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Modelling urban energy systems

Approaches, challenges and opportunities

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Outline

- What is an urban energy system?
- Approaches: State of the literature in UES modelling
- Challenges: data, model complexity and integration, policy relevance
- Opportunities: techniques, theory and implementation
- Conclusion

Introduction

What is an urban energy system?

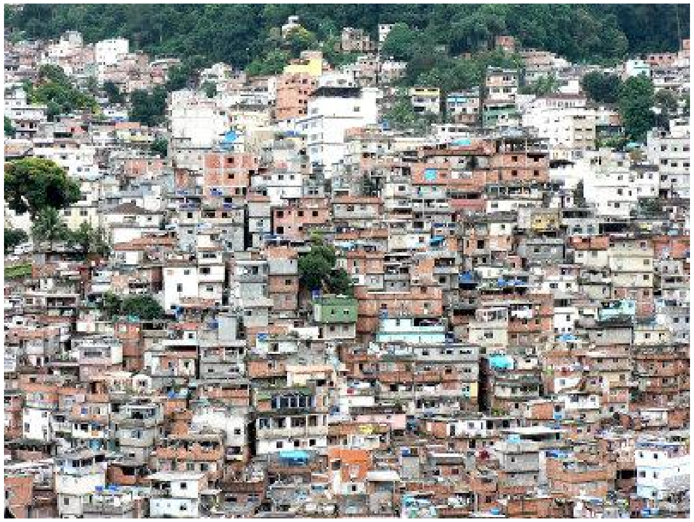
- "*the **combined processes** of **acquiring and using** energy to satisfy the energy **service demands** of a **given urban area***" after Jaccard (2005)
- Cities account for 2/3 global primary energy demand, 71% energy-related GHG emissions (IEA, 2008)

Key elements

- Land use and activity location
- Use patterns (human behaviour)
- Built environment (transport and buildings)
- Supply technologies and fuels

Drivers of coming urban energy transitions

- Increased urbanization in developing countries
- Aging infrastructure in developed countries
- Carbon, energy security imperatives
- New technologies at local and grid levels



Source: World Resource Institute on Flickr

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Approaches to UES modelling

- 6 approaches identified by a recent review*
  - Technology design
  - Building design
  - Urban climate and energy use
  - System design
  - Policy assessment
  - Transport and land use

- Each has its own methods, motivations, pros and cons
  - Growing interest in integrated modelling

*Keirstead et al (submitted)

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Approaches: technology design

Typical features:

- Small spatial scale
- Monthly temporal scale
- Simulation methods
- Supply-side focus

Range of technologies including:

- Transport, heat/cooling equipment, solar energy, ducted wind turbines in urban areas

Source: Grant et al (2008)

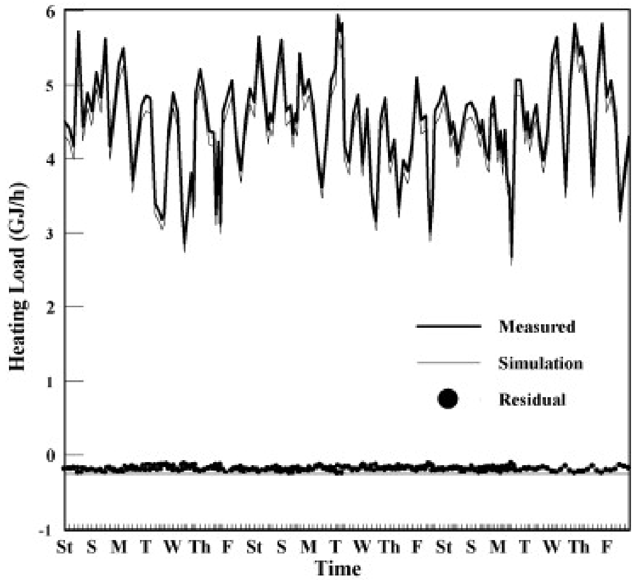
Approaches: building design

Typical features:

- Building spatial scale
- Annual temporal scale
- Simulation methods
- Demand-side focus

Examines design of building types

- e.g. Eskin et al (2008) on heating and cooling of offices
- Both new build and retrofit



Source: Eskin and Turkmen (2008)

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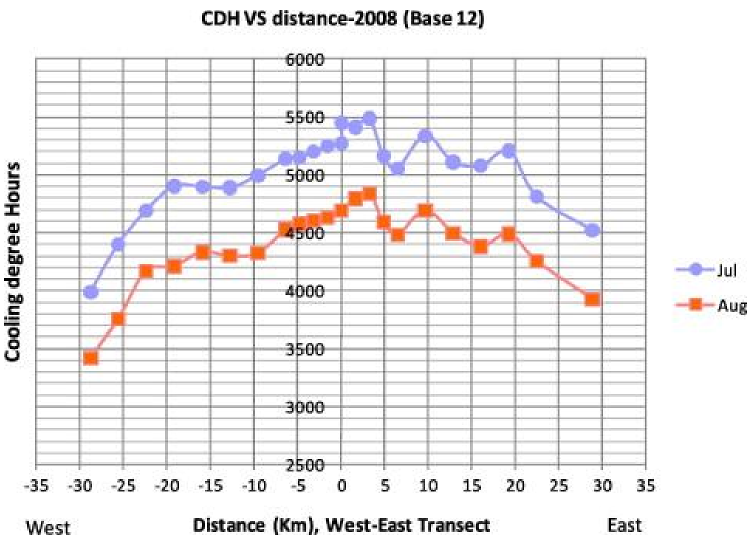
Approaches: urban climate and energy use

Typical features:

- Neighbourhood/street spatial scale
- Hourly temporal scale
- Simulation methods
- Indirect demand-side focus



Source: Kolokotroni et al (2010)

Drivers but not demands

- e.g. temperature, lighting, ventilation, not kWh
- Counter-example: Mavrogianni et al (2011) on urban heat island and impact on energy consumption

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Approaches: system design

Typical features:

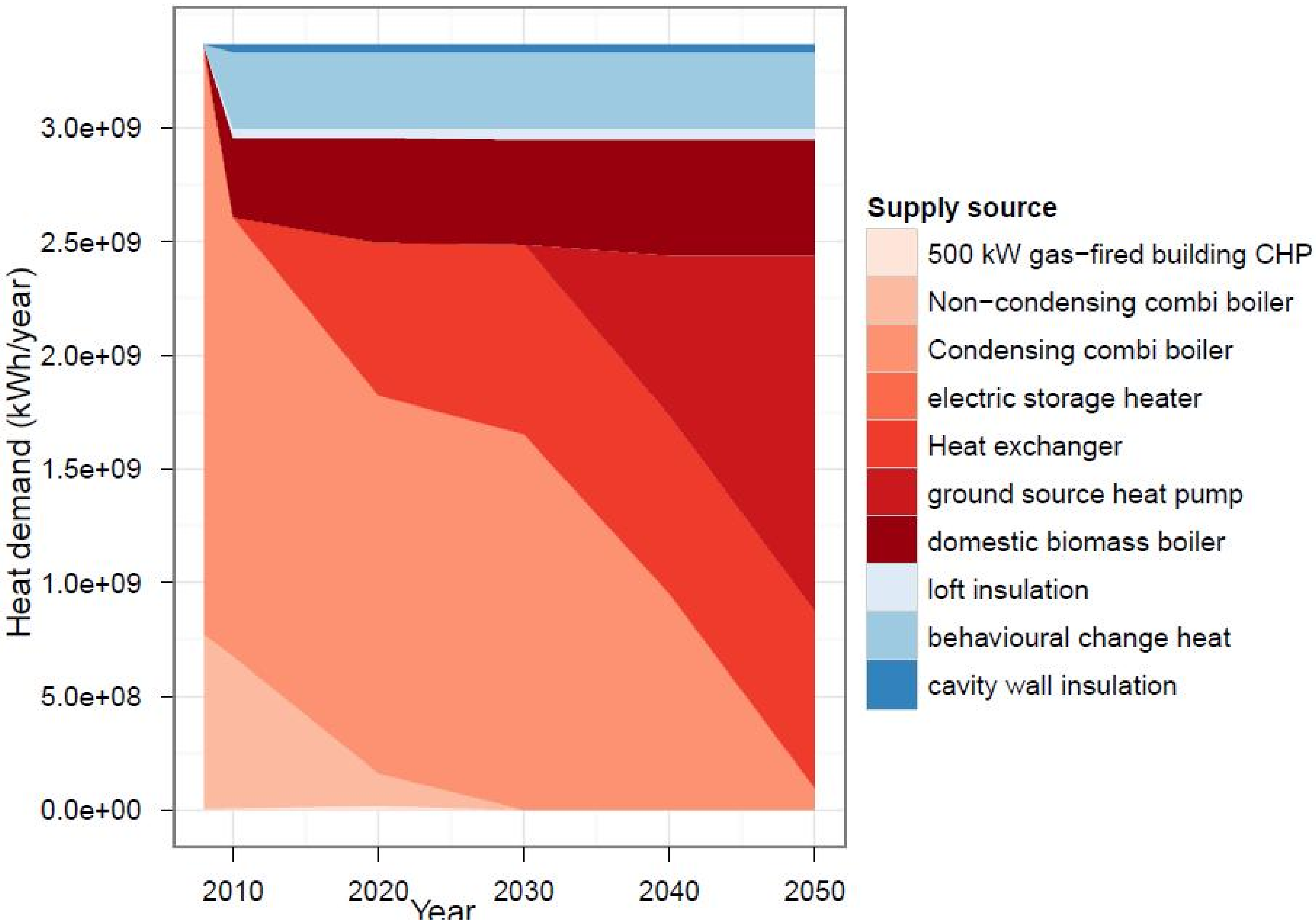
- District spatial scale
- Static (or annual) temporal scale
- Optimization methods
- Exogenous demands, endogenous supply

Typical use case:

- For a defined mix of energy service demands, what is the lowest cost energy supply system that meets a carbon constraint?

Approaches: system design

Meeting Carbon Reduction targets for Newcastle City Council



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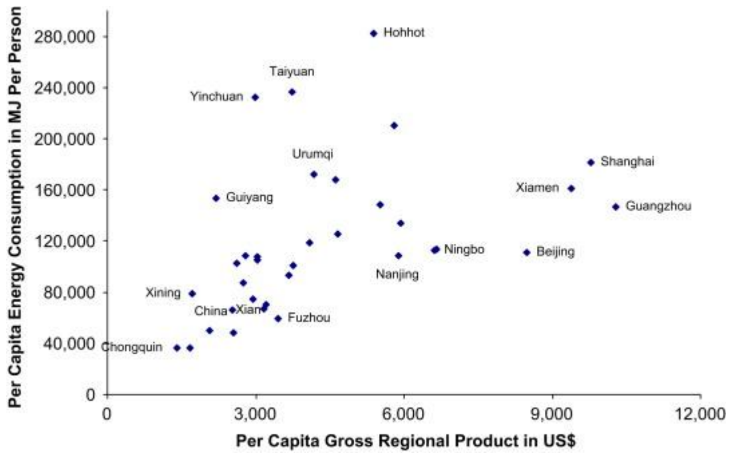
Approaches: policy assessment

Typical features:

- City spatial scale
- Static temporal scale
- Empirical methods
- Exogenous supply and demand



Source: Dhakal (2009)

Mainly descriptive studies of urban energy use

- e.g. Dhakal's (2009) study of energy use and carbon emissions in Chinese cities

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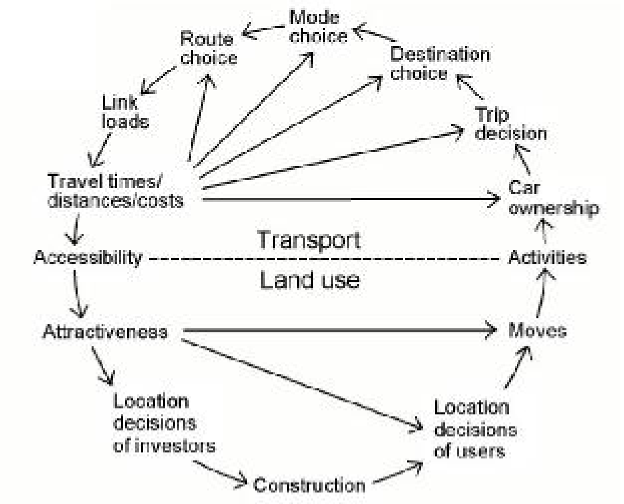
Approaches: land use and transport models

Typical features:

- District spatial scale
- Dynamic temporal scale
- Econometric simulation methods
- Endogenous supply and demand



Source: Wegener (2004)

Not normally thought of as urban energy models

- Historic interest in transportation energy but growing focus on stationary sector
- e.g. Wegener (2004) for a review, Ghauche (2010) for new interests

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Challenges: model complexity and integration

- Complexity
  - Uncertainty in model parameters and connections
  - Computational issues (e.g. optimizations taking multiple hours to solve)

- Integration, lack thereof
  - Connections between modelling sectors are largely piecemeal
  - e.g. climate model linked to building model, transport model linked to air pollution model

Challenges: policy relevance

- Policy analysis models have limited view of policy effectiveness and sectoral interactions
  - e.g. Add *x* thousand solar roofs, insulation measures etc. This may lower heat demand but what about rebound effects? Impact on energy supply system?

- Only land use and transport models begin to capture the direct and indirect effects of a policy intervention

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Challenges: data availability and quality

In a recent survey of energy modelling academics*:

- 68% said input data was difficult or very difficult to acquire
- Only 26% share model output data freely (most aggregate it into papers, or have commercial confidentiality constraints)
- 44% use formal data standards (e.g. ontologies, ISO or IEEE specs, etc.)
- Respondents lamented "a lack of easily extensible/adaptable ontologies"

* Keirstead and van Dam (2011)

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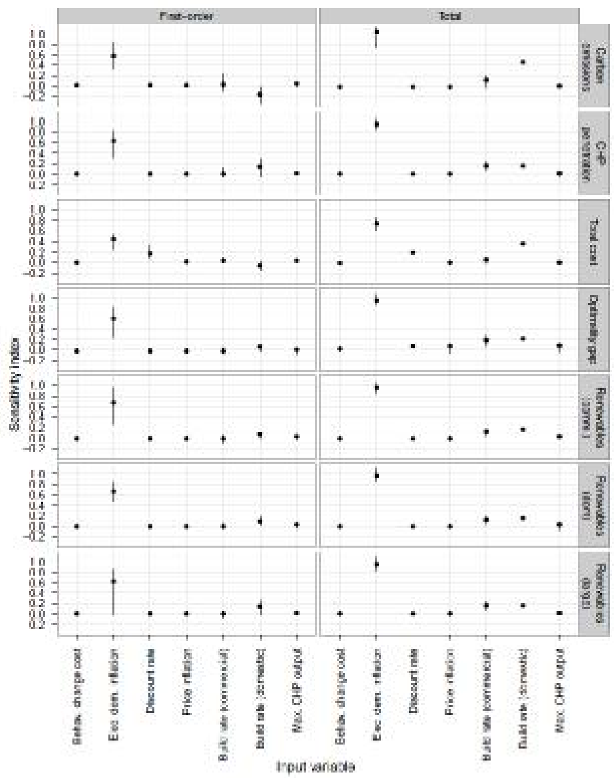
Opportunities: sensitivity analysis & cloud computing

- Existing literature rarely uses sophisticated sensitivity analysis; often just one-at-a-time variable changes



- Global sensitivity analysis methods promising but rely on Monte Carlo simulation

- Cloud computing to handle load?

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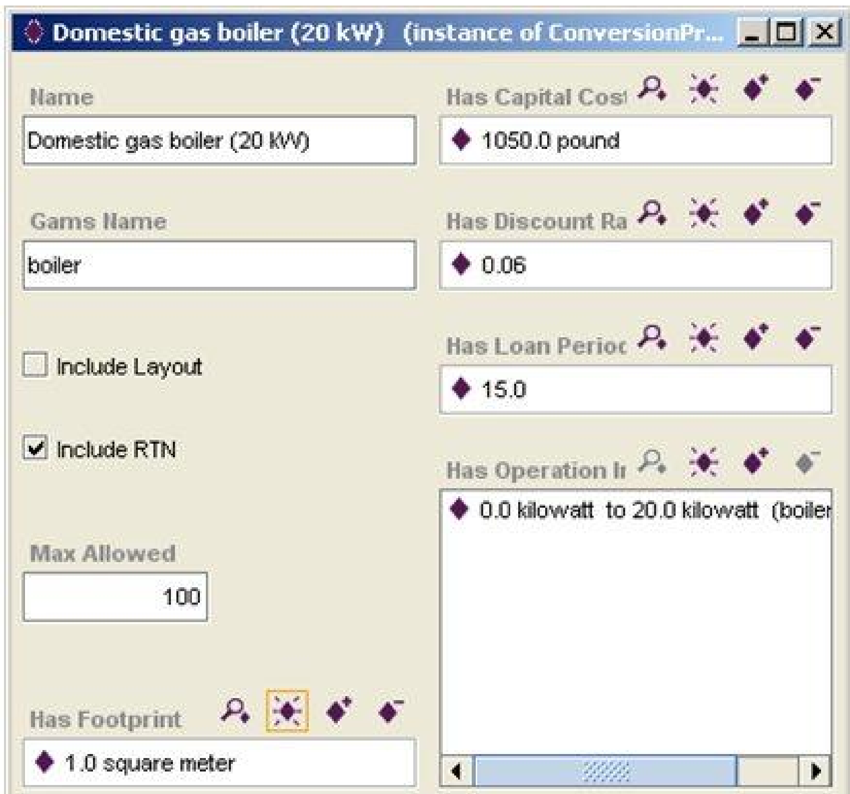
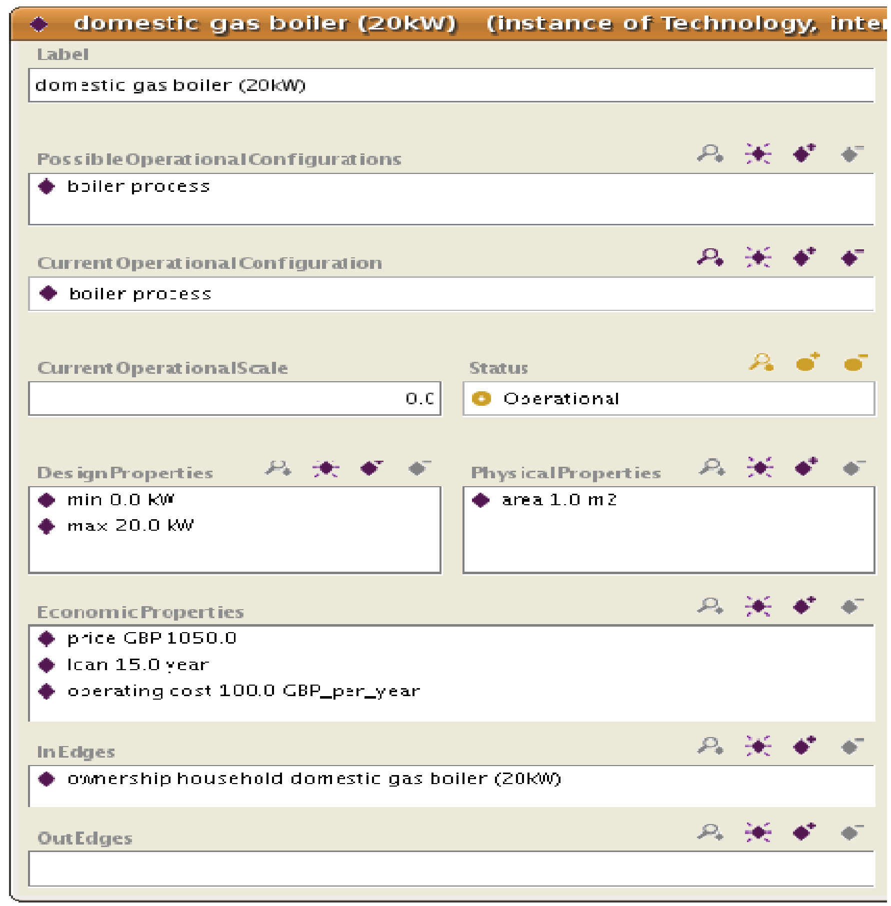
Opportunities: data collection and integration

- Development of standard middle-level ontologies?





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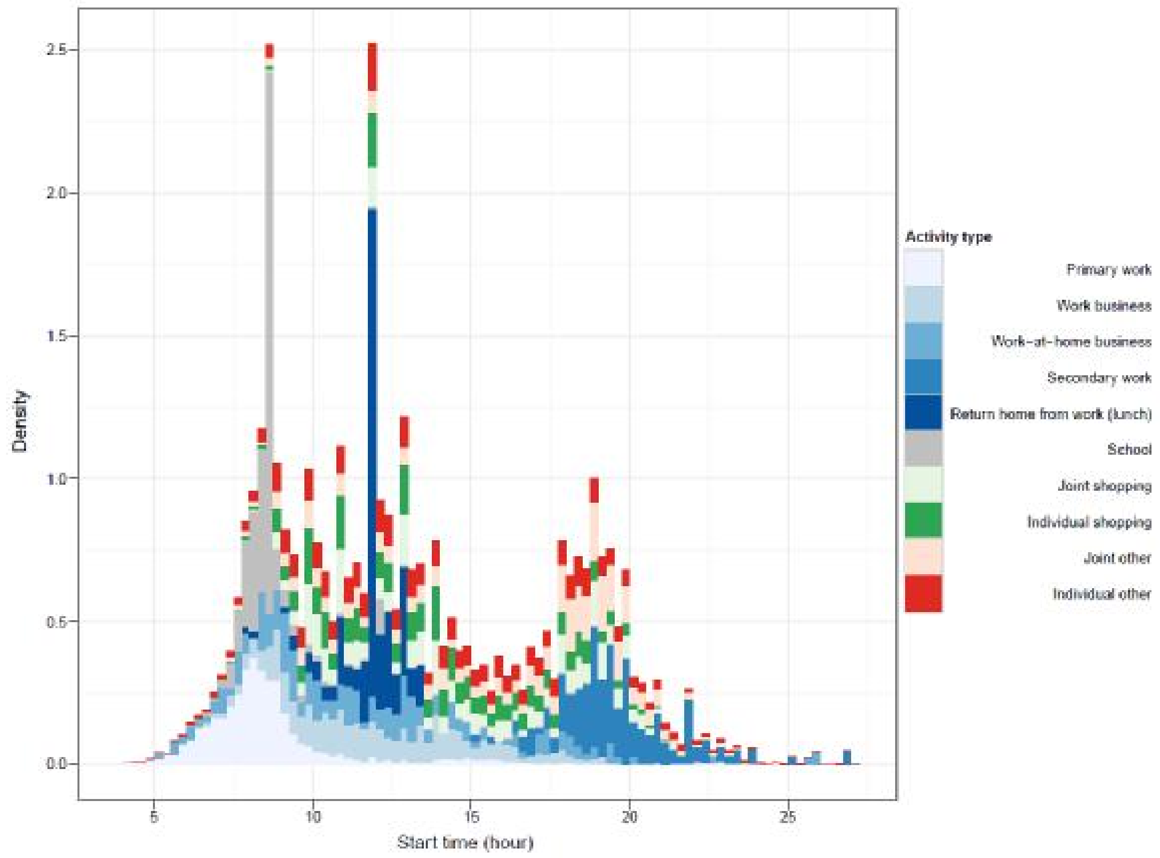
Opportunities: integration via activity-based modelling

- Human activities drive energy consumption
- Activity-based simulation methods as foundation for policy-responsive models



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Conclusion

- Understanding urban energy consumption is vital to addressing wider energy and climate challenges
- Wide variety of methods currently used, at a range of scales
  - Common difficulties in capturing interactions between sectors, indirect policy effects, data access and uncertainty
- Opportunities include improved methods, such as use of sensitivity analysis and ontologies, and model integration via activity-based simulation

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Questions?

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