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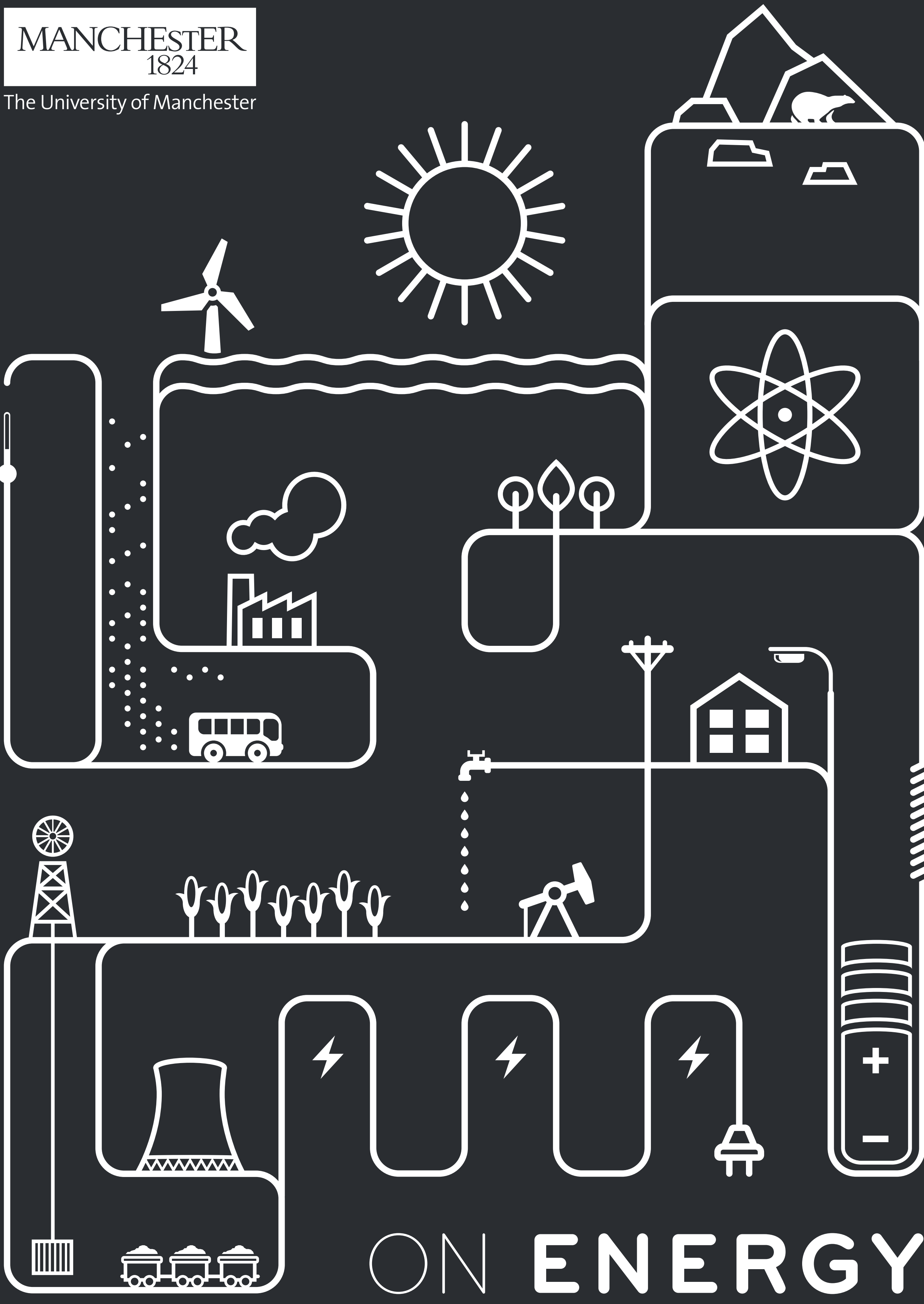

ON ENERGY

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What does the future hold for the demand and supply of energy?

Lord Jim O'Neill

In 1982 I completed a PhD in Economics, writing a thesis about the – then - Organization of the Petroleum Exporting Countries (OPEC) surplus profit and an investigation into its disposal. I tried to build a macro economic model to explore how oil prices were determined and, in particular, how OPEC oil-producing countries that had excess revenues would invest their proceeds. It was quite topical as it was during the second oil price explosion that started at the end of the 1970s. Frankly, one of the strongest things I learnt was that it was extremely difficult to predict oil prices! Indeed I still have a stack of research papers tucked away in a cupboard, many of which confidently predicted that the next decade and beyond would witness a period of continued surging oil prices and associated disruption. In actual fact, what followed was a long period of continuously declining prices as the world slowly adapted to the previous decade's sharp rise.

Predicting energy prices

In the early "Noughties", with me now being the Chief Economist of Goldman Sachs, my team applied our so-called BRICS thesis (the predicted collective rise of Brazil, Russia, India and China to become the largest economies in the world by the mid 2030s) to a number of markets, including for that of crude oil. In this paper, we showed that the strength of global demand would outstrip supply for the best part of 20 years, and we implied that this would be likely to be supportive of oil prices. As we approach the latter part of the second decade, it is starting to appear as though this period might have lasted less than 15 years.

One economic characteristic stands out from both these eras in my view, and it is this; the long-term elasticity of demand and supply to rising oil prices is typically stronger than most observers expect. Consumers find themselves exploring alternatives as well as ways to cut back on using oil as prices bite into their real incomes. Simultaneously, energy suppliers find themselves attracted to providing different sources of energy that become more attractive as the price of oil rises.

Global developments driving demand

What do I think about the future now? My strongest view is that I shouldn't confidently offer a view of oil (or any other energy) prices given what I have learnt, as well as my experience of managing a team of commodity price forecasters for many years.

But with this caveat, I will offer a few generalised thoughts. Firstly, given the global policy focus to reduce the challenge of climate change, there are obviously additional forces beyond the pure natural supply and demand forces for different types of energy, and energy overall. Policies to encourage other forms of energy supply and to discourage forms of carbon-producing energy are set to persist, and it seems to me that unless, or until, we see multiple years of evidence of the climate change battle being beaten, which would possibly reverse these trends, such policies are not going to be supportive of higher oil (or coal prices), at least in real terms.

Secondly, there appears to be growing evidence that we have entered a generation where individuals have different preferences for some consumer durables, and in particular,

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the desire to own their car is becoming less popular amongst the young, especially the urban young in western developed countries. It is far from definitive evidence, but it seems quite feasible, that in the US, Western Europe and other places, this may become the norm. If true, the future of the auto company is perhaps likely to be extremely different from the one that has existed since the 1950s.

A similar pattern might emerge with other consumer durables. The ease in which technology allows for fridges and freezers in our homes to be apparently controlled for energy usage differently, and fuelled by wind and solar, suggests that, at least in the West, these kind of energies remain on par for an era to compete more and more with oil and other traditional forms of energy.

This said, and not withstanding climate change agreements, there are still plenty of emerging economies whose likely economic rise will require them to have ongoing challenges in order to replace traditional energy sources, as they try to support urban expansion and stronger growth. India is these days the most important, given the scale of China's switching to alternatives, but the likes of Indonesia, and others, are also important.

Although China is becoming, perhaps, the leading global supporter of climate-change-friendly energy policy, notwithstanding their economy gradually slowing to softer growth rates, they remain the marginal driver for everything in terms of demand, probably including coal and oil.

The North's civic and business leaders have identified four areas where the north of England has genuine world class economic competitive potential, and one of these is alternative energies.

It is, of course, worth briefly high-lighting the persistent turmoil in the Middle East, which means that there is a constant threat of a major supply disruption to oil supplies, which from my eyes, has essentially become a permanent risk. But given the demand shifts taking place, it is probably the battle between the race to alternatives and the sheer pace of growth in the emerging world that will be crucial to developments.

Potential for alternative energies through the Northern Powerhouse

As a final observation, I thought I would end with some comments about the so-called Northern Powerhouse, something which Manchester and its University sit in the middle of. I remain quite involved in all matters Northern Powerhouse, partly as a Board member of the Northern Powerhouse Partnership.

The North's civic and business leaders have identified four areas where the north of England has genuine world class economic competitive potential, and one of these is alternative energies. Beyond the areas already discussed, one of the additional ones I have become persuaded about in terms of its potential is; small modular reactors in nuclear energy, and I was a keen promoter of a bigger degree of government support for this during my brief time in government. It seems to me that more initiatives are likely here, something which the top research areas in the north, and its Universities need to be on the top of - Manchester - as well as others - must seize this opportunity.

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Local to global: connecting scales of climate change mitigation

Professor Alice Larkin and Dr Carly McLachlan

The annual United Nations Framework Convention on Climate Change (UNFCCC) Conference of the Parties (COP) progresses global efforts to tackle climate change. At the historic Paris COP in 2015, nations collectively agreed to limit the global mean temperature rise to "well below 2°C" above pre-industrial levels. At the same time, nations pledged to reduce their own greenhouse gases, reduce deforestation, use climate finance to help developing countries move away from fossil fuels, as well as build resilience and adapt to climate change impacts.

The pledges, or 'Nationally Determined Contributions' (NDCs), vary in scope and scale between countries. For example, some articulate absolute CO_2 reduction targets, while others focus on CO_2 intensity. However, there is a gap between the overarching 2°C goal, and the outcome if the NDCs are aggregated.

This raises questions around why the pledges are not more ambitious, and if there are missing elements. These are questions researchers within Tyndall Manchester are exploring - considering discrete parts of the energy system, as well as taking a whole-system perspective - to address climate mitigation and adaptation challenges.

An interdisciplinary approach and their breadth of expertise enables them to connect deep, bottom-up interrogations of the challenges for local policymakers in delivering NDCs, with higher-level global goals informed by carbon budgeting.

Three important elements of this debate currently receiving attention by Tyndall are:

i. The role of negative emissions technologies;
ii. Translating global policy to city region scale;
iii. International aviation and shipping emissions.

Whilst seemingly disparate, giving these three elements a higher priority and prominence in the debate could provide the global community with a much greater chance of achieving its climate policy objectives. Here we discuss why.

Negative emissions technologies

The lion's share of analysis informing policymakers is derived from 'Integrated Assessment Models'. These are large, complicated models connecting the physical climate system with cost-optimised economic and energy models. However, being technology and cost-driven with high levels of quantification, these models are ill-equipped to consider more socially, institutionally or politically–driven change that can have a major impact on energy consumption and agricultural practices, and hence alter levels of greenhouse gases.

Negative emissions technologies (NETs) include those that avoid the production of greenhouse gases and remove CO_2 from the atmosphere, such as Biomass with Carbon Capture and Storage (BECCS).

Negative emissions technologies (NETs) include those that avoid the production of greenhouse gases and remove CO_2 from the atmosphere, such as Biomass with Carbon Capture and Storage (BECCS). Whilst currently in their infancy, reliance on these mechanisms to remove huge amounts of

CO_2 from the atmosphere is dominant in the models. In other words, policymakers are being informed that delivering the 2°C commitment is doable within the current economic paradigm, as long as NETs work at scale.

To deliver a level and speed of change in line with Paris commitments, action at all scales must be ambitious.

While NETs may indeed have a role to play in reducing emissions, being heavy relied upon limits the other possible scenarios that policymakers are being encouraged to consider. The NETs attraction is clear from the maths: because CO_2 accumulates in the atmosphere, we have a limited stock of CO_2 that can be released over coming decades to avoid '2°C'. Removing CO_2 from the atmosphere leads to a reduced pressure to tackle CO_2 from other energy system elements. Some less politically-palatable ideas that may be necessary and should be at least debated are overlooked as a result. For instance, how can policymakers deliver a step-change reduction in energy consumption in wealthy nations to meet the 2°C goal? The level of change required in energy and economic systems is highly ambitious under this scenario.

Nevertheless, while we continue to rely on a NETs silver bullet to avoiding '2°C', we fail to take up opportunities to plan for a transformed low carbon economy. Over-reliance on NETs limits other options and presents serious risks if their widespread deployment falls below highly optimistic expectations.

Action at a city region scale

Despite the focus on national agreements and commitments, deployment of mitigation technologies and other changes happen at sub-national scales. Tyndall's researchers work with Greater Manchester Combined Authority's Low Carbon Hub to evaluate progress on 2020 emissions reductions commitments to develop plans for future action. Multi-organisation partnerships come to the fore at this scale; Local Authorities, housing associations, network operators, regulators, transport and health bodies, community groups, businesses and universities combine to ensure services are resilient, citizens are protected over the short and longer term, and quality of life is improved.

With newly devolved powers and responsibilities in areas including planning, health, housing, transport, skills and training and support for local business, city regions like Greater Manchester can take a joined-up approach that explicitly values and supports delivery and amplification of co-benefits locally. For example, health benefits of tackling hard-to-heat homes through energy efficiency measures; improvements in air quality through electric vehicle take-up; new skills and training through community energy projects; using innovative local energy supply options to retain profits locally and use them to support other local needs.

To deliver a level and speed of change in line with Paris commitments, action at all scales must be ambitious. Knowledge sharing networks (such as 'Core Cities') are needed to build on learning, as actions are replicated and scaled up. Moreover, we must look across the devolved responsibilities to develop suites of interventions that build on synergies to avoid inconsistencies and conflicts (for example, ensuring housing development plans promote positive energy, health and transport outcomes).

International aviation and shipping

Finally, a missing element manifests in the international aviation and shipping industries. With emissions produced in international airspace and waters, these sectors are not party to the same scrutiny or policies as others. The International Maritime Organisation (IMO) and International Civil Aviation Organisation (ICAO) were given the remit within the Kyoto Protocol to mitigate their emissions. Despite limited progress during the Kyoto Protocol, they receive no mention at all the Paris Agreement. The mantra commonly heard is that their emissions are a small share of global emissions, with their activities fundamental for economic growth.

Yet it is not the case that their share of emissions is small. Together aviation and shipping produce 3–5% of global CO_2 emissions – equivalent to one of the top ten emitting nations, and their CO_2 emissions are anticipated to rise significantly. Nationally, there is also talk of boosting maritime-based trade post-Brexit, which could see the UK's contribution to shipping emissions increase further. It is dangerous to overlook international aviation and shipping, yet they are not included in any nation's NDCs. At the very least, articulating their own 'DCs' in line with the 2°C goal would be a much needed step forward.

It is dangerous to overlook international aviation and shipping, yet they are not included in any nation's NDCs

Conclusion

Digging into the detail of delivering on the Paris Agreement highlights three major challenges for policymakers.
Firstly, what if Negative Emissions Technologies fail at scale? Engagement with alternatives such as cutting energy consumption is urgently needed, and should be demanded from the academic community by decision makers.

Secondly, attention needs to be paid to those shaping change on the ground. The responsibilities of local policymakers are manifold, and there will be trade-offs. Learning by doing is essential, as is assessing success from the bottom up.

Finally, all emitters must be included in mitigation strategies. Aviation and shipping cannot be ignored at a national scale, as long as the efforts led by the IMO and ICAO remain out of kilter with 2°C. Only then can policymakers at all scales hope to deliver on what we committed to in Paris.

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Business as usual not an option for nuclear energy

Professor Tim Abram, Professor Francis Livens, Professor Juan Matthews and Professor Richard Taylor

What's going on in nuclear?

In the UK, nuclear energy is dominated by two distinct programmes: dealing with 'the nuclear legacy', resulting from many decades' exploitation of nuclear technology for civil and military purposes, often with little regard for the consequences; and 'new nuclear build', due to the return of nuclear generation, almost quarter of a century since the UK last built a power reactor. While the technical challenges in these two strands are quite different, there is a recurrent, overarching theme - anything to do with nuclear energy is too slow and too expensive. Here we examine reasons for this unenviable reputation and consider possible solutions.

Sellafield won't be solved by a widget

The nuclear legacy, a programme which will last over a hundred years at a cost of about £120 billion (although estimates can be as high as £220 billion), is dominated by Sellafield, where the numbers defining the decommissioning mission are almost too immense to contemplate. Under such circumstances one is tempted to seek divine intervention to provide deliverance, and it is this sentiment that elevates the concept of innovation to almost mythical status. The mantra of innovation pervades the language of decommissioning. 'Innovation will save us!' is its call to arms. It is easy to see how this zealotry can take hold; the idea of innovation is a beguiling one, it is both simple and elusive and has many definitions which can be adapted to the needs of the supplicant. It carries the promise of salvation through a paradigm shift which, in turn, makes it an ideal basis for oratory.

It is easy to get caught up in this but let's consider a few common definitions of innovation: 'the action or process of innovating' (not very helpful!). Alternatively 'a new method or idea', or, put another way, 'solving an old problem with a new solution.' So that's it, all we need to do is to do things differently and the Promised Land will be ours. Who wouldn't buy into that?

However, Sellafield, like life, is complicated. Its fate is determined by real people and it is governed by the laws of unintended consequence. So how do we harness the power of innovation in this environment? The key lies in the recognition that innovation is not selective but inclusive, determining that if we wish to succeed we need to do everything differently; we don't get to pick and choose. Innovation is not a flower that will flourish in a garden of weeds. If we recognise Sellafield as a holistic problem then our innovative solutions must be all encompassing. We must do everything differently, our technology, our governance, our regulation, our public engagement and anything else that defines the decommissioning challenge as a project in our society.

A starting point might be to take every facet of the problem and propose solutions which represent the precise opposite of established practice. Such an approach is pretty much guaranteed to result in a more insightful dialogue, although, to extend the analogy, it can earn the proponent a reputation as a heretic. Is it possible to fashion an environment where everyone is an agent of change rather than a victim of it? Because this is surely the trick we need to pull off if we want to create such

Is it possible to fashion an environment where everyone is an agent of change rather than a victim of it?

all-pervasive innovation? Our policy makers might be well advised to bend their minds to this problem.

New nuclear is eye-wateringly expensive

The price of renewable energy has fallen massively over the last year or two and instead of being able to defend the Hinkley Point C strike price of £92.50 per MegaWatt hour (price in October 2017) by pointing to the equivalent for offshore wind (about £120), nuclear has to recognise that its competitors now have a substantial cost advantage. We can argue forever about the importance of reliable baseload power, which nuclear gives you, whereas renewables don't, but does that reliability really justify nuclear being 50% more costly than its competitors? Nuclear has to look at its costs.

Most of the cost of nuclear energy is associated with building the power station. Billions of pounds are spent before any electricity is generated, and the cost of that capital is so high that is dominates the lifetime cost of a nuclear plant. Last year Simon Taylor of the Cambridge Judge Business School published a book *The Fall and Rise of Nuclear Power in Britain*. In it, he gives a detailed analysis of how the Hinkley Point C project is financed and why this finance is so expensive. Using some of his figures we might argue that, rather than having a strike price, the Government, which can borrow at 2 to 3%, should consider supporting the construction phase where rates of return are otherwise very high (maybe 15 or 16%). When the plant is operating, the private sector can take over the finance at a higher rate (5 to 6%) but still much lower than the rate of return that EDF is likely to make on Hinkley Point C. This would have the impact of reducing the cost of nuclear generation to £50-60 per MegaWatt hour. This could be a model which applies not just to nuclear plants, but to all large, risky infrastructure projects that are vital to the nation.

The alternative is to adopt a radically different approach to nuclear generation. Instead of spending years trying to build a huge piece of complex technology in a muddy field, why not shrink your reactor, build it in a factory out of the rain, and move it in big chunks to the site? We're used to modular construction of airliners and, more recently, aircraft carriers, so it can work very well. That's the thinking behind the Small Modular Reactor (SMR). Off-site manufacturing improves quality and reduces uncertainties, while a small reactor costs less and is operational sooner, so the cost of capital is much less. Rolls-Royce's recent study *UK SMR - A National Endeavour* describes the opportunity SMRs represent and, interestingly, suggests that SMR generation would cost about £60 per MegaWatt hour.

Where next?

Business as usual is not an option for nuclear. We don't just need new technologies, but new attitudes, organisational structures, and behaviours. Different models and new approaches to nuclear energy could make nuclear cost-competitive, but making such far-reaching changes requires commitment, courage and leadership from all involved. Will it happen? Only time will tell.

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Decarbonisation – the next step to a sustainable energy future

Professor Patricia Thornley

A low carbon milestone, but only the start of the journey

The UK has come a long way on its low carbon energy journey: early this summer renewable sources provided more than 50% of our electricity for the first time ever. The challenge now is to go beyond electricity to decarbonise other energy services and these tend to have more consumer interface.

Take heat for example: we have achieved significant reductions in carbon emissions by shifting domestic heat loads to highly efficient gas boilers and it is possible to build new homes with practically zero energy consumption. But we can't realistically replace the entire building stock, so if we are to reduce carbon emissions now we need to address existing homes. My domestic gas bill costs roughly the same as my domestic electricity bill, but I consume much more gas than electricity. So we need to drastically reduce energy consumption for heat or decarbonise the fuel source.

Decarbonising heat is technically possible: heat pumps and electrical heating work but they change the energy service offering to consumers. When we decarbonise electricity, consumers still receive electricity (but from low carbon sources) and they still use light bulbs (just low energy or LED). But heat pumps and electrical heating are less flexible, responsive and controllable, so consumer reactions have been mixed.

One way round this is to adopt the same approach we took with electricity: decarbonise the source and limit consumer interaction. The UK's extensive natural gas grid is a huge asset: if we can decarbonise that then we could have a tremendous impact on carbon emissions, and this is technically possible. UK companies are already turning waste into gas, upgrading it and injecting it into the gas grid. We should encourage more of that but the upgrading process reduces the carbon savings, so if the gas grid could function with higher levels of other gases the carbon savings could be increased.

In the long term such a transition could have huge benefits: a hydrogen grid would have zero carbon emissions at point of use (just like electric vehicles). So, encouraging and facilitating new gas networks is key, but would require a massive central infrastructure effort and extensive programme of appliance switching.

We have already seen substantial progress in the development of hydrogen as a fuel source for vehicles in Scandinavia, for example, and work on developing a viable hydrogen energy infrastructure is advancing in Japan, Germany and the United States (particularly in California, with significant state government support through their Air Resources Board). These are examples that we can learn from and will no doubt continue to monitor, but it is essential that the UK is not left behind – we have all the knowledge and technical skill needed to make hydrogen development a real success story for sustainable energy here as well.

UK companies are already turning waste into gas, upgrading it and injecting it into the gas grid.

Networks and infrastructure – setting the policy agenda

Other options include district heating and heating networks. Here the challenge is about infrastructure. Many European countries already have efficient heat networks and we could learn from their experience. But while European municipalities often provide energy infrastructure there are few UK entities with the capacity and remit to do so. So, our current governance frameworks do not encourage development of such schemes.

It should be possible for us to sustainably expand liquid biofuels that deliver real carbon reductions while monitoring adverse consequential impacts.

Then let's think about transport: liquid fuels are as embedded into the transport delivery infrastructure as wires are for electricity. Electric vehicles have a role to play in decarbonising transport, but it is difficult to imagine how they can service the aviation, shipping, heavy goods and agricultural sectors in the decarbonisation timescale available. So low carbon liquid fuels are also essential. Biofuels have helped here, but were limited because of concerns about the wider impacts of land-use and carbon stock changes. The key here is regulation and the UK has led the way on implementation of sustainability criteria, with huge knowledge and expertise in this area. So, it should be possible for us to sustainably expand liquid biofuels that deliver real carbon reductions while monitoring adverse consequential impacts.

In summary, many of the remaining challenges are less about the technologies and more about how they are implemented, governed and used. As is so often the case with questions of scientific progress, the capacity exists and is waiting for a lead from policymakers. They alone can create the frameworks within which scientific advances can be translated into real change. A key role for scientists, industry, and citizens now is to make the case for the investment and attention that low carbon technology and systems need to become commercially and politically viable here in the UK. Perhaps the difficult bit is just beginning!

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Batteries, Britain and Brexit

Professor Robert Dryfe and Professor Andrew Forsyth

Batteries have become an integral part of our lives, so much so that most of us will not venture on an overnight trip without our phone and, as essential, its charger. We have all come to rely on electrical energy stored using the lithium ion battery (LIB) to power our mobile phones and laptop computers. Battery technology looks set to become even more dominant, with a revolutionary shift from petrol and diesel to battery-powered cars predicted to occur over the next decade, and batteries expected to make a major contribution to grid-scale energy storage and even the next generation of aircraft. How did this revolution begin and how is the UK positioned to exploit its next steps?

The lithium revolution

Technological revolutions are often driven both by scientific push and societal pull, and the recent lithium revolution has been no different. Much of the original groundwork for the lithium-ion battery (LIB) occurred in the UK in the 1970s, although it was originally brought to the market by a Japanese company (Sony) in the early 1990s, ironically at a time when the UK's 'indigenous' battery industry was in serious decline. Lithium ion technology succeeded because it offered a new, light-weight form of rechargeable battery, perfect for powering handheld devices such as Camcorders, technology which was subsequently - and crucially – transferred to the burgeoning mobile phone market.

The societal push has come from concerns about urban pollution, with the UK government proposing to end the sale of all new conventional petrol and diesel cars by 2040. An informed commentator writing this piece at the end of the 1990s would probably have predicted that the electrification of vehicles would be achieved through hydrogen-based fuel cell technology, rather than batteries. In fact, intense refinement of the performance and manufacture of LIBs, driven by their mass uptake in personal devices, has meant that battery technology has driven hydrogen-based cars off the road, at least for now. Elon Musk's Tesla brand is the standard bearer for the LIB-powered car: the aim of Tesla's Gigafactory, sited in the Nevada desert, is to reduce the cost of the LIB towards the $100 per kilowatt hour mark.

Lithium ion technology succeeded because it offered a new, light-weight form of rechargeable battery.

The UK and the global battery ecosystem

The UK has strengths in the fundamental science and engineering underpinning electrochemical energy storage and a strong car manufacturing base, which is already producing battery-powered vehicles in Nissan's Sunderland plant. This takes us to Brexit, with the attendant risks to the car industry supply chain associated with the UK leaving the European Single Market. The government responded early in the Brexit process with the much-discussed letter to Nissan, outlining as yet unpublicised (commercial confidentiality was invoked) reassurances to the Japanese manufacturer.

The UK government has also responded in a more transparent way by assuming that retention of a UK car manufacturing base will require investment to support the resurrection of domestic battery manufacturing on a large-scale. Accordingly, battery technology, specifically in the vehicular context, was at the heart of the Government's recently launched Industrial Strategy. The £1 billion Industrial Challenge was announced in the Spring of 2017, with details emerging over the following months. Electrochemical energy storage is the biggest single pillar of the Industrial Challenge with the government – via the Engineering and Physical Sciences Research Council (EPSRC) – announcing funds for new research projects in this area (the authors are leading one of these projects).

In parallel, the Government has announced a competition for universities to lead a hub to manage the designated Faraday Challenge and, most crucially, oversee the link between the academic research and transfer of the technology to industry, to prevent the UK missing out - yet again - on the development of new approaches to energy storage technology. The absence of a large player in the modern battery market, and associated significant battery manufacturing capability, is the Achilles heel tacitly recognised by the Government, and surely the key to successfully resolving the Faraday Challenge.

Grid-scale storage offers a route to help de-carbonise our electricity supply.

Grid-scale energy storage

In 2013, the UK Government recognised the future significance of energy storage on the grid-scale by naming it one of the Eight Great Technologies. Grid-scale storage offers a route to help de-carbonise our electricity supply, by allowing storage of intermittent wind/wave/solar-derived electricity, and balancing supply and demand in the smart grid of the future. Grid-scale battery storage has now become a reality both at the local/domestic scale, with the Tesla PowerWall for example, and at the national level with National Grid awarding contracts for 201 megawatts of, mainly, battery storage capacity to balance the grid on a sub-second time-scale in the UK last year.

One advantage of grid-scale storage, as opposed to transport applications, is that battery size and weight are not 'mission critical', therefore opening up the palette of potentially viable technologies to devices such as the redox flow battery, where the reactants are stored in tanks (as in a fuel cell, or conventional petrol tanks) but the chemistry is still reversible, so can be recharged many times.

Where next?

The UK has set ambitious targets to de-carbonise its electricity supply (the 2008 Climate Change act committed the UK to a target of 80% reduction of greenhouse gas emissions by 2050, relative to a 1990 baseline), so the 'societal push' to develop such large-scale storage technologies exists.

The final frontier for electrochemical energy storage is its extension to other forms of transport, such as the aircraft industry. In order to reduce emissions, a number of new aircraft propulsion concepts are under development in which jet engines will be complemented by battery-powered ducted-fans, for example allowing the jet engine to be turned off during the cruise phase of a flight. However, making this a reality requires a further revolutionary change in battery performance and weight.

Batteries, therefore, look set to become an even more important part of our future: a genuine opportunity exists for the UK to take the lead in the development and manufacture of this critical technology.

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Urban transformation: from replication to learning

Professor James Evans

How can we transform our cities? This question occupies an increasing number of funding bodies, researchers, companies and public authorities. As booming urban populations experience ever-worsening air quality and living conditions, cities have become the battleground on which the future of humanity and the planet on which we depend will be decided. No surprise that much ink is now spilt trying to understand how to change cities for the better. And funding has followed suit.

Urban transformation 1.0

'Urban transformation 1.0' began in the wake of the Rio Earth Summit in the 1990s, focusing minds and wallets on how to make cities more sustainable. Thousands of worthy projects were funded, with much success. Buildings went up with solar panels on them, zero-carbon housing estates appeared, cities consulted residents to make more appropriate decisions and so on. But the successes for the most part did not spread beyond the scope of specific projects - 99% of new urban growth and development resembles business as usual. New housing in London does not generally look like BedZed, a successful zero-energy development that is now almost 20 years old. Apart from being bigger, the sprawling informal settlements surrounding cities like Nairobi look much the same as they did thirty years ago.

The main problem for 'urban transformation 1.0' was that it had no theory of change. It was assumed that a successful project would be enough to prompt wider transformation by themselves. In reality, projects, and the best practice reports they spawn, change little. Academia and policy-makers became obsessed with developing and refining desirable futures at the expense of understanding how to actually achieve them. Sustainability, resilience, smartness, low carbon, and liveability are all eminently worthy goals that are hard to argue with. But they don't tell us much about how cities change on the ground.

Transformation as replication?

Emerging in the last ten years, 'urban transformation 2.0' focuses on the process of change. Fed up with funding one-off initiatives, funders, companies and authorities want projects that can be 'replicated', 'up-scaled' or 'mainstreamed' to achieve change beyond their specific boundaries. A bewildering array of words has emerged to describe how specific projects might achieve broader impact. In relation to urban and systems change the European Commission focuses on 'replication' as the vehicle through which demonstration projects are to achieve broader impact. More traditional academic funding bodies ask for applicants to show how impacts will be up-scaled. Organisations talk about mainstreaming innovation. This lexicon of transformation is problematic as the assumptions underpinning these words are largely unexamined. At worst they are used interchangeably. Each of these words comes with its own set of assumptions about how change happens, what will be changed, and who will be doing the changing.

Fed up with funding one-off initiatives, funders, companies and authorities want projects that can be 'replicated', 'up-scaled' or 'mainstreamed' to achieve change beyond their specific boundaries.

Modular design creates separate systems which function independently of the wider context.

The idea of replication is worth looking at in more detail, as it underpins the model of change adopted by the European Commission's Horizon 2020 programme, the largest publicly-funded research programme in history. The concept appeals as it suggests a factory line churning out large numbers of identical solutions. The market provides the replication mechanism, whereby demonstrating a (smart / sustainable / low carbon / 'goal of choice') solution in an actual urban setting supports the development of a business case. Other cities faced with a similar problem, and many of the problems are similar, purchase the solution in the form of a product. A good example would be an ICT platform to store and analyse urban data. The role of the European Commission is to support the establishment of a market in which private companies develop and sell urban solutions to local governments as customers.

Modular systems

While suggesting slightly different spatial patterns of adoption, notions of up-scaling and mainstreaming make similar assumptions about urban solutions. The city comprises a series of plug and play solutions, whereby new solutions are simply 'plugged in' to existing contexts. Such modular solutions lend themselves well to a market approach, as they can be packaged and sold as discrete products. This creates problems for cities, especially ones that are trying to be smart, resilient or sustainable, because they are supposed to be planned in an integrated and locally appropriate way. Modular design creates separate systems which function independently of the wider context.

Solutions for drinking water provide a great example. Desalinisation plants are not very sustainable, requiring large amounts of energy. But as modular solutions they can be sold and plugged in to a municipal water supply relatively simply. Wastewater treatment represents a more efficient use of resources, but requires considerable public coordination to integrate fully with an existing urban water system. In many drier parts of the world investment is going into desalinisation rather than wastewater treatment.

Modular understandings underplay the importance of adapting solutions for different places. This process of geographical articulation involves showing how a solution from one place can work within the institutional, legal, technical and political context of another. As Doreen Massey put it, "place is always different. Each is unique, and constantly productive of the new". Dutch-style cycling infrastructure is forty years old in the Netherlands, but its use in the UK today is considered highly innovative. Only showing solutions can work 'here' will convince people to fully adopt them.

This requires a city to learn which solutions work for it and which don't. Sometimes this happens through trials, such as the congestion charging schemes in London and Stockholm that were implemented temporarily so that residents could then decide whether it was desirable as a permanent solution. Other times it happens through small-scale demonstrations, for example of e-bikes or smart grids that can then be adopted more widely. The point is that cities have to learn what solutions will work for them, usually through trying them out in some way.

How cities learn

The real crux of urban transformation is in fact how cities learn. This does not mean that popular metaphors like replication, mainstreaming and up-scaling are redundant; far from it - they are useful descriptions of different routes to transformation. But each requires cities to learn what works for them at some stage. The notion that cities constitute a homogenous marketplace in which portable modular solutions can be sold and simply plugged in obscures the very real work of learning, and explains the failure of recent attempts to stimulate large-scale replication.

Learning is hard and time-consuming, involving substantial investment in partnership building and persuasion. It is as much political as economic. When it comes to learning, cities are more like people than machines or markets: first they have to want to learn; second they learn best through experience, or trying things out for themselves; and third they need to be able to reflect and act on what they have learnt. Those who are serious about urban transformation should focus on creating the conditions for these three elements of learning to happen.

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THERE CAN BE
NO JUSTICE
WITHOUT
CLIMATE JUSTICE

Reconciling fuel poverty and energy justice in a low carbon society

Dr Harriet Thomson, Caitlin Robinson, Dr Neil Simcock

Climate change is a critical global policy issue, with emissions of greenhouse gases (GHG) at their highest levels in history. Fundamental transformations to low carbon societies are urgently required to significantly reduce emissions in order to limit global warming to 2°C. It is widely accepted that such transformations require both significant investment in renewable forms of energy generation, alongside significant reductions in the consumption and use of energy. In industrialised nations a reduction in domestic energy consumption is of particular priority, with the domestic sector (excluding transport) accounting for approximately 28% of carbon emissions in the UK.

At the same time, the UK and many countries across Europe face significant problems with *fuel poverty*, a situation where a household is unable to attain adequate levels of energy services (such as heating, cooling, lighting and other important appliances) necessary to meet their basic needs. Its complex causes include poorly-insulated homes, inefficient appliances, low household income, high energy prices, and above-average energy needs. The human and societal costs of fuel poverty are extensive, resulting in worsened physical and mental health, increased usage of health services, and social isolation.

Reducing carbon emissions and alleviating fuel poverty are both vitally important policy goals, but they have the potential to be in conflict. Here, we explore some of the tensions and synergies between fuel poverty and carbon reduction in current UK policy, and present a set of practical recommendations for a more just energy future.

The human and societal costs of fuel poverty are extensive, resulting in worsened physical and mental health, increased usage of health services, and social isolation

Fuel poverty and the low carbon transition: tensions and synergies

To achieve ambitious carbon reduction targets of 80% by 2050 in the UK, considerable investment will be required in domestic energy efficiency and carbon saving programmes. Currently, there are three primary policy mechanisms designed to facilitate this:

- The Energy Company Obligation (ECO), which provides subsidies for the upfront cost of installing domestic energy efficiency measures to those on low-incomes or in properties that are difficult or expensive to retrofit.
- The Feed-in-Tariff (FIT), which provides payments to households for the electricity they generate from renewable sources.
- The Renewable Heat Incentive (RHI), which provides quarterly payments to eligible households that install renewable heating technology.

Targeting these policy mechanisms towards fuel poor households is particularly beneficial, firstly due to the role that improvements in energy efficiency and the ability to generate energy independently of the grid can have for fuel poverty alleviation, and secondly given that per pound of fuel households living in fuel poverty tend to use energy less efficiently and more carbon intensively.

However, whilst RHI is funded through general taxation, responsibility for delivering and financing the ECO and FIT lies with larger energy companies, who pass on the costs of these programmes to their customers via levies on domestic energy bills. This is argued to be a regressive and unjust funding approach that increases the burden of energy bills for those vulnerable to fuel poverty. This is because, by raising the average cost of energy, poorer households pay a greater proportion of their income toward the levies than higher income households. This is heightened by the fact that fuel poor or low-income households generally consume less energy than their more affluent counterparts, and so may well have contributed relatively less to UK carbon emissions.

Furthermore, fuel poor or low-income households can be less able to respond when the cost of energy rises. Many already carefully ration their energy consumption and so have little scope for further reductions; they can also be disadvantaged in their ability to seek cheaper tariffs, such as by switching supplier or utilising Direct Debit payment methods. As National Energy Action (NEA) argues, financing domestic low-carbon measures through energy bills, rather than taxation, means that 'the very households struggling to achieve affordable warmth are required to make a disproportionate contribution to the solution'.

In the UK, being defined as a 'vulnerable' consumer eligible for ECO funding is based on the receipt of means-tested welfare benefits, which is taken to a be a proxy measure for having a low-income.

Barriers to energy efficiency and micro-generation

In theory, the impact of rising energy bills should be ameliorated by the savings enjoyed by fuel poor households whose homes have been retrofitted under the ECO scheme. But in reality, poor targeting means that only a small proportion of these schemes actually reach those at greatest risk of fuel poverty. This has led NEA to state: "the injustice of a regressive funding mechanism is compounded by a lack of access to the potential benefits".

In the UK, being defined as a 'vulnerable' consumer eligible for ECO funding is based on the receipt of means-tested welfare benefits, which is taken to a be a proxy measure for having a low-income. But low-incomes are only one cause of fuel poverty, and so households can be ineligible for means-tested benefits yet still suffer from fuel poverty. Infrastructural issues – such as a lack of thermal efficiency in the home, or an inability to switch from expensive fuels such as oil for heating – are arguably more crucial yet are ignored by existing eligibility criteria. There is also a poor uptake of benefits in many countries, meaning that many vulnerable households receive no help.

In terms of support from the FITs, installing micro-generation technologies for electricity or heat often requires a significant upfront capital investment. This is a significant barrier for low-income households, particularly in the absence of effective subsidies. Micro-generation is also more easily available to homeowners, excluding private renters who are more vulnerable to fuel poverty but whose landlords have little incentive to engage. This unequal distribution has the potential to reinforce existing structural disparities between different groups, with a higher income, middle class 'elite' more likely to adopt and benefit from the technology.

Although some fuel poor households will be eligible for, and benefit from, domestic retrofit measures – particularly ECO – many will not. The regressive nature of the financing system means that the worst hit will be those on the lowest incomes who are ineligible for measures or support (or who do not take them up).

Designing a just low-carbon transition

Many policies that can successfully reduce carbon emissions in the domestic sector simultaneously have enormous potential to alleviate fuel poverty (energy efficiency schemes), and have significant emancipatory potential by providing fuel poor households their own means of generating electricity or heat independently from the grid (micro-generation).

The regressive nature of the financing system means that the worst hit will be those on the lowest incomes.

Whilst it is recognised that the long-term solution to reducing domestic energy consumption is a deep retrofit of the housing stock with appropriate energy efficiency and renewable energy systems, for these measures to alleviate fuel poverty they also need to be appropriately targeted and funded. Our suggestions for improving targeting and funding include:

- Review the 'cliff edges' in entitlement to support for welfare measures and low carbon measures
- Increase understanding of the barriers and pathways to involvement for vulnerable households within retrofit schemes
- Explore the 'polluter pays principle' for funding demand reduction policies
- Make energy efficiency a key national infrastructure priority.

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Expecting more from our electrical infrastructure

Dr Vidyadhar Peesapati

The UK electrical network can be divided into three categories: **Generation**, **Transmission** and **Distribution**.

The **Generation** side includes all forms of power plant, from conventional fossil fuel power stations (coal and gas) to nuclear power stations and renewable sources such as hydro, wind, tidal and solar.

The **Transmission** network is the system which transports electrical power across vast distances, connecting generation sites around the country to the distribution networks. There are three transmission operators within the UK and the networks operate at voltages of 400,000 and 275,000 Volts.

The **Distribution** network, a combination of seven companies within UK, effectively manage the electrical supply to our local areas, powering our industry, public services and houses. These three categories form the UK's electrical network.

Challenges and change in today's electrical system

The electrical system we know today is going through a significant change. The number of electric household appliances and gadgets has increased significantly in the past decade and whilst we are moving towards smarter, more efficient homes, where energy usage can be monitored and scheduled, pressures on our asset infrastructure still exist. Electric vehicles are also on the cusp of becoming mainstream alternatives to diesel and petrol power. This shift will significantly increase the load and shift demand patterns on our network.

Whilst we are moving towards smarter, more efficient homes, where energy usage can be monitored and scheduled, the need for more energy within households is increasing too.

The need for reliable as well as environmentally-acceptable energy will need to be met by different sources, including a significant amount of generation due to renewable energy and energy storage to help meet peak loads. National Grid estimates a 60% increase in renewable generation and 30% increase in peak demand by 2050.

The power of tomorrow

Traditionally, power flow has been a one-way journey. Starting with generation, power is transported through the transmission lines, through the distribution networks and consumed by the end users. In the near future, the system will become a two-way power flow, where end user will not only consume energy, but also store and generate useful power that can be returned to the grid, especially when demand is high. The government has also started to look into different schemes encouraging households to generate power locally and supply this to the National Grid. But does this have drawbacks? What are the implications on the resilience of an electrical network when we are dependent on small-scale storage systems and renewables alone?

Our network design was based on generating enough power instantaneously to provide the required capacity margin (the difference between supply and demand - usually there is an excess of supply to answer unexpected surges or sudden loss of generation). Are we leaving ourselves vulnerable by eliminating large multi-megawatt power stations? Also, do extreme weather events impact the resilience of the new system?

The need for research into understanding ageing and condition monitoring of old network assets is increasing, as is the need for funding long-term innovation projects.

Obstacles and opportunities in transmission

Most of the transportation of this extra power generated will need to be accommodated by the existing transmission network. This is a herculean task for an already ageing infrastructure. The UK transmission network is around 50 years old. The physical network is a combination of powerlines, cables, transformers, switch gear and other high voltage assets. It is a recognised fact that there is lack of sufficient investment into network infrastructure. There has been a push of innovation programs, like the Network Innovation Allowance (NIA), to encourage network owners and operators to find innovative solutions for future network reliability and asset management. The NIA, an incentive launched by OFGEM, allows network operators to fund small innovation projects, capable of providing long-term savings and benefits to the customer. But even with such programmes, historic underinvestment within the area will have serious implications for future power transmission and reliability.

The consequence of failure of these ageing network assets is considerable, leading to blackouts. It is neither technically plausible, nor financially viable to replace the entire network in one go. At the same time, the risks are too high in implementing untested technologies onto the network without understanding the long-term impacts they would have on the system as a whole.

This is not a problem faced by the UK alone, most European countries share these challenges. The need for research into understanding ageing and condition monitoring of old network assets is increasing, as is the need for funding long-term innovation projects. It is extremely difficult to replicate 60 years of ageing within laboratory conditions, thus researchers and utilities need to work in unison to tackle on-going infrastructure improvement.

The challenge with the transmission network is two-fold; primarily, trying to invest in new technologies and understand how these interact with the existing ageing network and secondly, understanding ageing and condition monitoring of existing assets in order to avoid failures on the network. It is important to understand that both of these have to be done in parallel. All of this development and innovation will require significant investment, which could affect the price of electricity to consumers. Energy not only needs to be reliable, but affordable too, so understanding the economics of this process is also important.

Our energy futures – local and global

Let's also look at the energy landscape from a global perspective. There are still many countries in the world that do not have the benefit of an uninterrupted power supply. There are a lot of regions within Africa where there is next to no electrification. The development of a country is directly influenced by its ability to provide a dependable and reliable energy supply. A lack of this can cripple economies and hinder development.

There is a large push towards developing smart and sustainable villages in poorer economic regions within the world, thus enabling development and progress within local communities. This means the use of renewable energy sources like wind and solar on a micro-grid level. So, can local distributed generation models be translated to smart villages? Is there a need for large transmission networks, or are localised energy systems the way forward?

There is definitely one thing for sure, the need for skilled engineers is vital in solving all the above uncertainties. The changes and innovations that will be seen in the next decade will define how we operate our electrical network - similarly to what was done in the 1950's. The current engineering graduates will be responsible for maintaining and innovating this network for the next 50-60 years.

Correction:
The original version of this article contained a statement that future power demand would increase six-fold by 2050. We have corrected this statement and included more context in the 'Challenges and change in today's electrical system' section. Re-published 29 March 2018.

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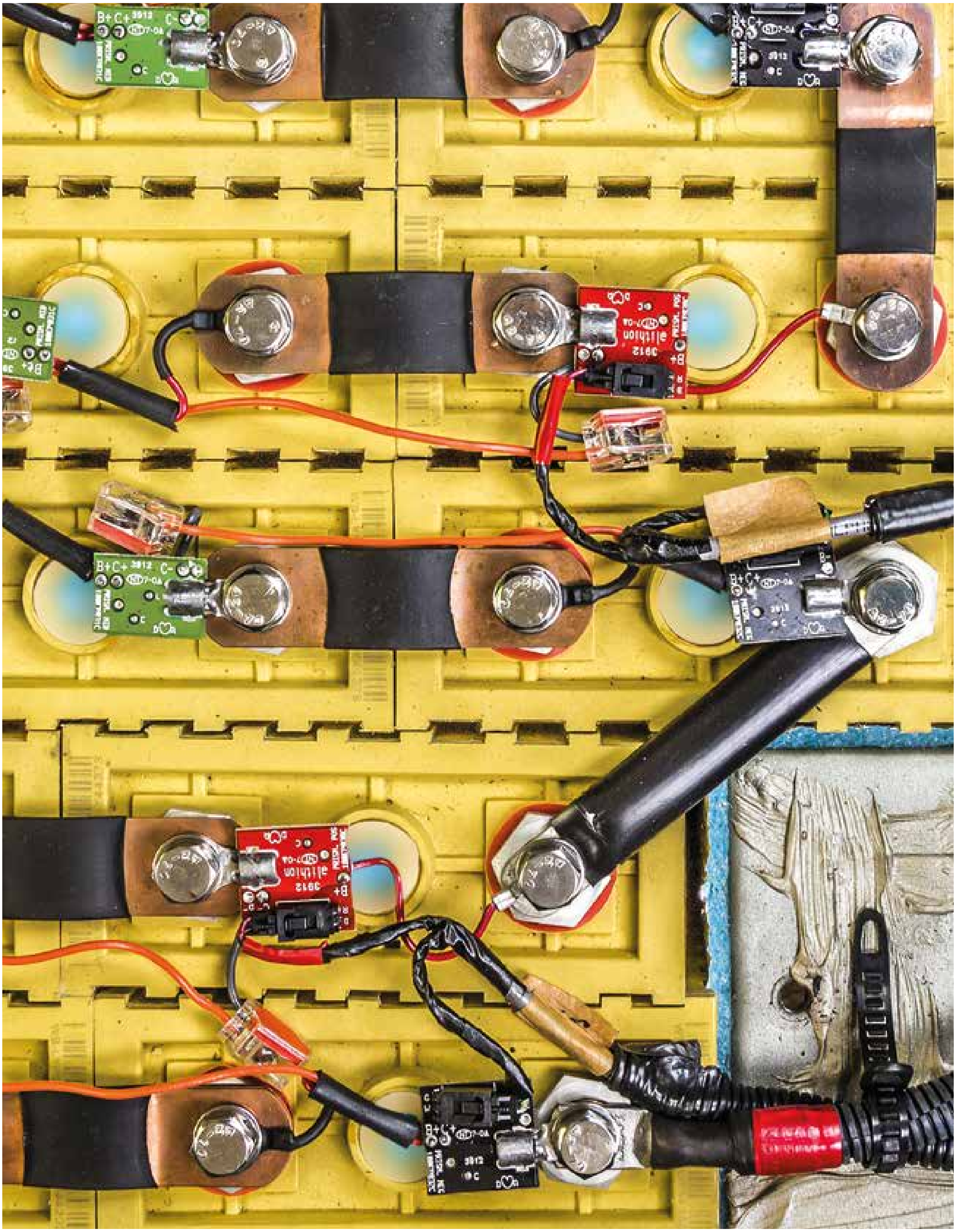

Multi-energy systems: the 'smart grid' beyond electricity

Professor Pierluigi Mancarella

Renewable energy: unprecedented challenges

The electricity sector is undergoing unprecedented changes, particularly driven by the need for fighting climate change and the associated international commitments such as the recent Paris Agreement. We have been witnessing various developments at the UK and European policy levels for several years, especially in terms of supporting various renewable energy sources (RES), such as wind energy, solar photovoltaic (PV), and so forth. These RES technologies are in turn also becoming cheaper, so that we are indeed seeing the positive feedback that was expected to move towards a low-carbon electricity system.

However, larger volumes of RES in the power system bring about significant operational challenges. In fact, most RES – whose energy output is variable and partly unpredictable, depending on the incumbent meteorological conditions – exhibit fundamentally different characteristics from 'conventional' fossil fuel-based power plants whose output is much more controllable. Since electricity generation and consumption need to be balanced on a second-by-second basis for the system to be operated stably and securely, larger volumes of variable and partly unpredictable RES therefore require more 'flexibility' to be available in the system. Currently, this is primarily provided by conventional generators, which have insofar been the 'traditional' providers of flexibility and guaranteed a high level of reliability.

RES energy output comes at very low operational cost and that may also be further incentivised by policy mechanisms, so RES typically operate with market priority over conventional power plants, which may be slowly pushed out of the market. Therefore, new sources of flexibility are needed at the system level.

Making the power system more intelligent

There is a no-brainer solution that would allow solving most of the aforementioned issues: building more asset and RES capacity, so that network and generation redundancy would ensure more reliable availability of renewable energy most of the time and that both renewable energy and 'flexibility' could easily travel across networks without bottlenecks. This would also mean that likely large volumes of electricity would have to be curtailed at times when generation exceeds demand, which we already see in some cases. Obviously, this is perfectly feasible from a technical perspective; however, the more general engineering, socio-economic and policy question is: 'at what cost?'

RES energy output comes at very low operational cost and that may also be further incentivised by policy mechanisms so RES typically operate with market priority over conventional power plants

The Smart Grid has been put forward as an alternative paradigm whereby greater observability and controllability of new technologies, including wind and PV, facilitated by fast developments of information and communication technologies (ICT), smart meters, etc., would prompt a shift from an asset-based to a control-based paradigm. This would

> **In the UK electricity represents only about 20% of the overall energy end use, while the rest is roughly evenly split between heating and transport.**

also mean a much cheaper, and to some extent reliable, renewable-based power system.

Electricity storage and the bigger picture

In the Smart Grid context, the required flexibility to provide supply and demand balance across time and space indeed come from new technologies. In this respect, electricity storage is often hailed as the Holy Grail of future power systems. In fact, small-scale batteries associated with house-level PV can bring benefits to system operation and even favour the integration of wind energy besides PV, as our recent research demonstrates. However, batteries are still relatively expensive, while other forms of electricity storage such as pumped hydro are constrained by geographical characteristics. Batteries are also more suitable to store relatively small amounts of energy, so the question of how to deal with large energy storage requirements would probably still hold even if batteries became more affordable.

However, while we are so worried about decarbonisation of the electricity sector and providing electricity storage, electricity is only a fraction of our overall energy consumption, as recognised by the Paris Agreement. In fact, in the UK electricity represents only about 20% of the overall energy end use, while the rest is roughly evenly split between heating (which is primarily gas-based) and transport (again based on different fossil fuel derivatives). The bigger question of decarbonisation of the whole energy sector therefore arises. Electrification of heating (e.g. through electric heat pumps) and transport (e.g. through electric vehicles) represent promising solutions towards decarbonisation of these sectors too, provided that electricity itself is decarbonised. However, the energy volumes and power requirements of a whole-electric system are daunting, and so are the relevant technical and economic challenges. Hence, while the Smart Grid is key to moving towards a sustainable power system, decarbonisation of the entire energy sector calls for rethinking the role of electricity, which would most likely be of paramount importance regardless, in a whole-system context.

Multi-energy systems: integration rather than electrification

It is critical to better understand how electricity interacts with end-use sectors such as heating, cooling and transport (which are all very large contributors to greenhouse gas emissions), as well as with different fuels (particularly natural gas). New concepts such as Multi-Energy Systems (MES) have therefore emerged, whereby multiple energy vectors and sectors are optimally integrated and other sectors are not just electrified. Widespread recent research, especially in Europe, China and Japan, clearly demonstrate how MES can increase the overall energy system's performance (and not only the power system) technically, economically and environmentally and from both the operation and the planning perspectives.

It is also worth highlighting that energy systems and sectors are actually 'naturally' physically integrated (for instance, in our houses we use electricity and gas to power our laptops and keep warm), while it is their engineering operation and planning, which are economically and commercially driven and this typically happens in sector 'silos' that can greatly benefit from more awareness in such integration. In particular, such smart MES thinking includes a number of emerging topics such as smart buildings, smart communities and smart cities, where indeed energy sectors are naturally interacting most as there is a pronounced need for different energy vectors.

MES have the potential to unlock value hidden when considering only electricity and access new forms of flexibility that may be essential in future power and energy networks. For example, renewable electricity could interact with the heating sector through various technologies (e.g. electric heat pumps or high-efficiency combined heat and power plants), while also benefiting from new forms of storage (e.g. through thermal storage such as hot water tanks or even thermal inertia in buildings) that may be much more affordable than batteries or the likes.

MES have the potential to unlock value hidden when considering only electricity and access new forms of flexibility that may be essential in future power and energy networks.

The same applies to transport, which could be powered by renewable electricity and at the same time provide new forms of energy storage, of a more short-term nature (e.g. battery electric vehicles) or long-term one (e.g. hydrogen vehicles, whereby hydrogen could be stored in large volumes in refuelling stations similar to current petrol stations). Further integration could also happen on the supply side, through interaction of electricity and gas again through hydrogen that would be produced by renewable electricity and blended up to certain volumes into the gas network: effectively, this is a means to decarbonise the gas sector while potentially providing a seasonal form of energy storage.

Do we really need batteries?
When looking at all the options that MES thinking opens up, the key questions suddenly change. For example, do we really need to invest in batteries today, or should we rather embrace a more holistic technology revolution with new alternative forms of storage or alternative approaches to provide system security, as for example recently discussed in the context of Australia? If we need to decarbonise heating and transport, why shouldn't we optimally use the storage available in hot water or battery/hydrogen vehicles instead of installing (still fairly expensive) batteries?

Of course it is not all so simple, and there are challenges to overcome, particularly associated to the disruptive changes to the status quo which MES could bring. The business case of existing actors would change significantly, and there may be oppositions to such changes. The role of regulation and policy is therefore crucial, to support not only new energy technologies that can be key in a MES context but also, and especially, to facilitate 'whole-system thinking' and suitable commercial cases when system-level benefits can be demonstrated, for which teaming up with research may be essential.

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