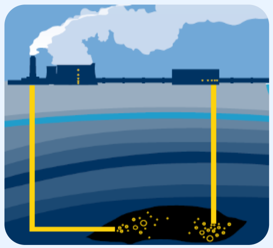








Modelling the infrastructure impacts of energy system transitions: Electrification of heat

WholeSEM 4th Annual Conference

3rd July 2017

Element Energy Ltd

Sam Foster

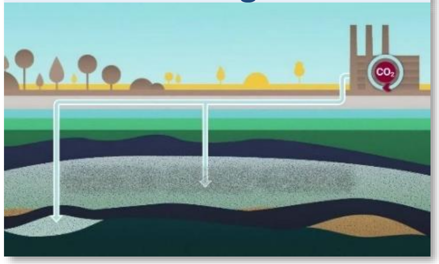
Element Energy is a consultancy focused on the low carbon energy sector

- Element Energy is a **specialist energy consultancy**, with an excellent reputation for rigorous and insightful analysis in the area of low carbon energy
- We consult on both **technical and strategic issues** – our technical and engineering understanding of the real-world challenges support our strategic work and vice versa
- Element Energy covers all major low carbon energy sectors:

Smart Electricity and Gas Networks

Energy Storage

Carbon Capture and Storage



Hydrogen

Low Carbon Transport

Built Environment

Our clients span the public and private sector in the UK and across Europe

- Our work with public sector clients, from local authorities to national government departments and international NGOs, has influenced policy decision making at all levels
- Private sector clients encompass both start-ups looking to commercialise and large multi-national corporations

Selected clients:

Public sector

Department for Transport
Department of Energy & Climate Change
Department for Communities and Local Government
Committee on Climate Change
Transport Scotland
Transport for London
Greater London Authority
scottishcitiesalliance
Aberdeen • Dundee • Edinburgh • Glasgow • Inverness • Perth • Stirling
Birmingham City Council
Roinn Cumarsáide, Fuinnimh & Acmhainní Nádúrtha
Department of Communications, Energy & Natural Resources
seai Sustainable Energy Authority of Ireland
European Commission

NGOs

iea International Energy Agency
European Climate Foundation
Transport & Environment
icct The International Council on Clean Transportation
World Bank Group
UNDP

Public-Private Partnerships

energy technologies institute
UK H_2 Mobility
LowCVP low carbon vehicle partnership
FCH Fuel Cells and Hydrogen Joint Undertaking

Private Sector

British Gas
nationalgrid
EDF Energy
Scottish and Southern Energy
UK Power Networks
Intelligent Energy
ESB Energy for generations
Air Products
Shell
bp
BOC Member of The Linde Group
Nissan
Rolls-Royce
Toyota
Daimler
zipcar

Key features of the energy transition

Centralised
Segregated
Fossil-fuel driven

- Embedded and distributed generation
- Electrification of heat and mobility
- Transition to other energy vectors (bio-energy, H_2)
- Deeper energy efficiency
- Increasing participation of consumers
- Increasing flexibility of the demand-side (DSR, storage)

Decentralised
Integrated
Renewable

Focus of this presentation

LOW CARBON HEATING

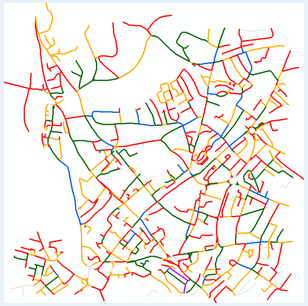
Three key themes are frequently raised by our clients – key themes the WholeSEM community should be looking to address

LOW CARBON HEATING

- What will be the impact on the **peak electricity load**?
- What will be the requirements for distribution and transmission **grid reinforcement**?
- Over what **timescale** will these impacts occur?
- What **policy actions** are required to drive consumer uptake?

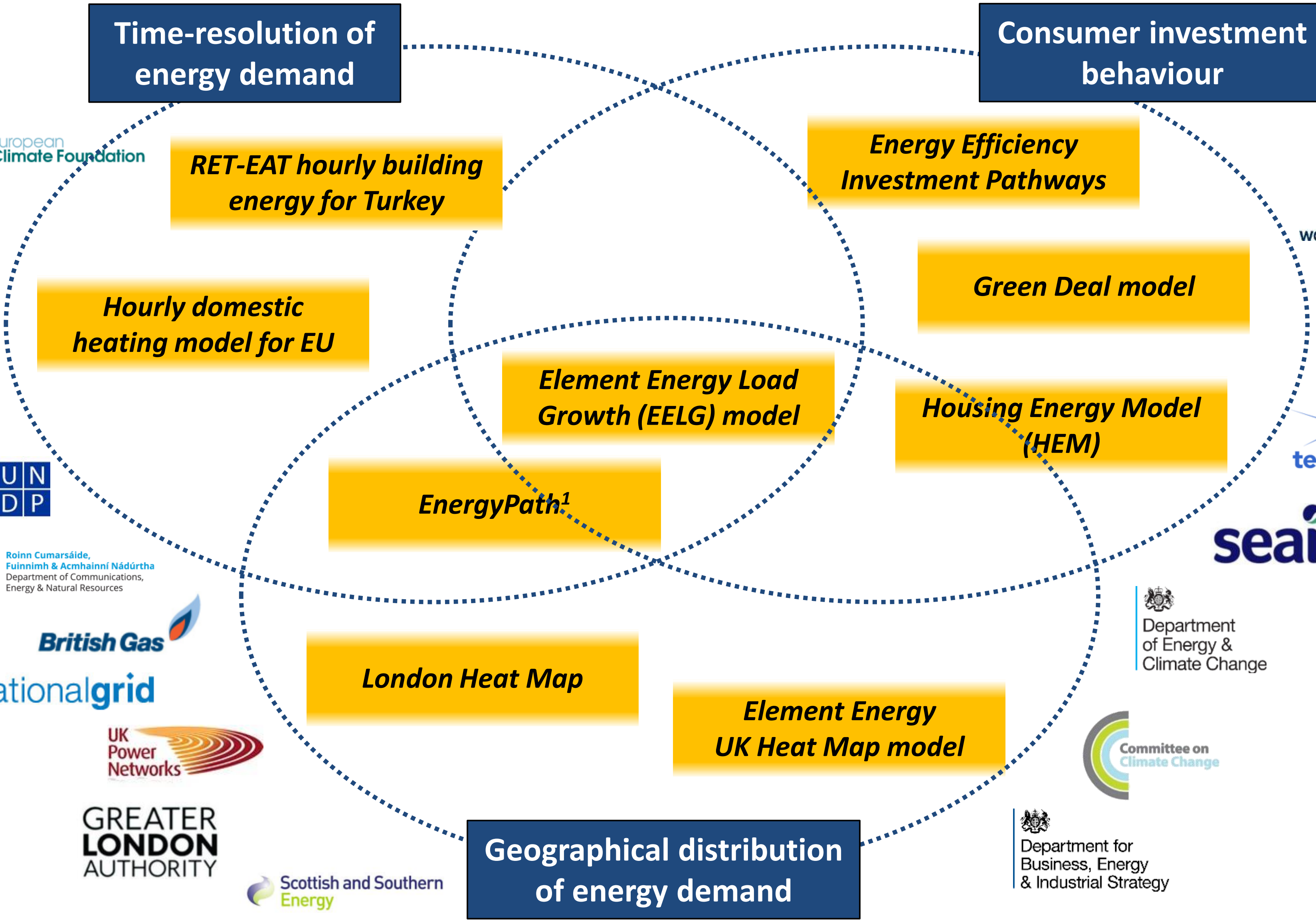
1) Timing of heat demand matters

2) Geographical distribution of heat demand matters



3) Consumer behaviour matters

Element Energy has been developing models to answer questions like these over a number of years



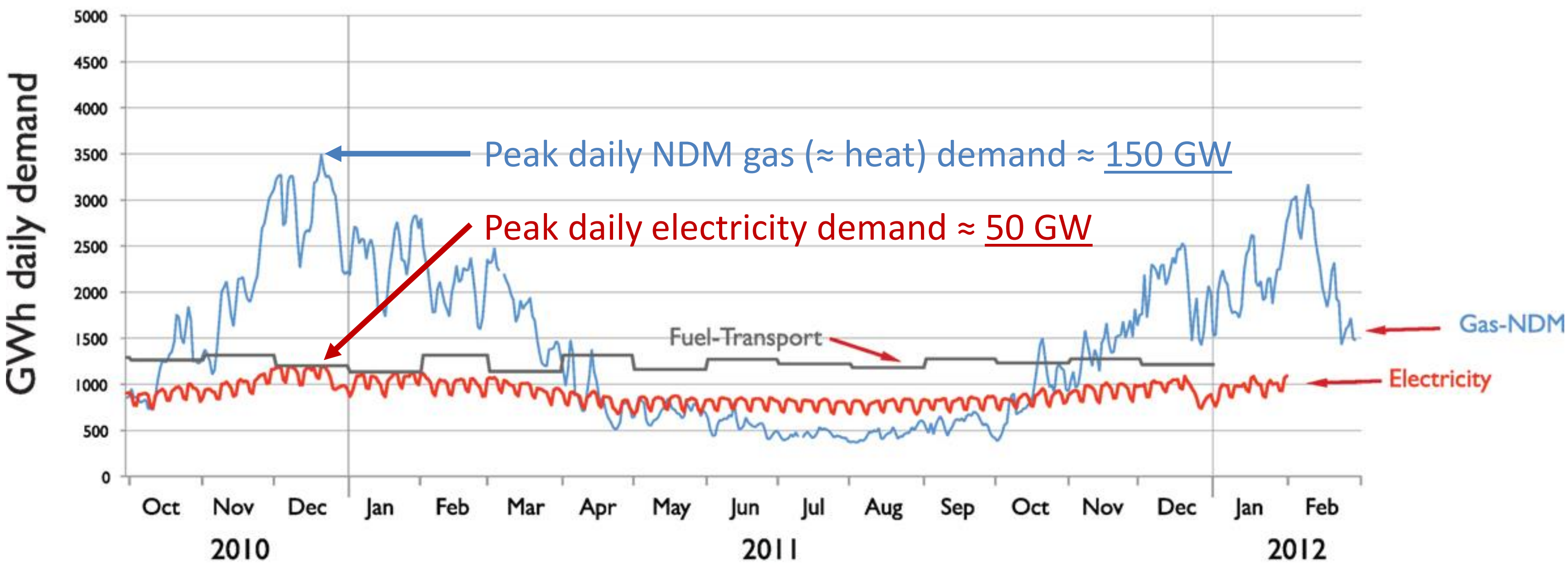
(1) Developed as part of a consortium including Baringa and Imperial College

Agenda

- Time-resolution of energy demand
- Geographical distribution of energy demand
- Consumer investment behaviour

1) Timing of heat demand matters: Peak heat demands can be several times larger than peak electricity demands

Daily variation in gas and electricity demand in the UK

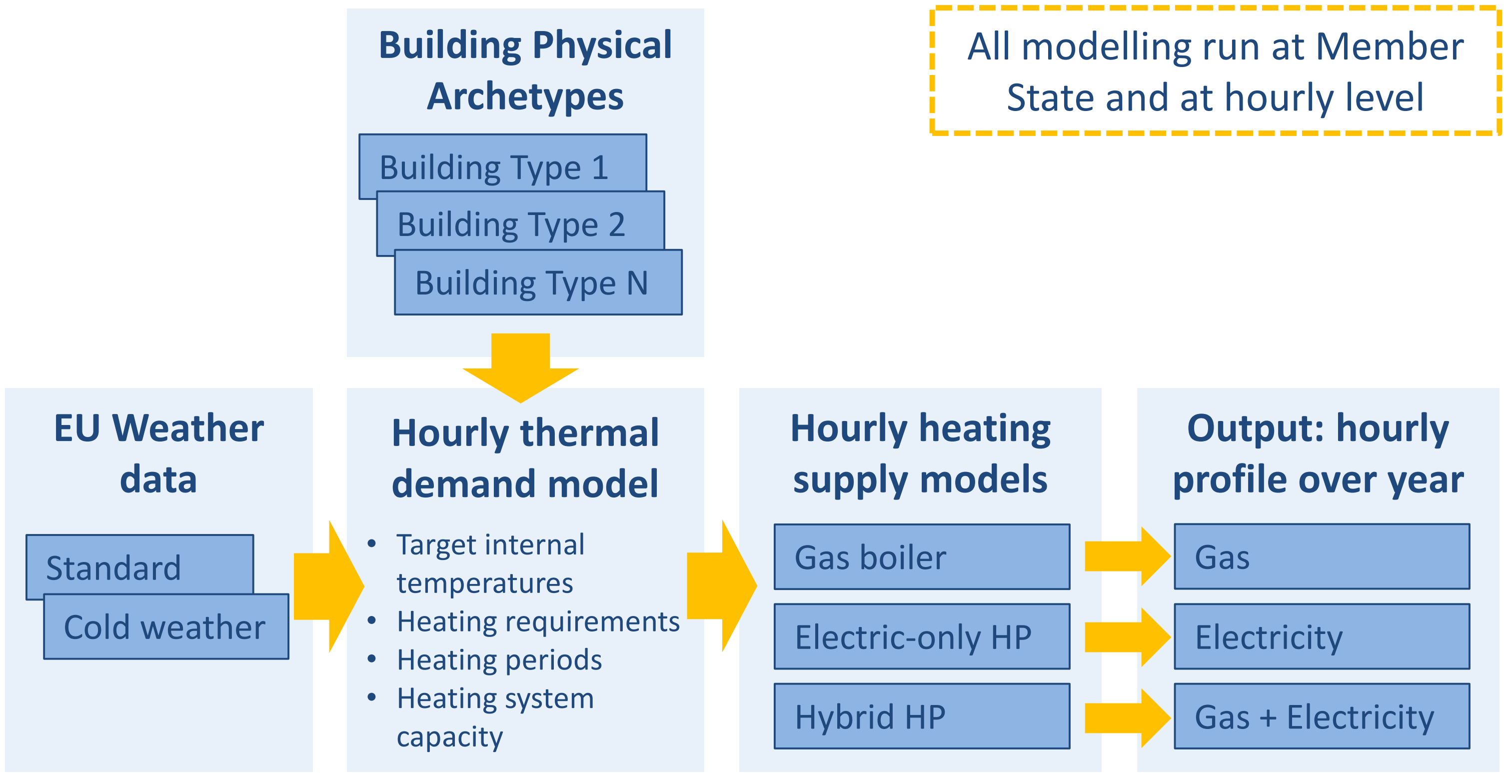


- A substantial shift to electric heating will result in a **large new signal** for electricity demand
- Crucially, this new signal is likely to be **much more 'peaky'**
- Note that the figure shows only *daily* resolution – at higher levels of time-resolution the heating demand would show even more pronounced peaks → **Hourly peak heat demand > 150 GW**
- This poses a challenge for the electricity system, as **storage is more challenging** than for gas

Grant Wilson IA (2016) Energy Data Visualization Requires Additional Approaches to Continue to be Relevant in a World with Greater Low-Carbon Generation. *Front. Energy Res.* 4:33. doi: 10.3389/fenrg.2016.00033

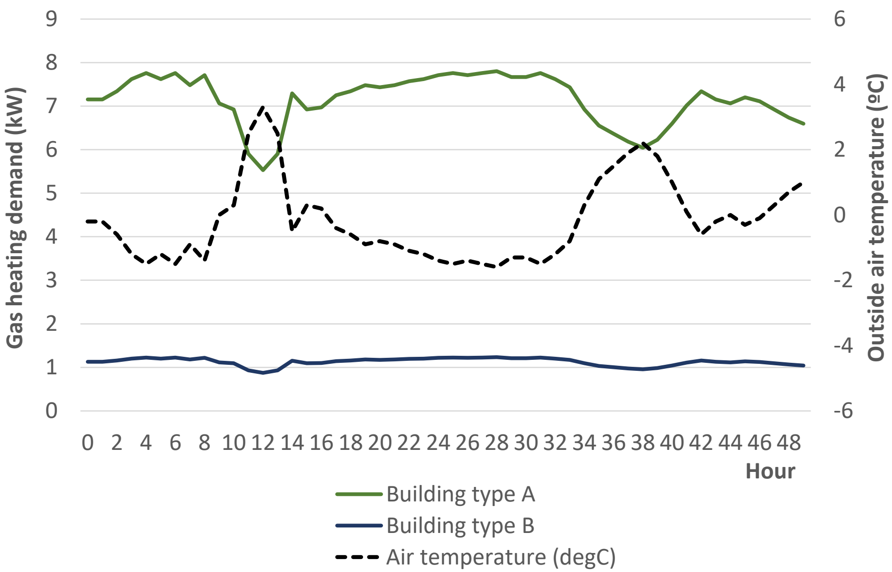
Element Energy hourly domestic heating model for Europe

- Element Energy carried out a project for the European Climate Foundation on the infrastructure impacts of energy system transitions
- As part of this, we studied the potential impact of electrification of heat
- To do so, we built a **model of the hourly heating demand** in Europe

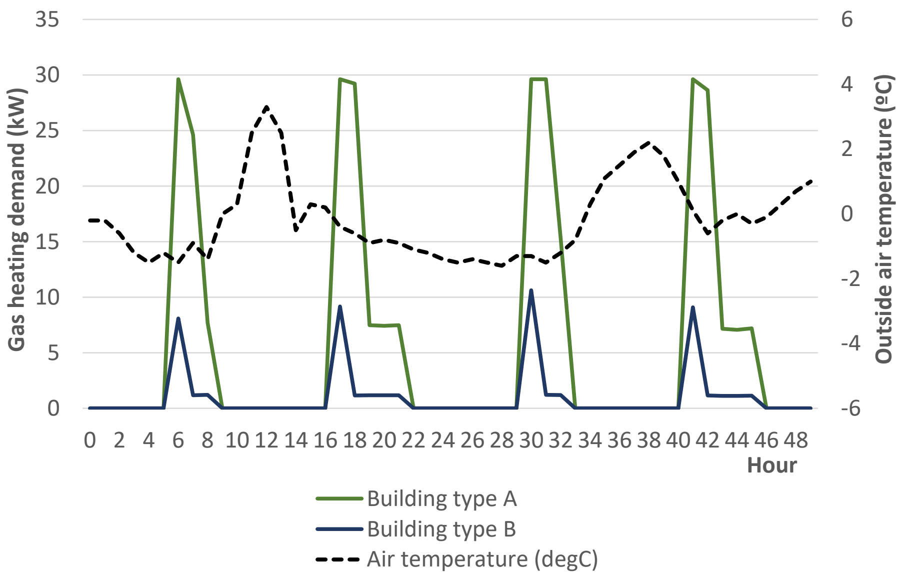


Illustrative outputs from the model – Gas heating in individual dwellings

Gas heating over 48 hrs: Continuous heating



Gas heating over 48 hrs: Two heating periods

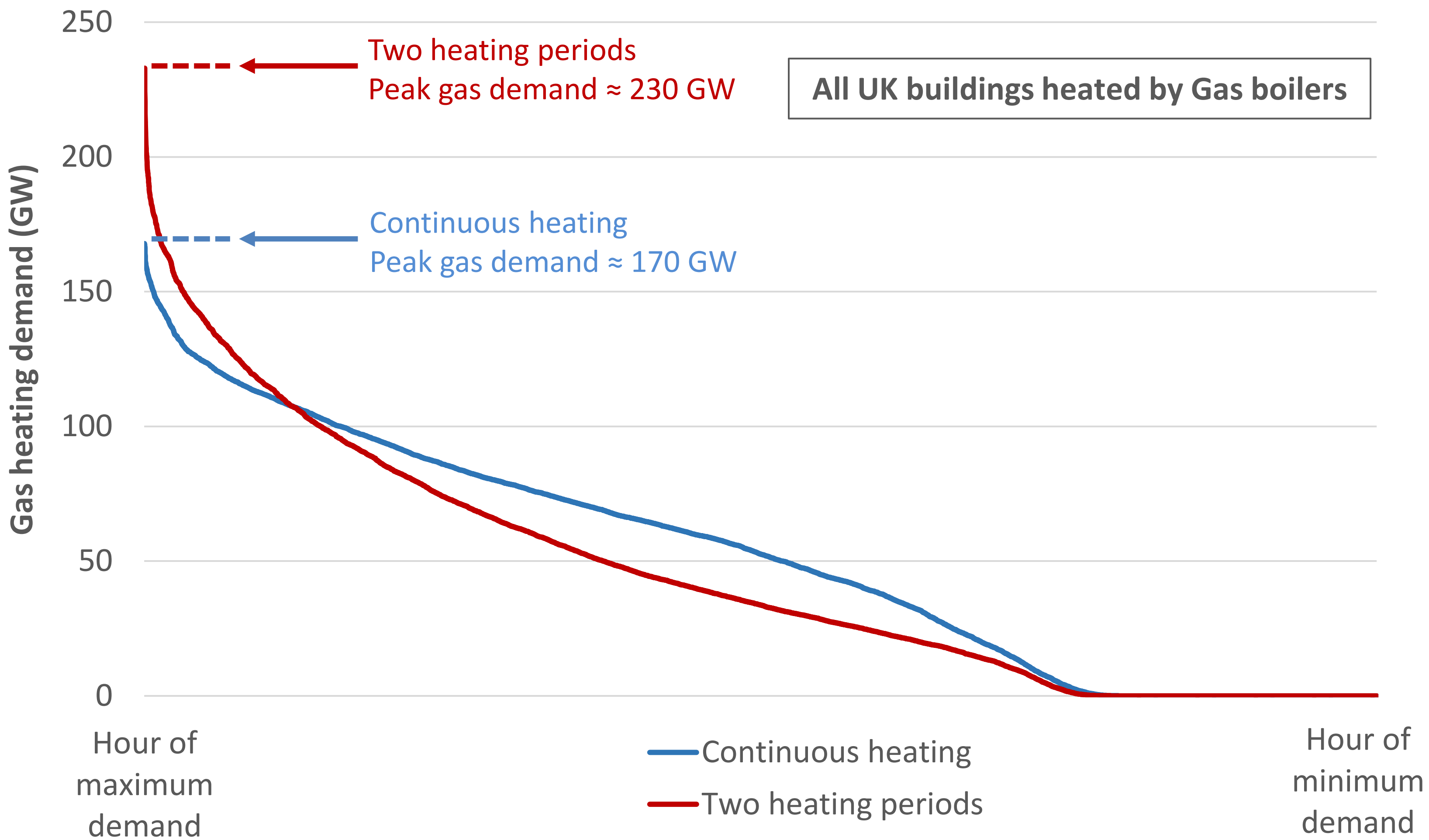


- Graph shows hourly Gas demand profiles for two building types heated by Gas boilers over 48 hours
- Variation between two building types reflects differences in thermal efficiency, size and geometry
- In this example, the occupant employs **continuous heating** (i.e. the heating is on all day and all night)
- However, this is **not how most people use heating**

- Typical heating behaviour is two heating periods – morning and evening
- In this case, **peak heat demand is higher** than for the continuous heating case – often limited by size of boiler
- This is due to the **thermal mass** of the building, which has cooled down outside the heating periods
- **Heating schedule** – i.e. the way the consumer uses the heating system – is **critical in influencing peak demand**

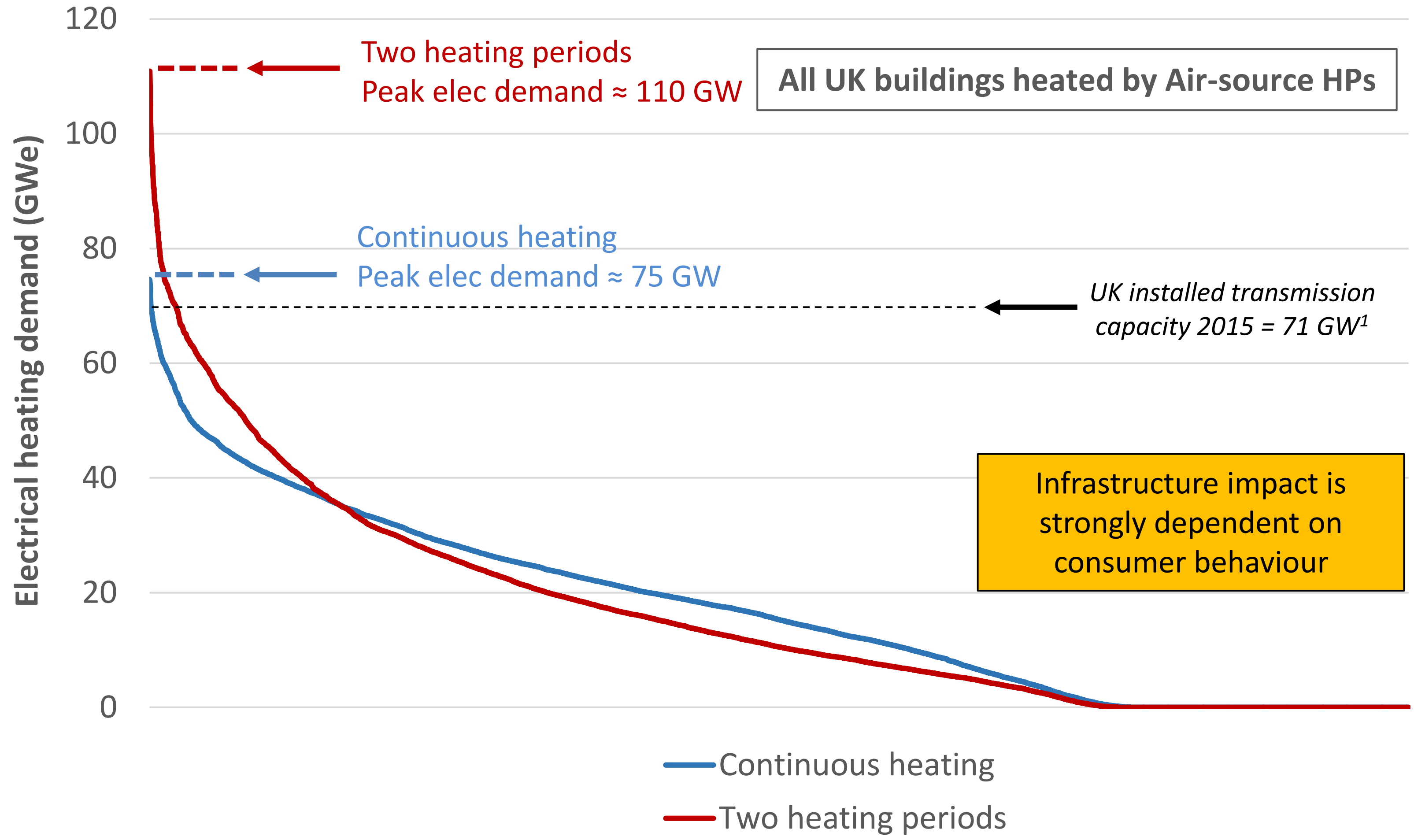
Aggregating over the whole UK building stock and accounting for diversity, peak gas heating demand in a typical year can be simulated

Simulated load curves for gas heating in UK for a typical year



Full electrification of UK domestic heating could increase peak electrical demand by 75-110 GW, strongly dependent on consumer heating behaviour

Continuous heating could reduce the peak electrical heating demand by more than 30%



(1) UK Transmission network capacity as of end December 2015 (UK Government)

Agenda

- Time-resolution of energy demand
- Geographical distribution of energy demand
- Consumer investment behaviour

2) Geographical distribution of heat demand matters: Transitions will often occur in localised clusters

- Where will uptake of technologies be distributed geographically?
- Will they be **uniformly distributed** or **clustered**?

- Highly relevant in terms of impact on **local distribution systems and infrastructure**

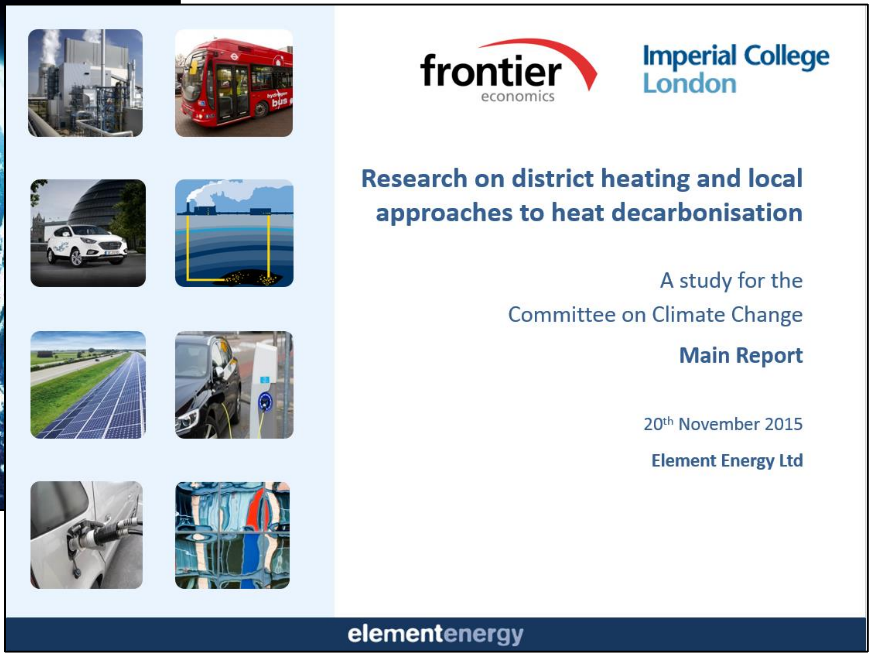
- *Example*: Grid constraints for connection of Solar PV in Cornwall

> *"A delay of 3-6 years will apply to all generator connections requiring works at HV (i.e. 6.6kV or 11kV) or above"*
> *Western Power Distribution, Presentation (April 2015)*

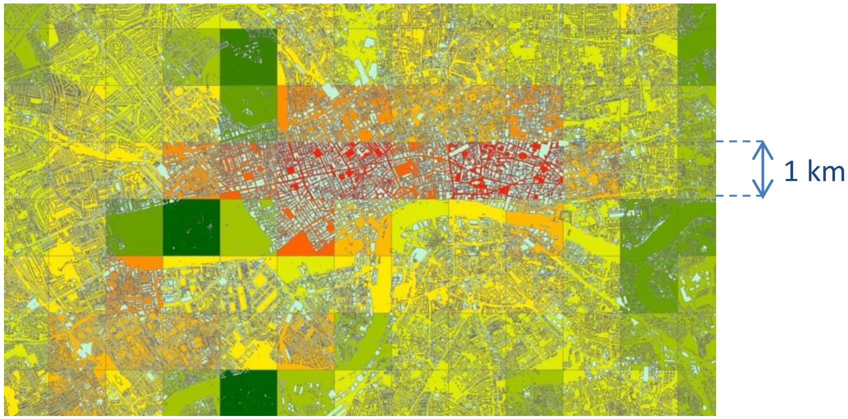
- Will similar challenges be encountered with widespread deployment of heat pumps, electric vehicles and other technologies?

Project example: Heat network scenarios to 2050 for the 5th Carbon Budget

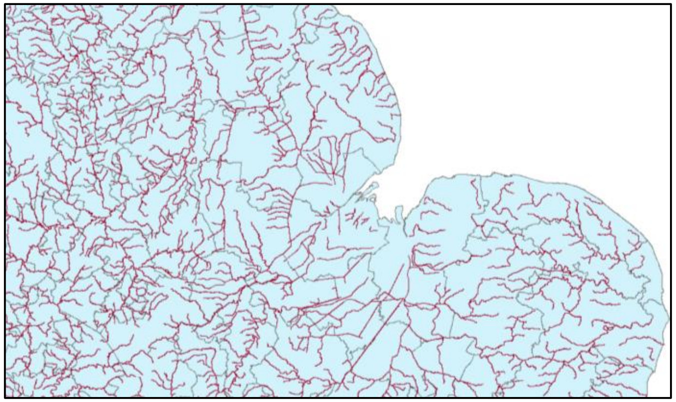
- Element Energy worked with Imperial College and Frontier Economics for the Committee on Climate Change to develop scenarios for heat network deployment
- Inherently a spatial / geographically-resolved challenge



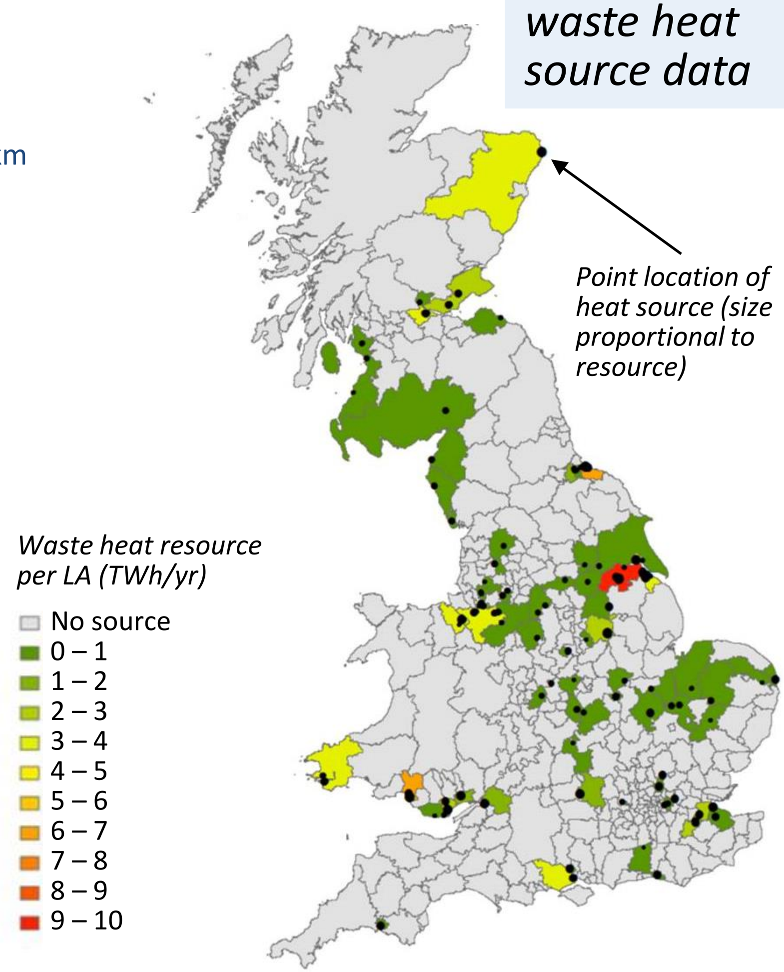
Geographical-resolved datasets on heat demand and potential heat sources were used



DECC heat map data



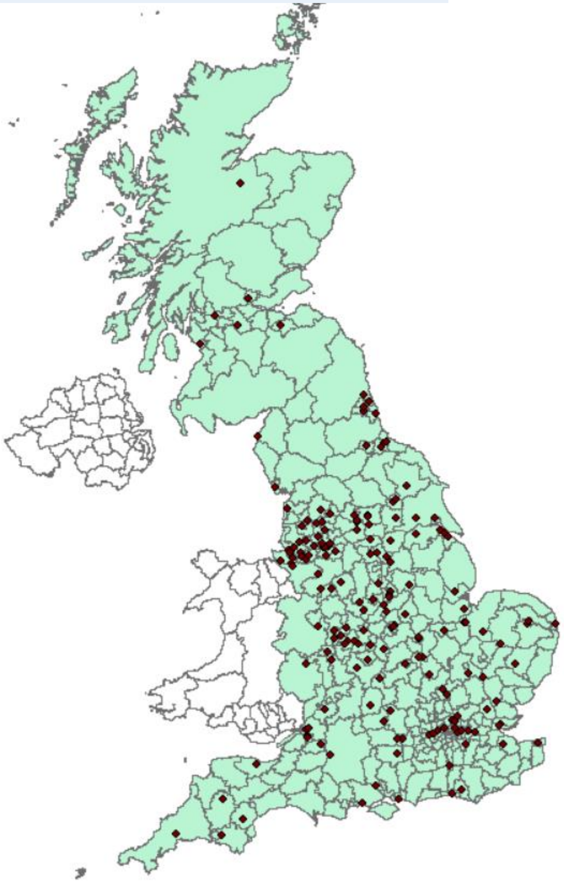
DECC water source data



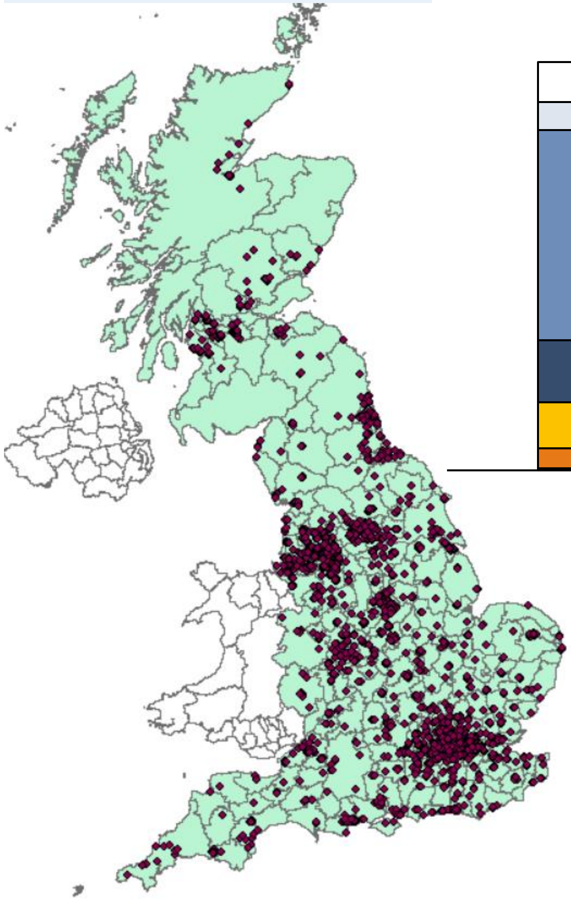
Element Energy waste heat source data

This allowed scenarios to be developed for the deployment of heat networks based on cost-effectiveness

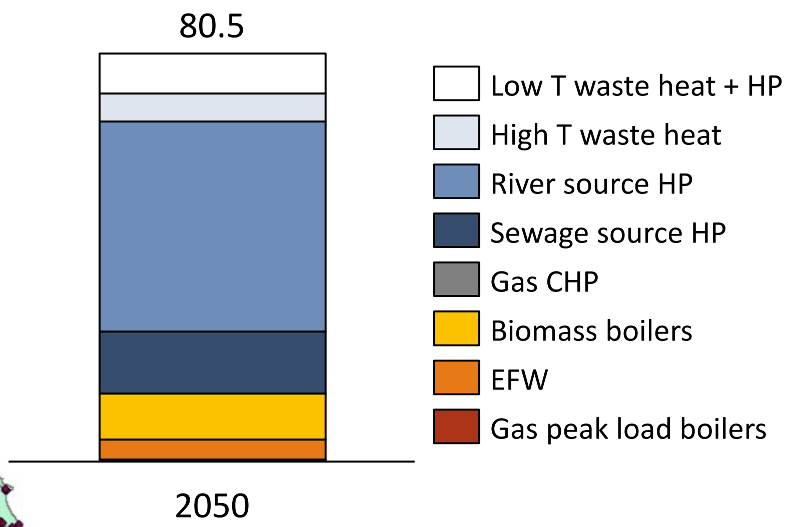
2020: 171 schemes in England and Scotland



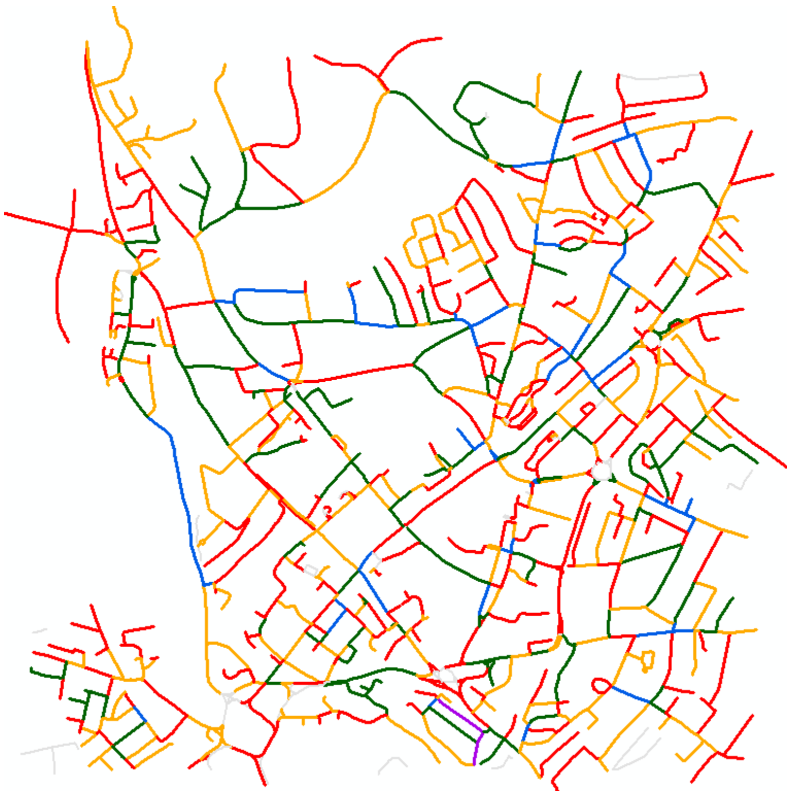
2050: 2,722 schemes in England and Scotland



Heat delivered by DH, by technology (TWh)



Example study: EnergyPath Networks software tool (Energy Technologies Institute)



An electricity distribution network synthesised using an automated GIS technique, developed by Element Energy, on the basis of road layout, supply locations and demand connections. Roads are colour coded to represent spatially contiguous low voltage (LV) feeders. (Image taken from the EnergyPath project).

EnergyPath Networks

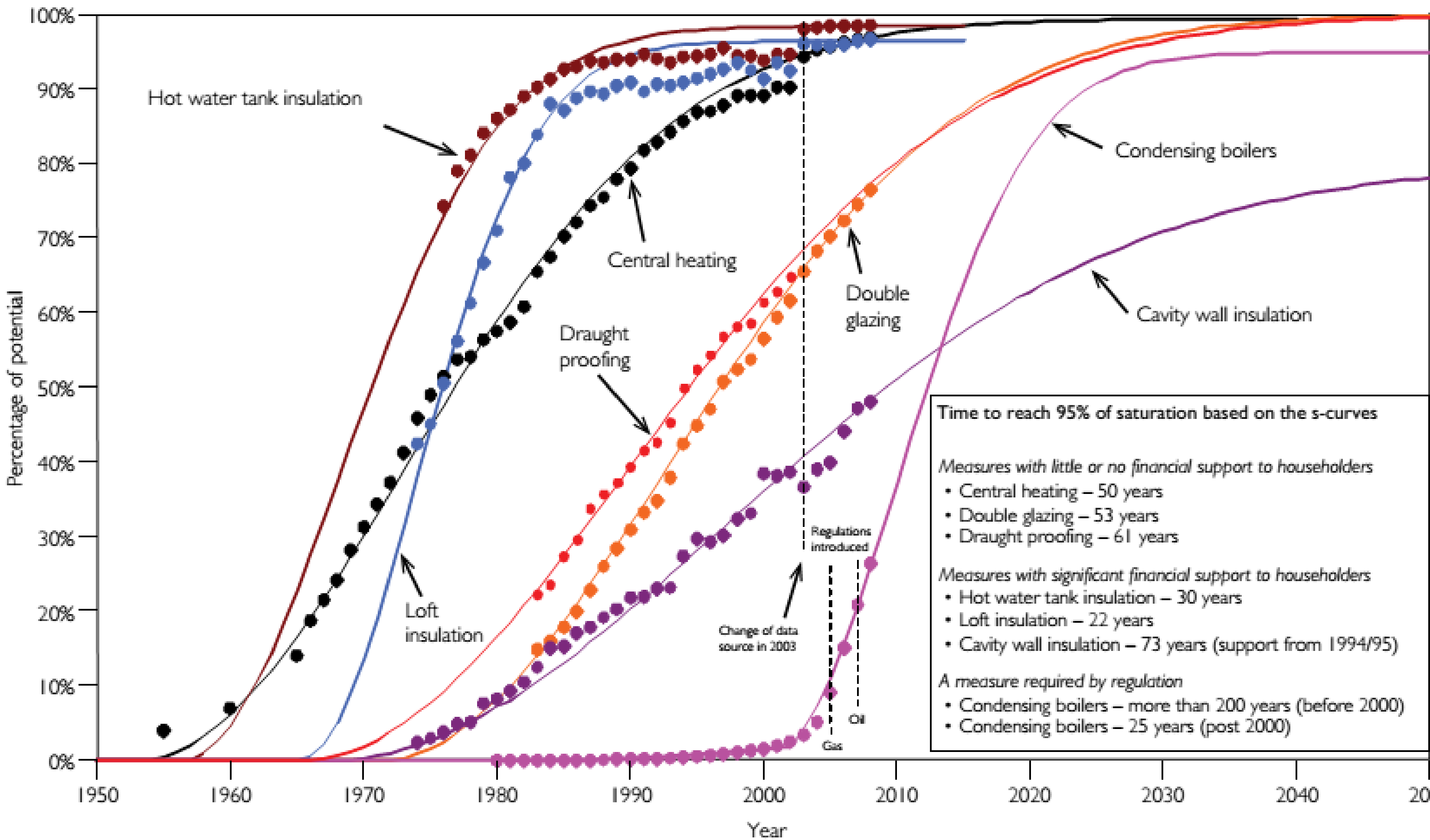
- Element Energy in a consortium led by Baringa, also working with UCL
- EnergyPath is a software tool which can be used to study a range of **energy pathways for local authority areas** based on a broad range of local data
- Based on input of various building stock and spatial datasets, enables detailed analysis of network infrastructure reinforcement costs (electricity and gas networks) and district heating viability
- The initial software version has been released and is being **trialled by a number of local authorities**

Agenda

- Time-resolution of energy demand
- Geographical distribution of energy demand
- Consumer investment behaviour

3) Consumer behaviour matters: Policy can greatly accelerate deployment, but the cost implications and level of disruption for the consumer are key

Historic market penetration of domestic energy efficiency technologies

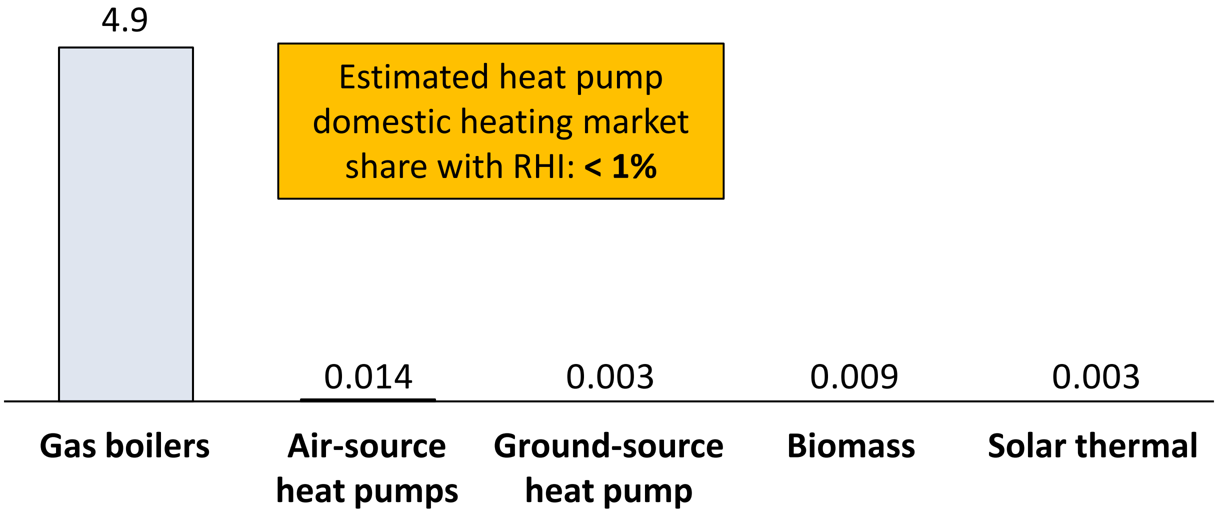


Les Shorrock, 2011, Time for Change, Proceedings of the European Council for an Energy Efficient Economy (ECEEE) 2011 Summer Study, Balambra Presqu’ile de Giens, France, 6-11 June 2011. Stockholm, ECEEE, 2011, pp 1043-1048

3) Consumer behaviour matters:
Current policies designed to deliver low carbon heating are failing

Comparison of Gas boiler and Renewable heating system sales in the UK since 2014

Estimated sales since introduction of Domestic RHI
(April 2014 to May 2017, millions)



- **Renewable Heat Incentive** designed to **bridge the economic gap** between conventional and renewable heating technologies
- However, in the 3 years since inception of the Domestic scheme, **uptake remains very low**
- How do consumers make **decisions** on the choice of heating systems?
- What **incentives** will be required to drive this? Will it need to be **regulated** (i.e. ban boilers)?

Estimated heat pump sales correspond to the number of Domestic RHI accreditations, for new installations only; see *RHI monthly official statistics tables* (May 2017); estimated boiler sales based on Heating and Hot Water Industry Council figures for 2014 and 2015 calendar years and extrapolated: http://www.hpmmag.com/news/uk-boiler-sales-fall-by-1-9-in-2015

We have built models to simulate consumer behaviour across building archetypes and consumer segments

BUILDING STOCK SEGMENTATION (Building archetypes)



- Building type
- Building age
- Main heating fuel
- Thermal efficiency level
- …

≈10s-100s combinations

CONSUMER SEGMENTATION (Consumer archetypes)



- Ownership/tenancy group
- Private/social housing
- Employment status
- Early adopter/Majority/Laggard
- …

≈10s-100s combinations

Energy efficiency and renewable energy technologies

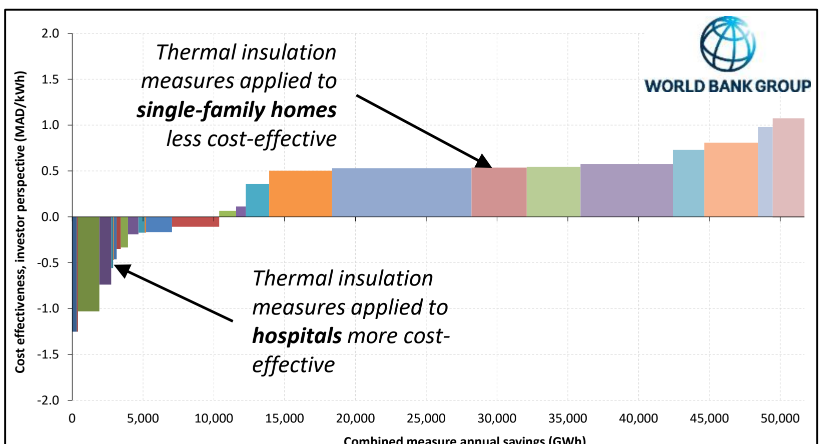
Energy consumption in building
Technology cost
Energy and carbon savings
Fuel bill savings
Technology payback time etc.

CONSUMER UPTAKE MODELLING

Segmentation is important to capture variation in measure impact, cost-effectiveness and uptake across different building types and consumers

Importance of segmenting by building type

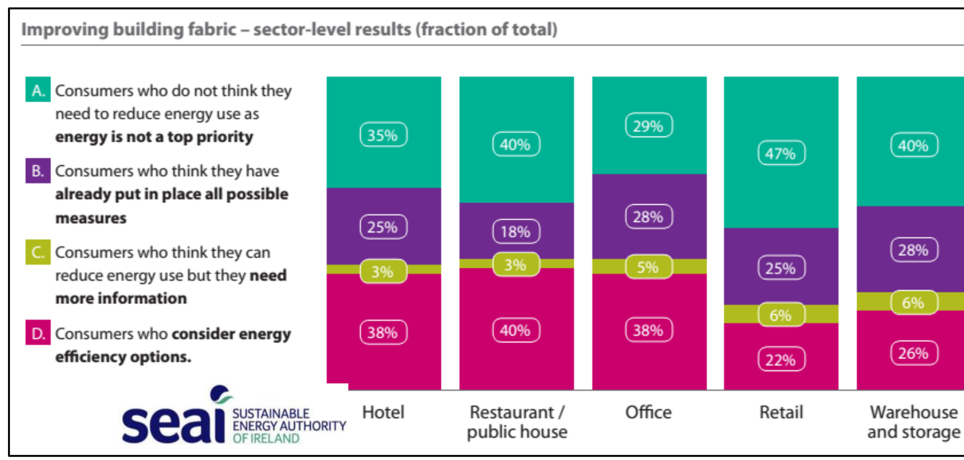
- **Differences in the physical building stock** and appliance stock lead to a wide **variation in the impact and cost-effectiveness** of energy efficiency and renewable energy technologies
- Factors such as the heating fuel, the building geometry, the construction method and insulation level of the building all impact strongly on the technology cost-effectiveness
- This variation leads to a '**supply curve**' of opportunities for energy and/or carbon savings



Cost curve for energy saving measures in Morocco: Differences in building characteristics lead to variation in cost

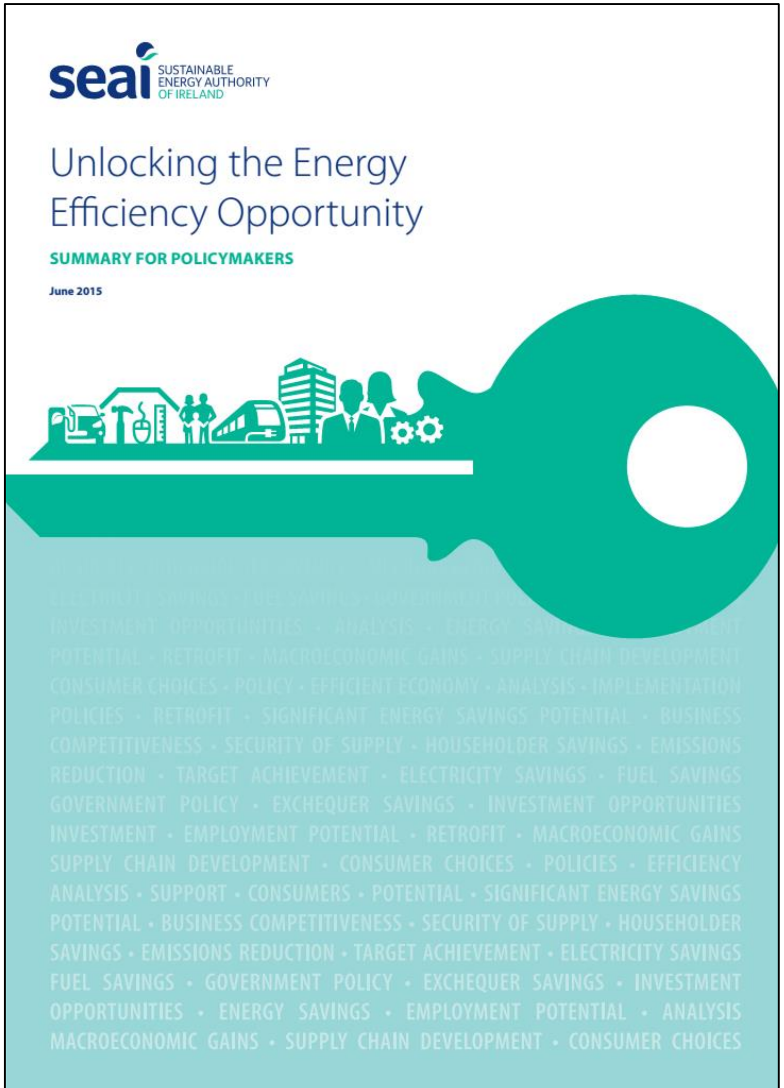
Importance of segmenting by consumer group

- On top of this 'supply curve' due to physical factors, **differences in consumer behaviour** lead to a **wide variation in the uptake** of those opportunities
- Factors such as the ownership/tenancy status, the household budget, the level of engagement with energy supply and fuel bills, the propensity to adopt new technologies and many other factors impact whether the consumer is likely to deploy low carbon technology



Results from a survey of commercial building occupants in Ireland: Fraction of consumers engaged in energy efficiency strongly varies by sector

Example study: Unlocking the Energy Efficiency Opportunity in Ireland



Element Energy-led study for SEAI:

- Assessment of the energy efficiency opportunity across all energy-consuming sectors in Ireland
- Design of concrete and actionable policy interventions to unlock those energy savings
- The study informed the development of Ireland's 3rd National Energy Efficiency Action Plan to achieve a 20% reduction in primary energy demand to 2020

Key findings:

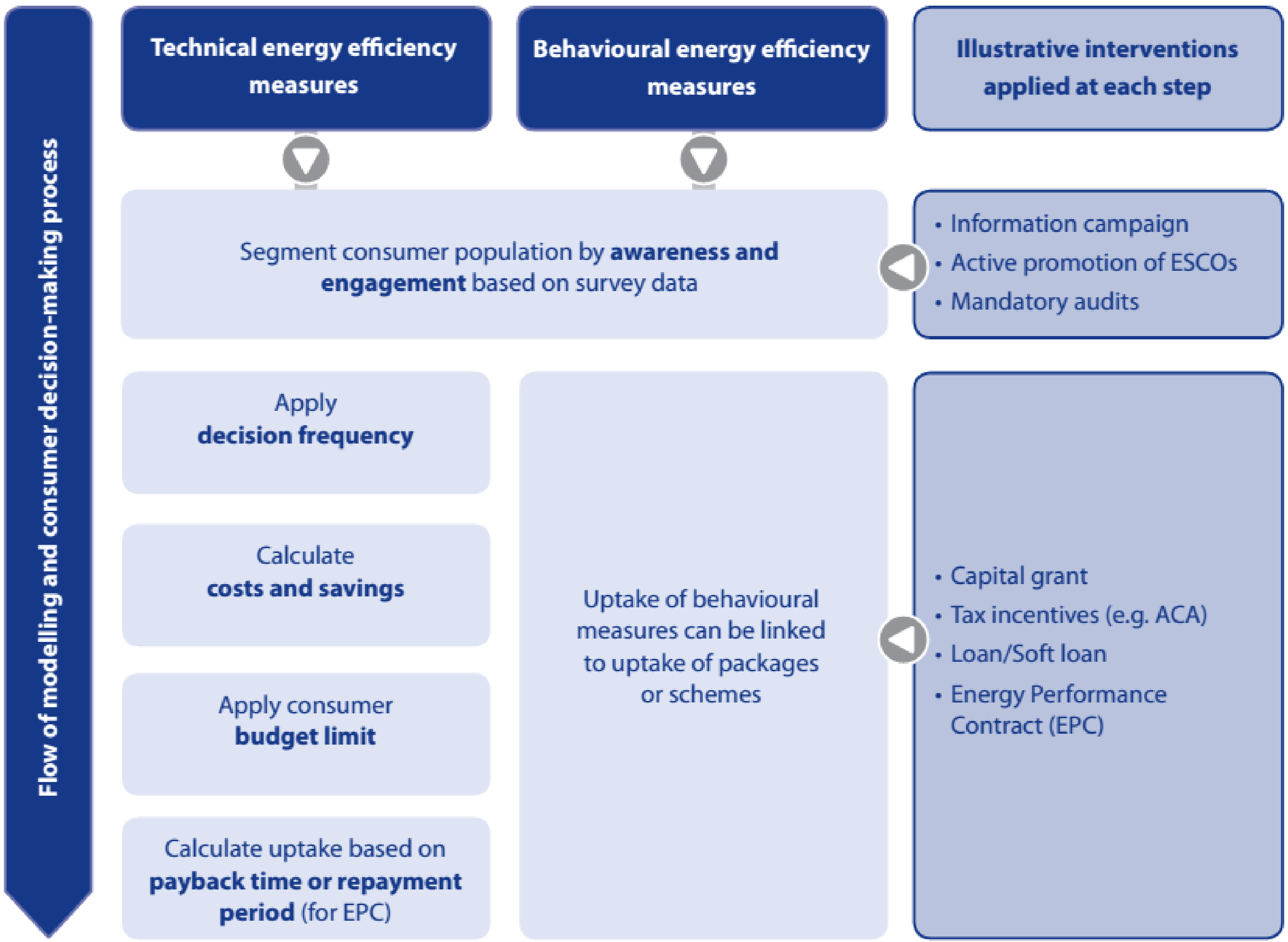
- 2020 target is very challenging
- However, a range of policies including regulation, low-interest loans and targeted grants could allow the target to be met
- Likely to require a total investment of just over €3 billion…
- …but lead to lifetime savings of over €11 billion, and provide a net benefit to the Exchequer of more than €1 billion

Our conceptual model of consumer behaviour is informed by primary surveys of consumers in the commercial and residential sector

- **Element Energy designed and carried out a survey of consumer behaviour** in the commercial building sector for the Sustainable Energy Authority of Ireland (SEAI)
- 1,500 organisations surveyed
- The survey included a range of questions designed to inform a **quantitative model** of consumer behaviour:
  - Segment the population by building type, size and other physical building characteristics
  - Segment the population by **awareness and engagement** in energy issues
  - Understand consumers' financial constraints including **payback requirements** and **budget limits**
  - Understand the frequency with which potential '**trigger points**' for energy efficiency occur, including regular maintenance work and major building renovation

Conceptual model of consumer behaviour includes a description of how policy interventions might impact each decision point

Model of the consumer decision-making process



The model was used to estimate the potential contribution of individual policy interventions to Ireland 2020 energy efficiency target

Policy intervention	Primary energy savings 2007-2020 (% savings)		
	Central scenario	**High** scenario	**Very high** scenario
Savings already achieved 2007-2012	5.0%	As for Central	As for High
Existing interventions (including ACA and Energy Performance Contracting)	3.9%		
Information campaign for energy efficiency	0.0%		
Active promotion of ESCOs	1.6%		
Behavioural change	0.6%		
Regulation for minimum boiler and lighting efficiency	2.6%		
Mandatory energy audit for large companies	2.8%		
Direct support of up to 30% of capex (for Deep retrofits)	Not included	1.6%	
Direct support of up to 60% of capex (for Deep retrofits)	Not included	Not included	2.2%
Total	**16.5%**	**18.1%**	**20.3%**

Some challenges for energy modelling for the present/future

- The above examples are meant to highlight several themes that energy modelling must be able to address **to be relevant**:
  - **Greater time-resolution**
  - **Greater geographical resolution**
  - **Better representation of consumer behaviour**

- These themes must form part of any model (or suite of models) able to:
  - Understand the implications for **infrastructure** and the wider system
  - Understand **localised impacts**
  - Design **effective policy**

- Great to see many references to these aspects in some of the work presented here
- However, these aspects are not routinely part of whole-systems energy modelling
- How can the WholeSEM community best progress in this areas?

Thank you for your attention!

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