Energy system modelling to inform policy: necessity and challenges

Keith Bell

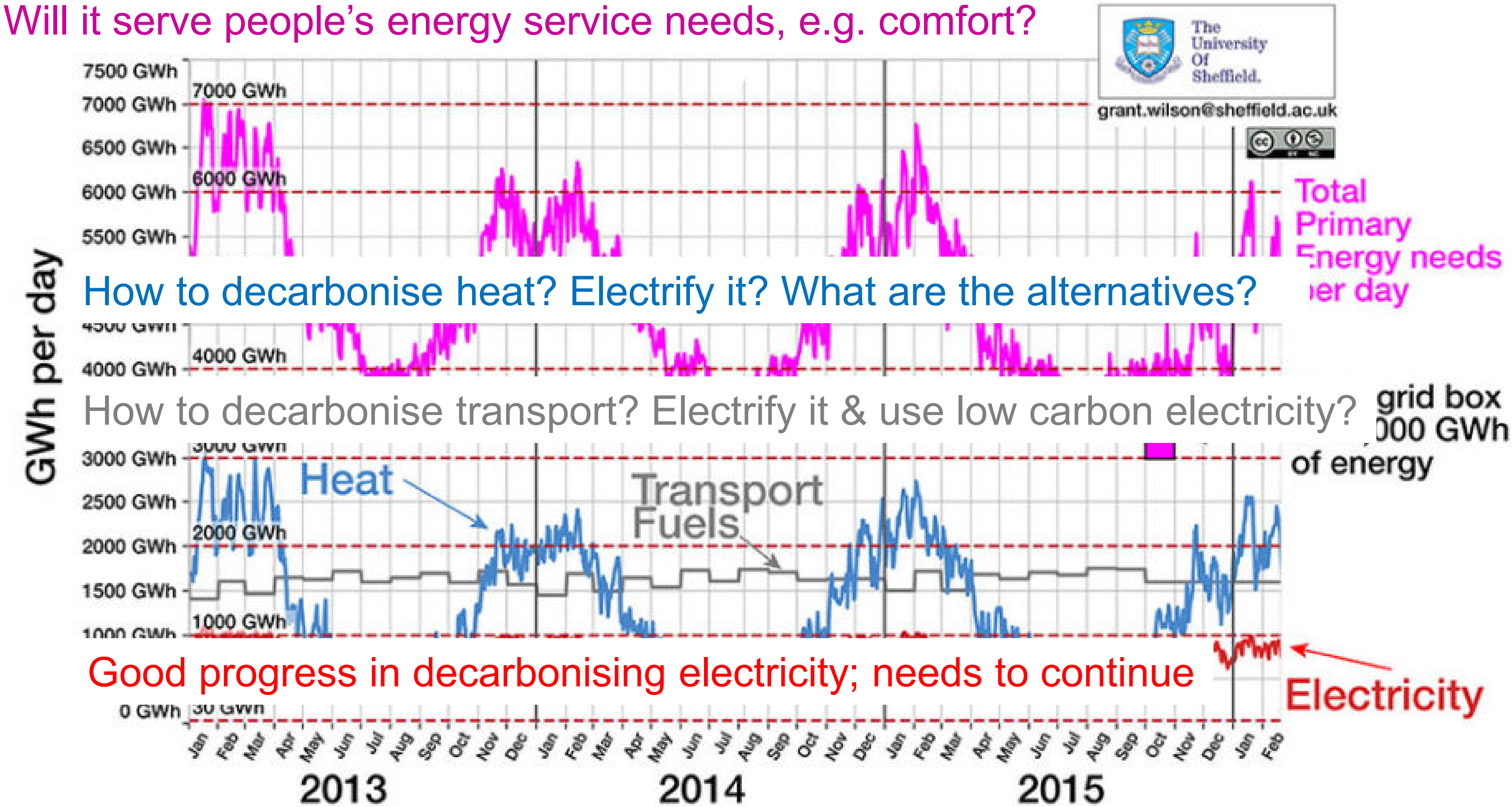
Scottish Power Professor of Smart Grids
at the *University of Strathclyde*
and a *co-Director* of the *UK Energy Research Centre*

https://www.strath.ac.uk/staff/bellkeithprof/ http://www.ukerc.ac.uk/about-us/people/keith-bell.html

Britain's energy demand

How much will it all cost?

Will it serve people's energy service needs, e.g. comfort?



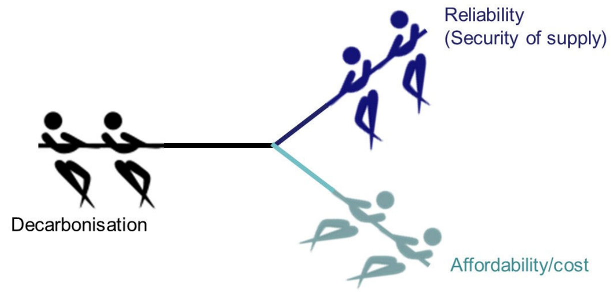
How to decarbonise heat? Electrify it? What are the alternatives?

How to decarbonise transport? Electrify it & use low carbon electricity?

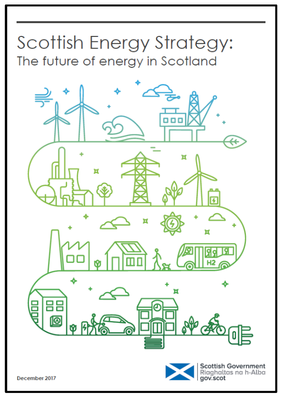
Good progress in decarbonising electricity; needs to continue

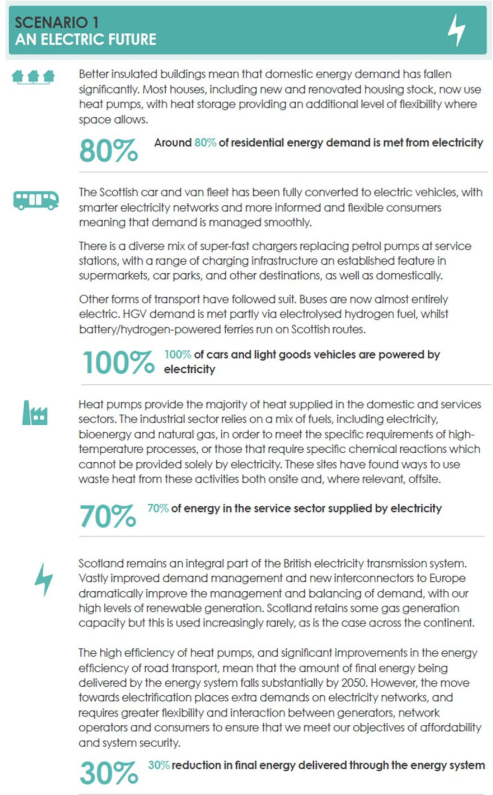
Figure: Grant Wilson, Sheffield University

Uncertainty



- What is the right energy future?
  - Future costs are uncertain
- What should policy makers do now?
  - What are the enabling investments for different pathways?
    - How well can they be adapted to different futures as uncertainties are resolved?
  - When do decisions need to be made?





SCENARIO 1
AN ELECTRIC FUTURE

Better insulated buildings mean that domestic energy demand has fallen significantly. Most houses, including new and renovated housing stock, now use heat pumps, with heat storage providing an additional level of flexibility where space allows.

80% Around 80% of residential energy demand is met from electricity

The Scottish car and van fleet has been fully converted to electric vehicles, with smarter electricity networks and more informed and flexible consumers meaning that demand is managed smoothly.

There is a diverse mix of super-fast chargers replacing petrol pumps at service stations, with a range of charging infrastructure an established feature in supermarkets, car parks, and other destinations, as well as domestically.

Other forms of transport have followed suit. Buses are now almost entirely electric. HGV demand is met partly via electrolysed hydrogen fuel, whilst battery/hydrogen-powered ferries run on Scottish routes.

100% 100% of cars and light goods vehicles are powered by electricity

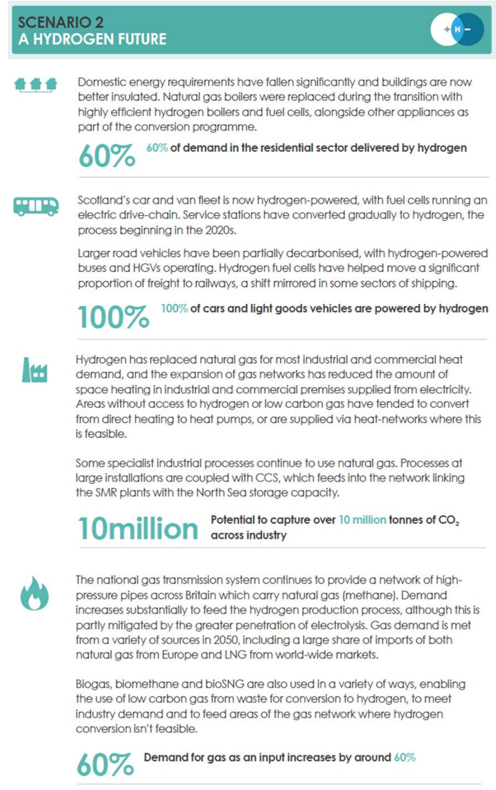
Heat pumps provide the majority of heat supplied in the domestic and services sectors. The industrial sector relies on a mix of fuels, including electricity, bioenergy and natural gas, in order to meet the specific requirements of high-temperature processes, or those that require specific chemical reactions which cannot be provided solely by electricity. These sites have found ways to use waste heat from these activities both onsite and, where relevant, offsite.

70% 70% of energy in the service sector supplied by electricity

Scotland remains an integral part of the British electricity transmission system. Vastly improved demand management and new interconnectors to Europe dramatically improve the management and balancing of demand, with our high levels of renewable generation. Scotland retains some gas generation capacity but this is used increasingly rarely, as is the case across the continent.

The high efficiency of heat pumps, and significant improvements in the energy efficiency of road transport, mean that the amount of final energy being delivered by the energy system falls substantially by 2050. However, the move towards electrification places extra demands on electricity networks, and requires greater flexibility and interaction between generators, network operators and consumers to ensure that we meet our objectives of affordability and system security.

30% 30% reduction in final energy delivered through the energy system



SCENARIO 2
A HYDROGEN FUTURE

Domestic energy requirements have fallen significantly and buildings are now better insulated. Natural gas boilers were replaced during the transition with highly efficient hydrogen boilers and fuel cells, alongside other appliances as part of the conversion programme.

60% 60% of demand in the residential sector delivered by hydrogen

Scotland's car and van fleet is now hydrogen-powered, with fuel cells running an electric drive-chain. Service stations have converted gradually to hydrogen, the process beginning in the 2020s.

Larger road vehicles have been partially decarbonised, with hydrogen-powered buses and HGVs operating. Hydrogen fuel cells have helped move a significant proportion of freight to railways, a shift mirrored in some sectors of shipping.

100% 100% of cars and light goods vehicles are powered by hydrogen

Hydrogen has replaced natural gas for most industrial and commercial heat demand, and the expansion of gas networks has reduced the amount of space heating in industrial and commercial premises supplied from electricity. Areas without access to hydrogen or low carbon gas have tended to convert from direct heating to heat pumps, or are supplied via heat-networks where this is feasible.

Some specialist industrial processes continue to use natural gas. Processes at large installations are coupled with CCS, which feeds into the network linking the SMR plants with the North Sea storage capacity.

10million Potential to capture over 10 million tonnes of CO_2 across industry

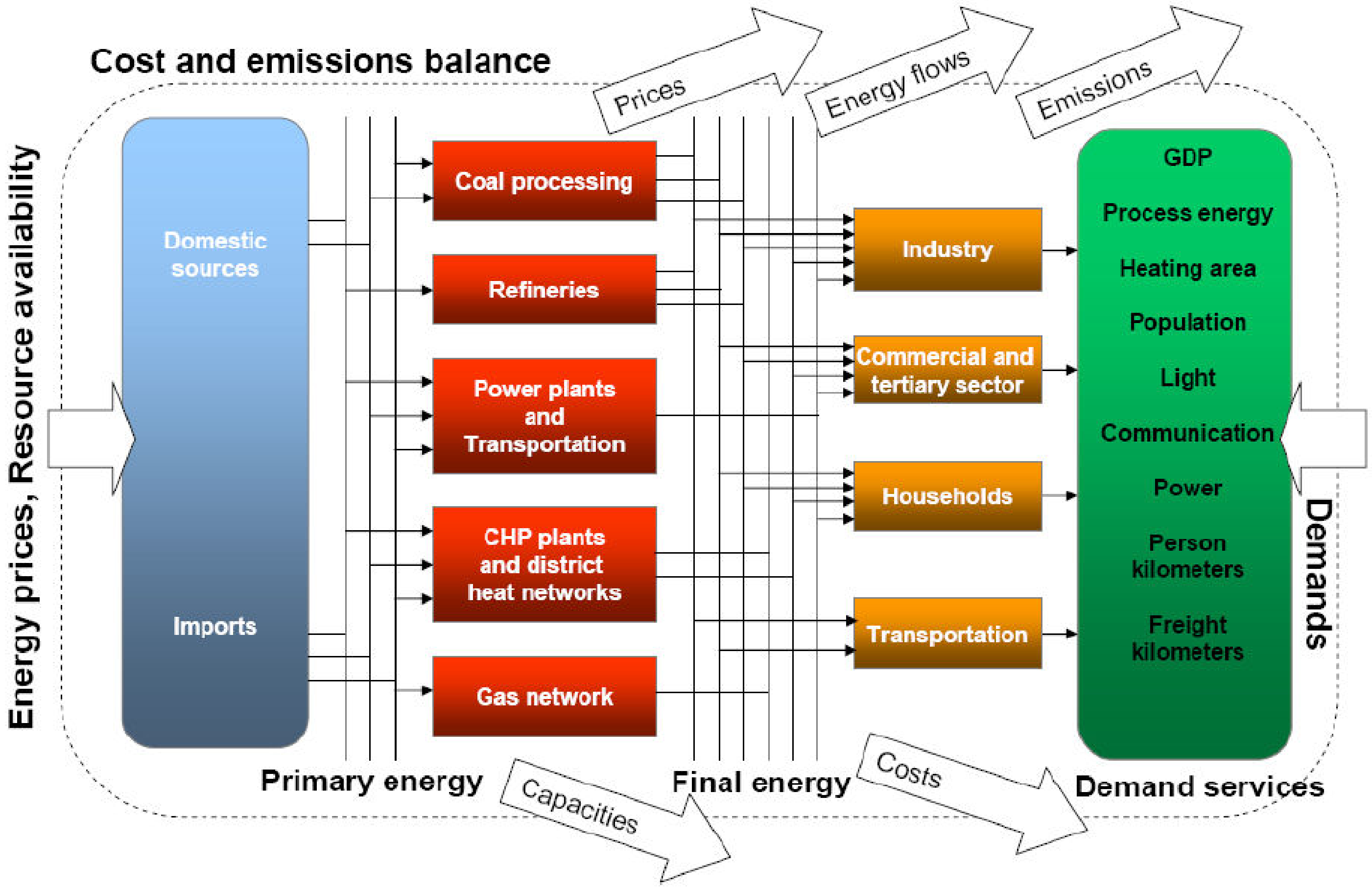
The national gas transmission system continues to provide a network of high-pressure pipes across Britain which carry natural gas (methane). Demand increases substantially to feed the hydrogen production process, although this is partly mitigated by the greater penetration of electrolysis. Gas demand is met from a variety of sources in 2050, including a large share of imports of both natural gas from Europe and LNG from world-wide markets.

Biogas, biomethane and bioSNG are also used in a variety of ways, enabling the use of low carbon gas from waste for conversion to hydrogen, to meet industry demand and to feed areas of the gas network where hydrogen conversion isn't feasible.

60% Demand for gas as an input increases by around 60%

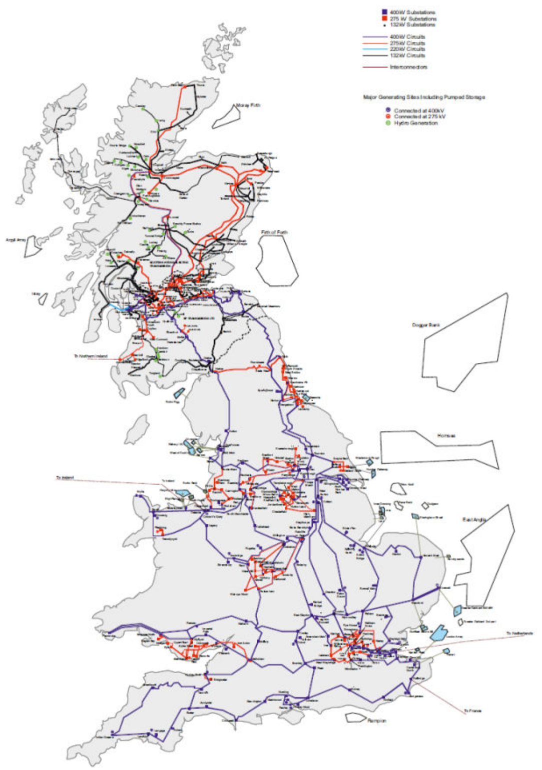
“We need to model the future”
“We need a whole system approach”

Multi-vector modelling of energy conversion, transfer and use, e.g. TIMES

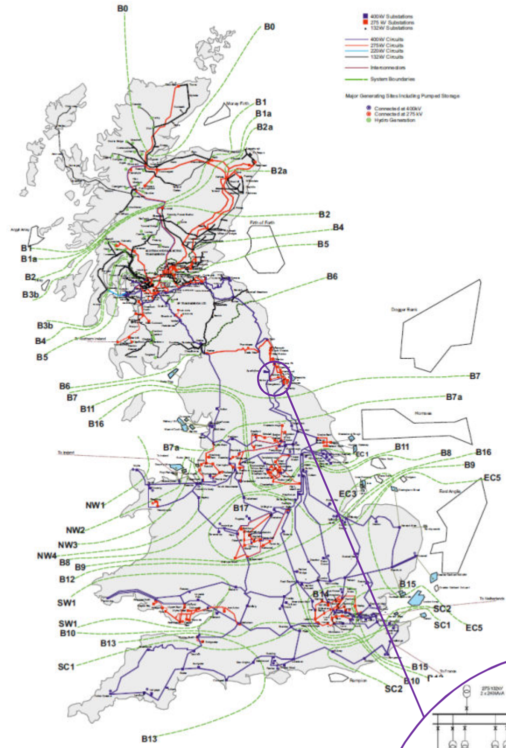


R. Loulou, G. Goldstein, A. Kanudia, A. Lettila, and U. Remme, "Documentation for the TIMES Model - Part I," Energy Technology Systems Analysis Programme, [Online]2016, Available: https://iea-etsap.org/docs/Documentation_for_the_TIMES_Model-Part-I_July-2016.pdf, Accessed on: Jun. 29, 2017. Remme U. 2007 Overview of TIMES. Proc. ETSAP Workshop November 2007 Brazil..

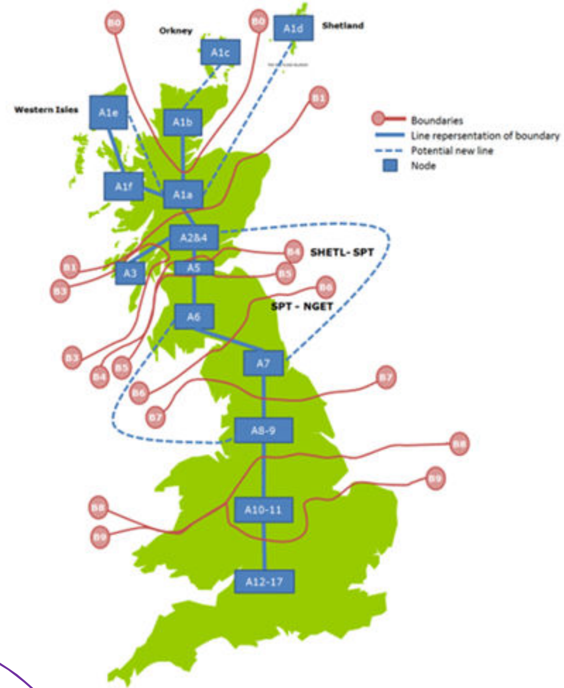
Model choices: spatial scale



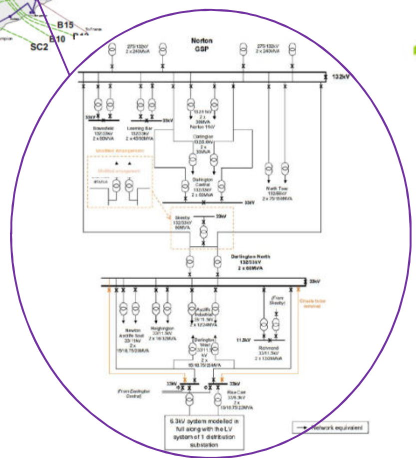
National Grid, ETYS



National Grid, ETYS



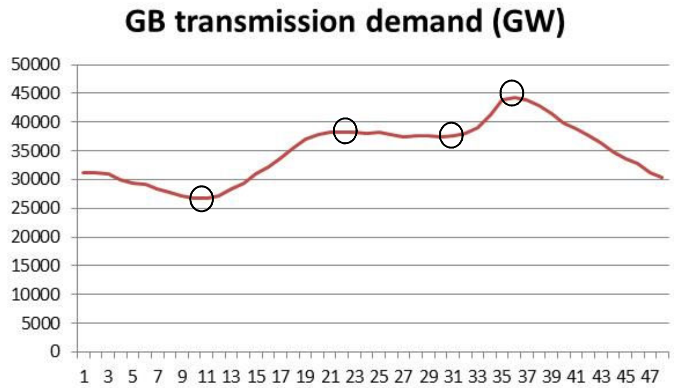
Scottish Government / SEDM

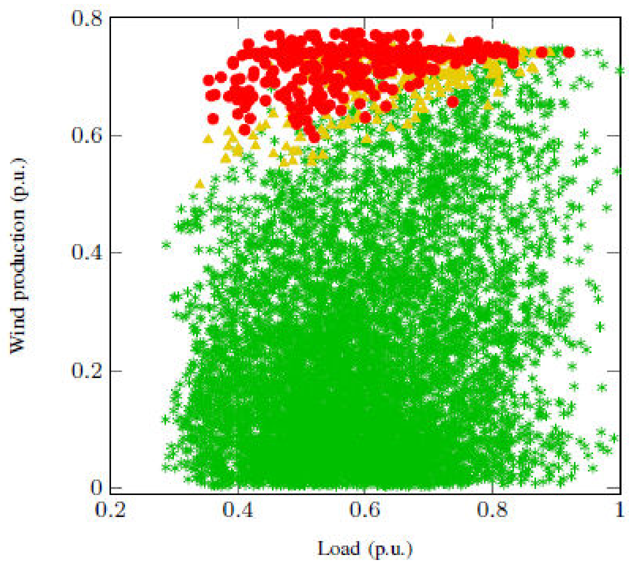


Northern Power Grid / DS2030 project

Model choices: temporal scale

- Do interactions between time slices matter?
  - If there is two-way storage or time-shifting of demand, yes
  - If rates of change of responses to inputs are restrictive, yes
- If not, which snapshots to use?
  - Annual peak demand?
  - Daily ‘cardinal points’?





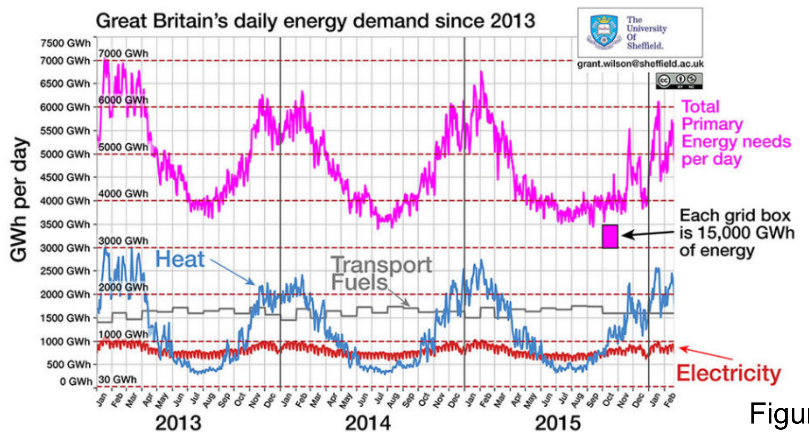


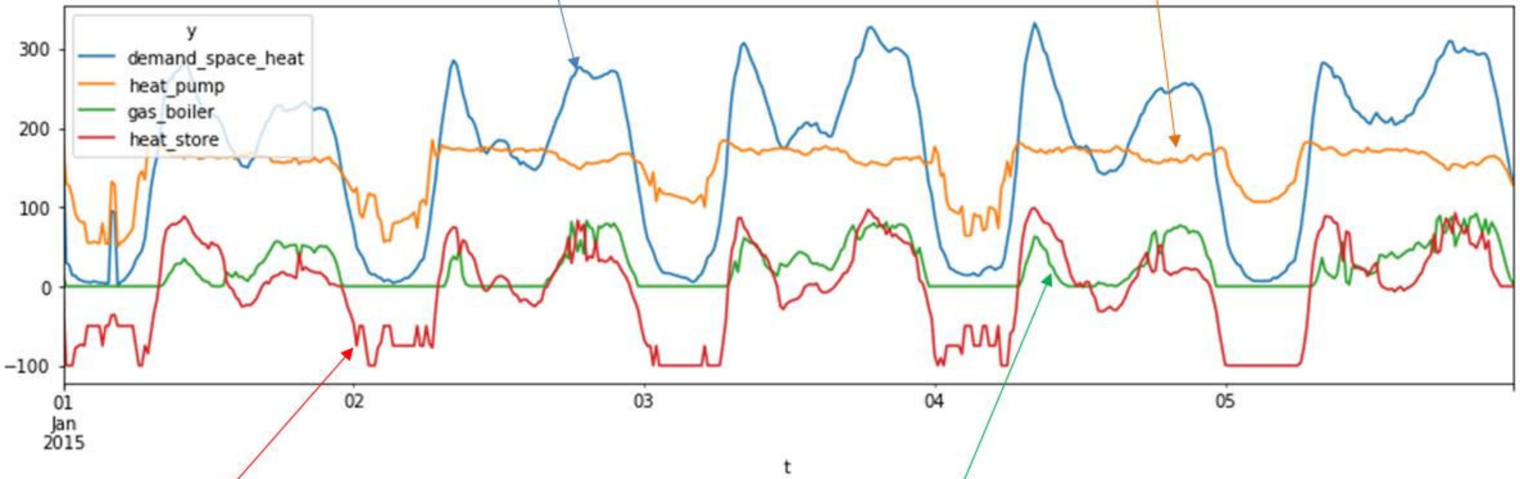
Figure: Grant Wilson

Model choices: temporal scale

Work by Graeme Hawker at University of Strathclyde

Net space heat demand: building efficiency reduces total energy and provides temporal buffering

Heat pumps utilise decarbonised electricity (local and grid) to limit of network capacity (minus other electrical demand)

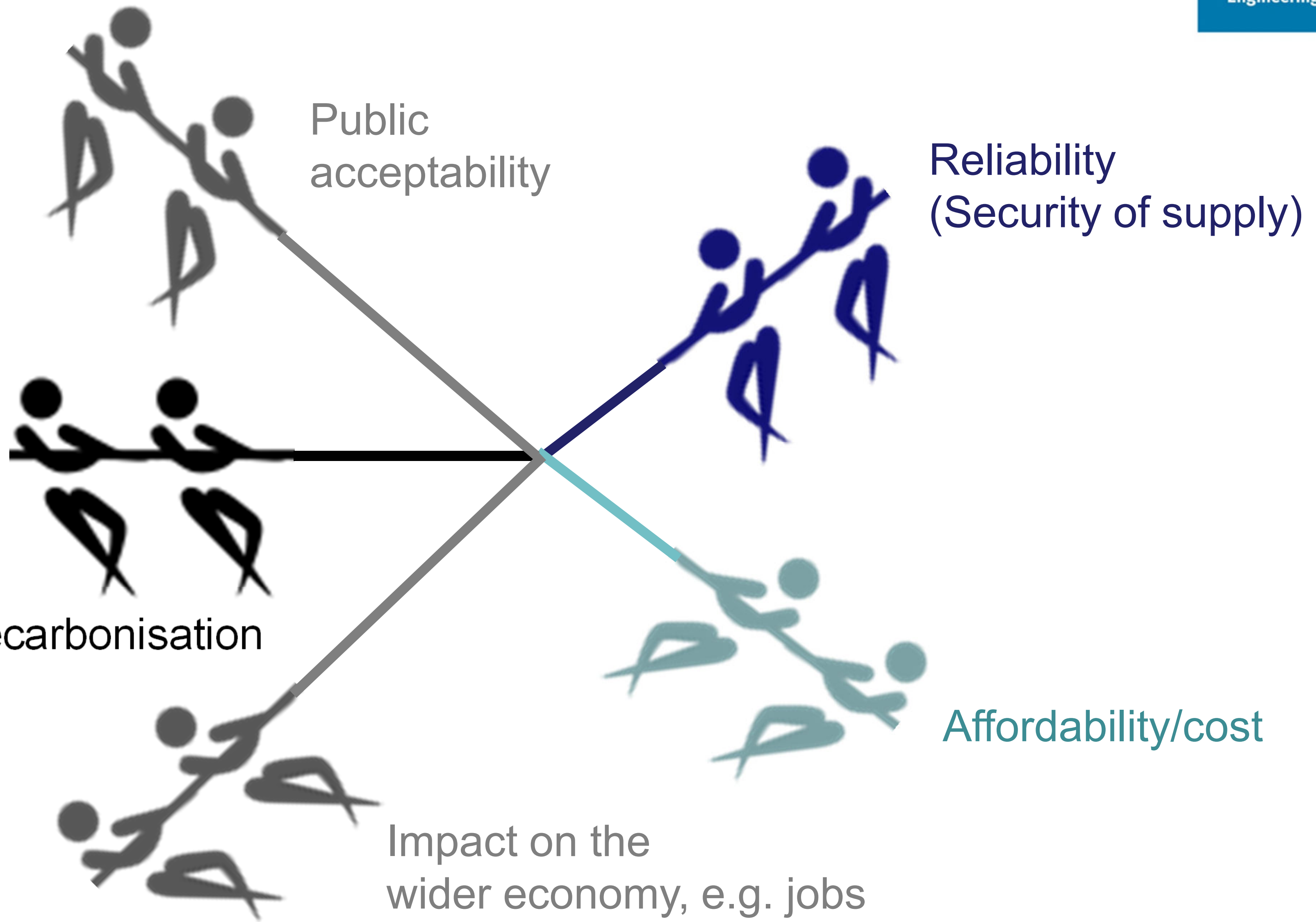


Heat storage increases utilization of heat pump capacity

Existing gas network and boilers provide remainder of space heating

Would the system being modelled actually work?
Could it be planned and invested in?

Not just techno-economic



Who are the actors in an energy system and what do they decide?

- In electricity and gas sectors:
  - ‘the market’ decides on and invests in conversion or import facilities
  - regulated network utilities must
    - provide new connections when asked
    - provide timely, economically justified investment in shared infrastructure

Under the influence of policy makers (to some extent)

- Major market actors respond to
  - Short term price signals (including willingness to pay)
  - Forecasts of longer-term price signals. (*How long is longer-term?*)
  - (*Who decides how price signals are formed?*)
- Investors in big conversion facilities do consider cross-vector interactions
  - e.g. price of electricity versus price of gas
- What about smaller actors?
  - e.g. what will demand for electricity or gas be in future?
  - What influences are smaller actors sensitive to?
- Where there are no regulations, who provides shared infrastructure?

Modelling questions

- Behavioural detail
  - Realistic market bids and offers?
  - Realistic energy use patterns?
  - Sensitivities to interactions?
  - What make reasonable proxies for actor behaviours?
- Modelling of uncertainty
  - What uncertainties do modelling choices bring
    - How epistemic uncertainty can you tolerate?
  - Which things cannot be known with confidence?
    - How to model them? (Aleatory uncertainty)

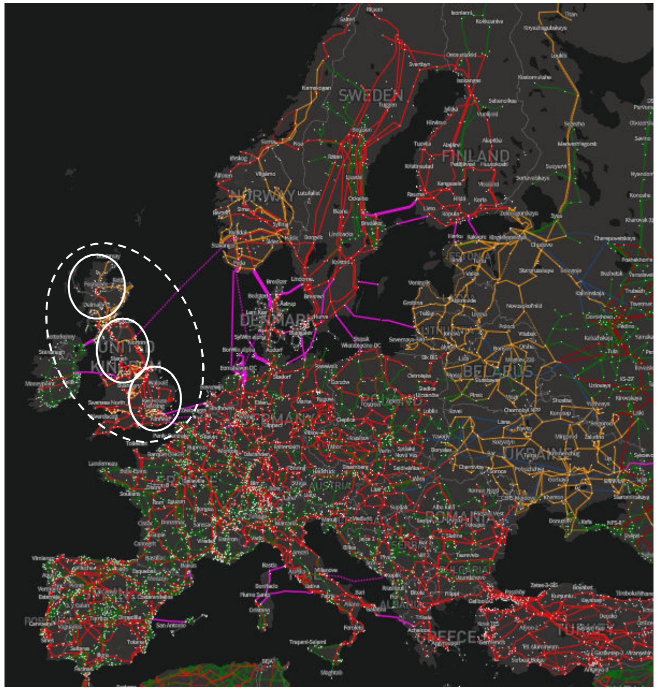


Figure: ENTSO-E

More modelling questions

- What data do you have?
  - System parameters (things that are fixed)
  - Values of state variables (things that vary)
    - Access to a historic record?
    - Extrapolate from the past, assume the future is like the past, or…?
- What data can you usefully use?
  - How precise do you need to be?
  - How much can you compute?
  - What can you make sense of?
  - With so much uncertainty, is there any point in being precise when you will probably be precisely wrong?
- What procedures do you have in place to build confidence in models and data and maintain them?

Access to data

- "The accuracy of the probabilistic reliability management approach is dependent upon the availability and quality of data. It is recommended to put in place common guidelines to persistently ensure the collection of data, maintain the databases and the inferred models, and share the relevant parts of these data and models among the different stakeholders concerned."

  A New Approach to Reliable and Affordable Electricity Supply in Europe: The GARPUR Project Results, October 2017

- "Anyone attempting to develop evidence highlighting the extent of the challenges the power system faces or in support of particular interventions … is hindered by much of what is required to model the GB system being regarded as 'commercially confidential' even though it is often hard to envisage what commercial advantage might come from having it or commercial disadvantage might come from disclosing it"

  UKERC response to Ofgem/BEIS call for evidence on system flexibility, January 2017

Whole system models

A ‘model’ as a particular combination of data (inputs) and tool (set of equations and solution method)…

- Targeted at specific questions
- Bespoke
- Complex
- Difficult to use and maintain
- Encapsulates significant time, effort and intellectual property
- “If it’s not got a name, it’s not worth anything”

- Complex
- Obscure
- Difficult to interpret results
- Not portable
- Places power in the hands of the ‘expert’

Does it help policy development and defence if access to a model is restricted and details of how it works are hidden?

Summing up

- Whole energy system questions are difficult to assess
  - Need good whole system models
- What is a good whole system model?
  - with appropriate spatial and temporal detail
  - for which reasonable data can be sourced and maintained
  - for which results can be explained
  - that allows testing of assumptions and sensitiviites
  - that describes a system that can actually work, be used and be invested in
- One model doesn’t have to do everything
  - Often, the greatest value is in revealing the next question
- Eventually, some real-world demonstration is needed to build confidence and commercial viability
  - Feedback: test model assumptions and calibrate the model