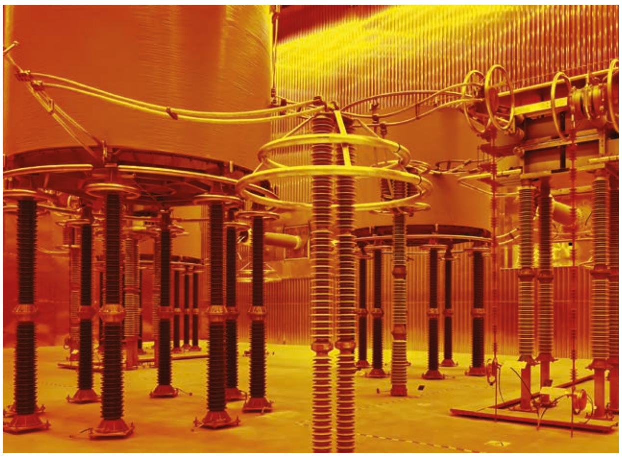
ENERGY SYSTEM TRANSITION

Research priorities – what do we need to know?



Inside an HVDC station – much of the scale up of offshore electricity network capacity is expected to use high-voltage direct current technology
Photo: Shutterstock

An essential foundation of any programme to transform the UK energy system is to identify what we don't yet fully understand about both the current situation and the scope for change. UKERC's *Keith Bell* surveys priorities for R&D.

Everyone knows – or everyone who's been paying attention knows – that we need to transform the way we use energy, not just in the UK, but all across the world. We cannot continue the unabated burning of fossil fuels, but we still need access to energy that meets society's needs.

To a large extent, we already have the technologies required and some choices among them, but what costs do they each have, monetary and otherwise? How do we minimise adverse impacts and ensure continued political and societal support for the transition? How do we make decisions about what to do and when to do it?

I am one of seven Co-Directors of the UK Energy Research Centre (UKERC), a collaboration involving 20 universities and around 100 researchers investigating key issues affecting the transition of the UK's energy system. This article is not the result of a systematic survey such as InnovateUK carries out to inform its periodic *Energy Innovation Needs Assessment*. Instead, drawing on insights from colleagues, I outline my own perspective on research priorities.

Energy demand

Heat in buildings

Perhaps the UK's single biggest energy system challenge lies in the decarbonisation of heat. This is graphically shown in **Figure 1** where not only the magnitude of demand but also its huge seasonal variability are evident.

The challenge is vast but can be reduced by being more efficient in our use of energy. New techniques in the construction of buildings can make a dramatic difference to energy efficiency; however, they are expensive and can be difficult to get right when being installed. Improvements to materials and methods can make the retrofitting of insulation cheaper and less disruptive.

In locations with high heat demand, heat network investment can be worthwhile and aid a more efficient use of heat. However, these energy efficiency improvements need to be allied with low carbon sources of heat.

The high coefficient of performance of electric heat pumps makes them attractive when electricity supply is low-carbon, but exactly how they are deployed depends on the heat source and on how the heat is to be distributed. Industrial scale heat pumps are now starting to exploit water sources such as rivers or sewage, and flood water in disused mineworkings might also be potential sources or stores of heat.

Heat networks – between buildings or within them – can be operated at different temperatures with different efficiencies. Progress in refrigerant development can allow existing 'wet' systems in buildings – radiators – to be used at similar temperatures to those used with gas boilers, avoiding replacement with larger radiators working at lower temperatures. If not, hybrid systems might be needed, which adds to the capital cost and occupies more space.

Heat pumps are not the only option, we might continue to use gaseous fuels provided they cause no carbon emissions. Hydrogen is one option – it can be manufactured from reformation of methane provided the resulting carbon dioxide is capture and stored. Work has been ongoing to prove the safety of hydrogen boilers and hobs, but consumer acceptability is yet to be proven. The new H100 project in Fife promises to help with that but more work is needed.

A further important area of research in respect of buildings is the verification that measures to transform their use of energy is effective. In particular, to what extent does actual performance match the modelling? Easy but accurate ways of establishing this are going to be ever more important to verify compliance with standards and that government incentives are producing the intended results.

Transport

Unless always connected to an energy network, such as via overhead lines, all transportation vehicles must carry a store of energy. This must have sufficient energy capacity and power rating and be lightweight. Significant progress has been made in decreasing the cost of batteries to the point where, small and medium sized plug-in battery electric vehicles are almost cost-competitive with internal combustion engine vehicles. Further cost reductions and increases in performance will help allay range anxiety.

There are strong incentives for industry globally to invest but there remain manufacturing challenges, not least in the supply of different materials. Work is ongoing to find effective alternatives.

For heavier vehicles that require more energy, it's not clear that batteries would be the best option. Does hydrogen represent hype or hope? Whether using compressed hydrogen in fuel cells on buses or lorries, or ammonia in engines on ships, it's becoming ever more hopeful that the technologies will soon become a commercial reality. For air travel, however, reduction in the associated global warming remains a major challenge.

We need to better understand the need for mobility across different segments of society; how can it be reduced? That question is now starting to be asked, prompted in part by the growth in working from home and the notion of a '20 minute neighbourhood.' The Scottish Government's update to its Climate Change Plan promised to reduce total car-km in Scotland by 20% by 2030, though the full set of policies to achieve this is yet to be defined.

Industry

Many industrial processes are large users of energy. Resource efficiency – optimising designs to use less material and materials with lower embodies emissions – and energy efficiency, can reduce the energy required. Switching from fossil fuels will be necessary if carbon dioxide is not captured and stored. This represents a particular challenge in processes using high temperatures.

Hydrogen combustion would appear to be the closest substitute but plant using hydrogen is not yet generally commercially ready.

A vitally important 'system issue' is the availability of knowledge and skills to deliver the energy transition – how will this be ensured for all the necessary roles: technicians, engineers, lawyers, project managers etc

Moreover, if the hydrogen is manufactured using electricity, why not use electricity directly? Cost-effective high temperature electrical plant needs to be developed and brought to full maturity.

Energy supply

The carbon intensity of electricity production in the UK has fallen from 496 gCO_2/kWh in 2012 to 193 gCO_2/kWh in 2019. However, to achieve net zero across the whole economy, the carbon intensity of electricity needs to be zero or even, through use of bioenergy with carbon capture and storage (CCS), negative. This requires continued growth in use of renewables where cost reductions of wind and solar have been significant in recent years.

For further reductions, the costs of manufacture, construction and maintenance of ever larger offshore wind turbines need to be reduced. However, we may soon be reaching the practical limits of how large single turbines can be, though novel multi-rotor designs are worth exploring, along with ways of reducing the intrusiveness of onshore wind farms.

Enough schedulable, persistent sources of electricity are essential to meeting demand in what is called '*Dunkelflaute*' in Germany: relatively cold, dark, still periods lasting perhaps many days with little wind or solar production.

Nuclear's '24/7' operation means that it potentially has a role though many energy economists are sceptical, mainly due to costs and that most existing projects in Europe are behind schedule. There is currently little evidence that the sector will deliver the cost reductions it habitually promises, though that might be because, in Britain, at least, we have never had a programme of delivering reactors of similar designs.

Use of methane in electricity generation is also possible, provided it is associated with CCS. In being both schedulable and persistent, it offers an alternative to nuclear power, though the case for either would be enhanced by a capability to operate flexibly, in response to demand, something that is unproven for generation with CCS and has been done only to a limited extent with nuclear reactors. Commercial confidence in electricity production with CCS in Britain also needs to be established.

Across the five scenarios outlined in its advice on the 6th carbon budget, the Climate Change Committee suggests that between 124 and 324 TWh of hydrogen will be produced in the UK in 2050. This production must be low-carbon. Although reformation of methane currently appears to be the cheapest method even with CCS, work is need to improve the carbon capture rates. The alternative method – electrolysis – will be lower-carbon when the electricity supply is decarbonised and offers the potential for cost reductions through improved designs and manufacturing and new materials.

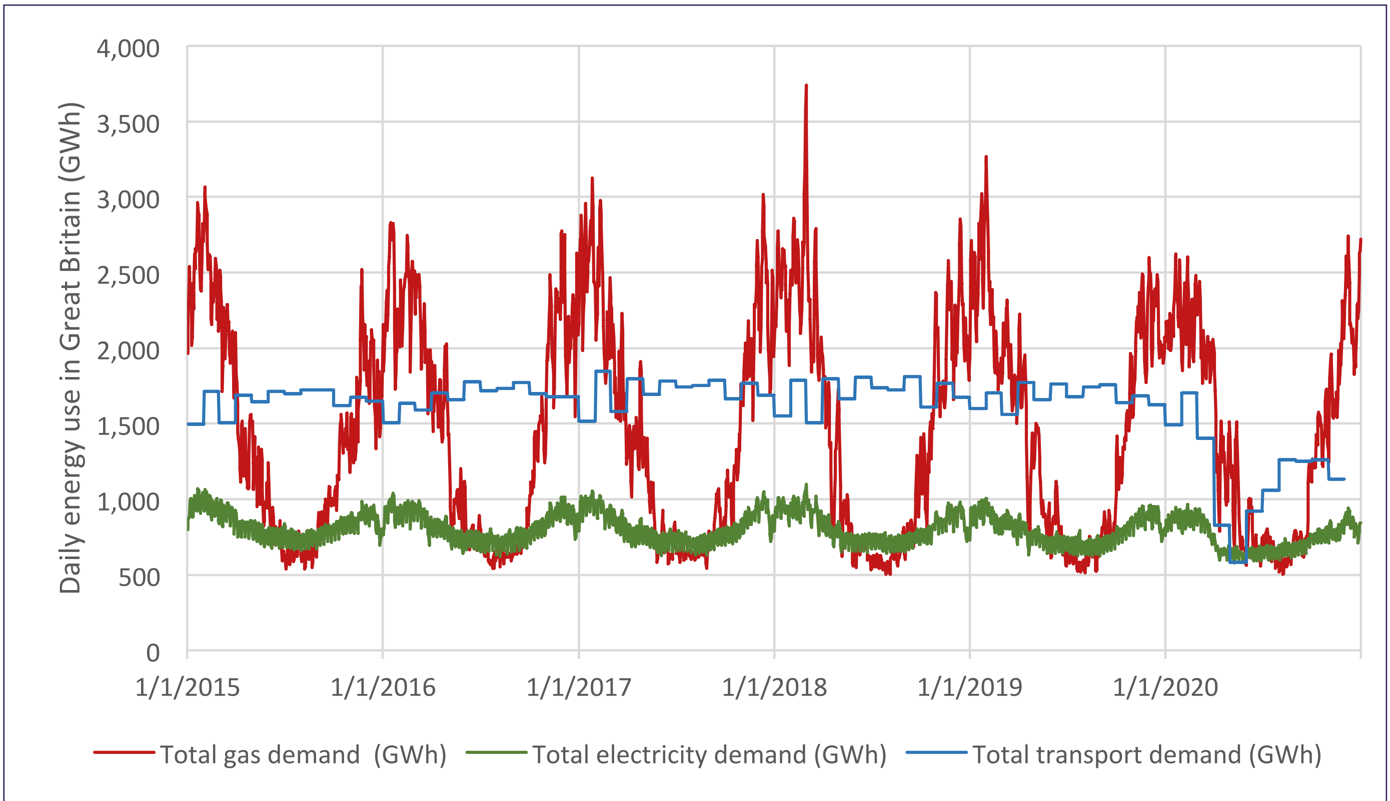


Figure 1. Britain's energy carriers by volume: gas, electricity and transport fuels
Figure courtesy of Dr Grant Wilson, University of Birmingham; data from National Grid, Elexon, and Department for Business, Energy & Industrial Strategy

Moreover, there will be periods when the available electric power far exceeds demand: will the market signals be strong enough to motivate investment in electrolysers to utilise it, even if they are not operating all the time? Hydrogen could be stored and then used in industry, transport and, potentially, in providing heat to buildings.

However, it might also be used in combined cycle turbines in providing a schedulable and flexible source of electricity for which the inter-seasonal storage alternatives are currently few.

The scale of the energy resource around Britain's coast suggests a need for continued research to make floating wind turbines and tidal and wave generators viable options.

System issues

There has been much talk of the need for the future energy system to be developed in a whole systems way that takes proper account of alternative options for supply and use of energy and the coupling between different sectors. However, in an institutionally fragmented system in which governance arrangements are complex, and even single vectors such as gas and electricity have many different companies involved in sourcing, trading and transferring energy, the means by which that can be achieved are unclear.

Among the things to be decided is the basis for decision making on, for example, the future of the gas network. After upgrading as part of the long-running iron mains replacement programme, the gas distribution network will be technically capable of carrying 100% hydrogen, but what will the demand for hydrogen be and how will a switch-over be achieved while minimising disruption?

Massive growth in the energy carried on the electricity network is expected. The peak power flow can be somewhat reduced by flexibility, but the commercial and practical means of enabling it are currently immature. Moreover, energy retailers and network operators will need to develop advanced means of deciphering large volumes of data and the inherent system uncertainty to make optimal use of flexible demand, generation and storage across the network.

Much of the huge scale-up in offshore network capacity will use high voltage direct current (HVDC) technology that has rarely been interconnected. The energy produced offshore needs to be brought to shore in ways that minimise environmental impacts. The methods and regulatory frameworks to resolve the many tensions among different stakeholders are yet to be defined.

Those that seek magic bullets to solve the climate crisis should be aware that technological innovations typically take decades to come to fruition

HVDC makes use of power electronic converters that are increasingly ubiquitous on the electricity system, from small power supplies on computers to drives on electric trains. They are extremely flexible and their fast responses can help mitigate impacts of system disturbances. Exactly how the control software is written is confidential to the manufacturers, yet these devices are all connected to the same power system and interact in ways that are currently little understood and will become ever more important.

Appropriate commercial arrangements are required to incentivise investment in new energy production and network assets, the facilities to enable flexibility and the frameworks to utilise them optimally. Reduction in energy-related emissions to date has been achieved almost without people noticing. There was recognition in the Climate Assembly convened last year that banning the sale of combustion engine cars and the conversion of heating systems are necessary but will be disruptive.

Energy users will expect some choice about how their buildings are heated, but how will that be informed and exercised when major investment decisions, such as whether or not to develop hydrogen supplies or district heating, will affect the options available?

A vitally important 'system issue' is the availability of knowledge and skills to deliver the energy transition. How will this be ensured for all the necessary roles – technicians, engineers, lawyers, project managers and so on – and how will public bodies', companies' and individuals' efforts combine to deliver it most effectively?

The responses of organisations and individuals to different commercial and regulatory arrangements are very difficult to foresee ahead of implementation, making decisions subject to significant uncertainty.

Analytical approaches such as agent-based modelling might provide some insights. As a minimum, they need to be calibrated using 'backcasts' – reproducing the past – but, as we have seen with epidemiological models, they need to use many assumptions. Randomised control trials are difficult to do while providing consumer protection; often, the best that can be achieved is to carry out qualitative research on different actors' motivations as a trial proceeds, and to use the evidence gained to refine commercial and regulatory frameworks.

The foundations of innovation

Much has been written about innovation timelines and how to take ideas through the 'valley of death' to commercial viability. Those that seek magic bullets to solve the climate crisis should be aware that technological innovations typically take decades to come to fruition.

A number of innovation areas are attracting significant private investment worldwide, eg batteries and new photovoltaic materials, where commercially valuable intellectual property is being developed, often in partnership with universities. However, almost all technological innovations have depended on some degree of public support, from education of the researchers to direct grants for R&D work.

Public support to bring innovations through the last stages to commercial viability can be part of industrial policy and can help to create jobs within a green economy. Moreover, energy-related innovation is not solely about taking products or services to commercial viability. The history of innovation has shown that public investment can develop public goods – ideas that can be accessed and used by many parties to share benefit.

There are system issues to be addressed in the energy transition – questions of decision making between options, about keeping options alive and the timing of investment, around societal preferences and impacts, and how to ensure stable operation of complex interactions. All parties affected by the energy system depend on gaining knowledge about the risks and opportunities associated with the system itself.

That knowledge is not commodifiable or easily traded, but is essential. It will be needed to inform business models, regulatory frameworks and political decisions. The processes to gain knowledge must be well-defined and use of it well-considered if access to energy is to be reliable and affordable and public support for the transition is to be maintained. ●

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