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
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)
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)
Approaches: urban climate and energy use

Typical features:
• Neighbourhood/street spatial scale
• Hourly temporal scale
• Simulation methods
• Indirect demand-side focus

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
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

Graph showing the heat demand and supply sources from 2010 to 2050.

Supply source:
- 500 kW gas-fired building CHP
- Non-condensing combi boiler
- Condensing combi boiler
- Electric storage heater
- Heat exchanger
- Ground source heat pump
- Domestic biomass boiler
- Loft insulation
- Behavioural change heat
- Cavity wall insulation
Approaches: policy assessment

Typical features:
• City spatial scale
• Static temporal scale
• Empirical methods
• Exogenous supply and demand

Mainly descriptive studies of urban energy use
• e.g. Dhakal’s (2009) study of energy use and carbon emissions in Chinese cities

Source: Dhakal (2009)
Approaches: land use and transport models

Typical features:
• District spatial scale
• Dynamic temporal scale
• Econometric simulation methods
• Endogenous supply and demand

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

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
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)
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?
Opportunities: data collection and integration

• Development of standard middle-level ontologies?
Opportunities: integration via activity-based modelling

• Human activities drive energy consumption

• Activity-based simulation methods as foundation for policy-responsive models
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
Questions?

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