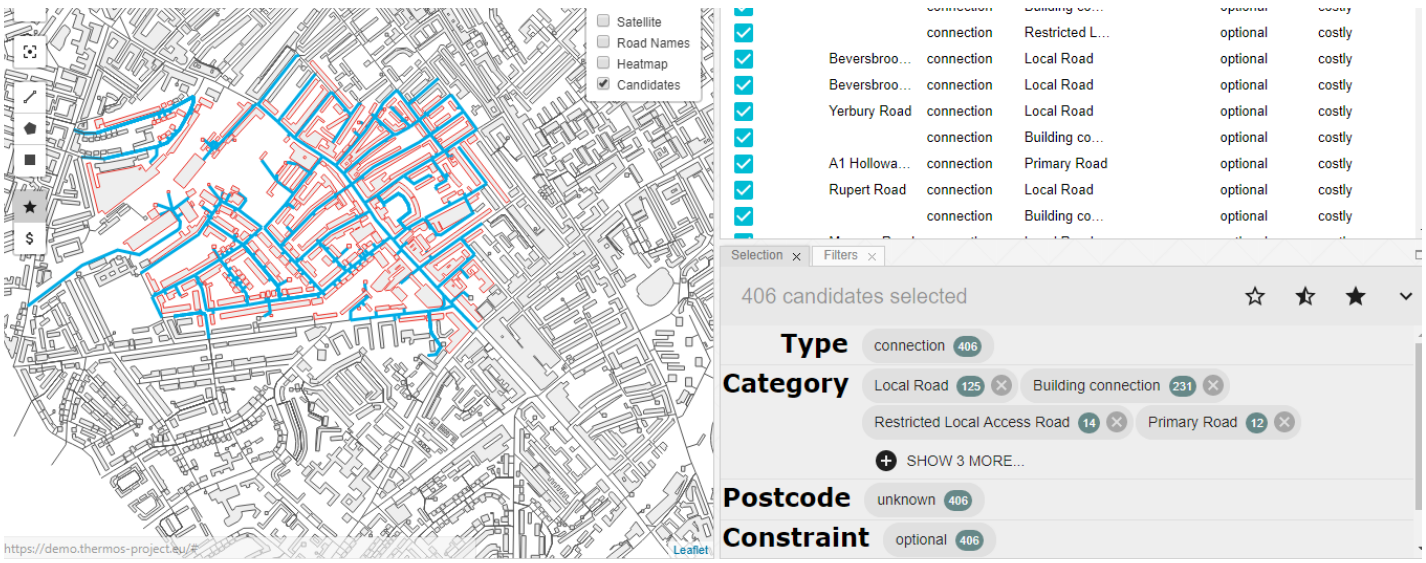
Application architecture

THERMOS will be a **web application**, accessed using a browser. There are a few reasons for this:

- Speed of development
- Ease of distribution
- Cross-platform compatibility
- Flexibility to vary the resources available to the application.

Application features

- Search for and view a map of the area of interest.
- The map displays the sites (buildings and energy sources) and available routes in the area, over a base-map.
- Edit the map by adding/removing sites and connection routes



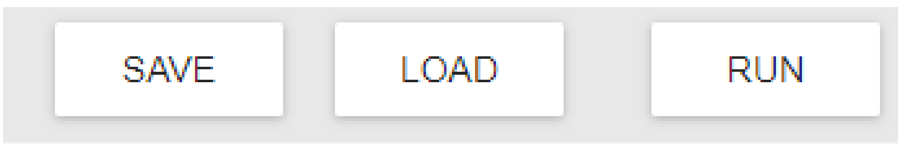
Application features

<u>Setting up a question:</u>

- Select sites and routes, by area or individually, and set their status to:
  - “**Forbidden**” – cannot be in the solution
  - “**Optional**” – could be in the solution
  - “**Required**” – must be in the solution
- Selecting the desired objective: the definition of “best”, e.g. maximise demand or net present value; minimise emissions

Application features

- Questions can be saved and submitted to the solver prior to viewing and downloading the solution

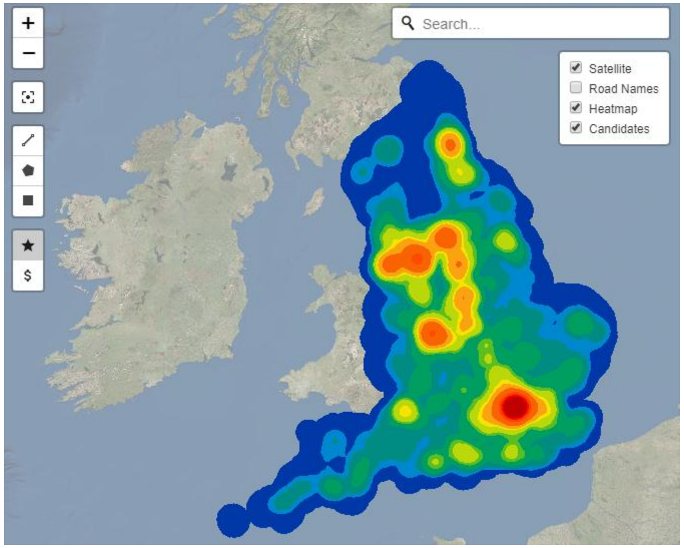


- Default values for various quantities can be overridden, such as:
  - Site energy demands
  - Route connection costs
  - Technology characteristics

Added Value

- Includes **building-level energy system mapping** – scalable to cities, regions and countries
- Incorporates **energy system models** with direct representation of networks: **going beyond 2D heat mapping**

- Uses **optimisation** to identify best solutions
- Free, **open-source product**, aimed at local authorities: no requirement for expensive third-party software



Added Value

- Use of **open-data** for inputs whenever possible
- Close collaboration with **Pilot local authority partners** is ensuring we build tools with the most meaningful features
- Supported rollout to **Replication partners** is ensuring post-project sustainability.

To make the most of THERMOS, you will need:

- An understanding of thermal energy systems for buildings
- Good local knowledge of the study area
- Ideally this will include access to local data on:
  - building demands
  - supply locations
  - technology and fuel costs

To make the most of THERMOS, you will need:

- Specific questions which map to the THERMOS features.
- A reasonably up to date computer, with a good internet connection, preferably with the Chrome browser installed.

- GIS skills and software, for creating reports on the results.

Summary – THERMOS

- The **THERMOS Tool** is a map-driven open-source web-based application tailored to the real-world requirements of energy planners to make heat network planning faster, more efficient and more cost effective.
- It identifies the best solution (depending on user definition of '*best*'), given a set of available energy supplies, demands, and distribution routes.
- Developed in conjunction with the four THERMOS pilot cities and tested by the four THERMOS replication cities
- Development is on-going – final version expected early 2019.

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