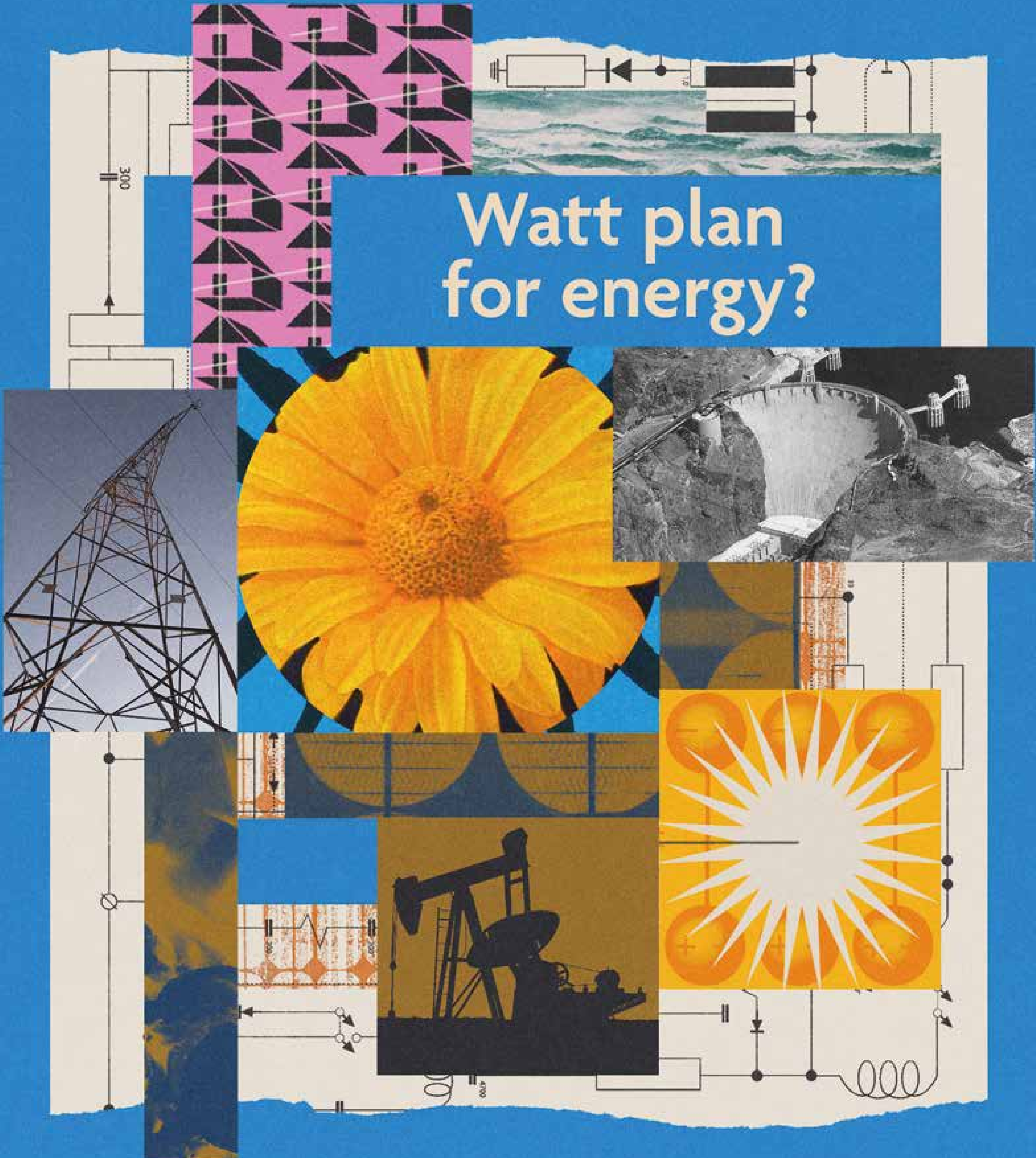
environmental SCIENTIST

March 2023
Journal of the Institution of Environmental Sciences

Watt plan for energy?



EDITORIAL

Taking a positive approach to a cleaner, low-carbon energy future

I was recently at a workshop for projects that had successfully participated in Innovate UK's 'Prospering from the Energy Revolution' programme. Those taking part were invited to position themselves in a tetrahedron, with social, environmental, economic and technical lessons learned forming the corners. To everyone's surprise, most people gravitated towards the social corner. In moving to a sustainable, low-carbon economy, we had found it was the people that mattered: the users of the new energy systems as well as the designers, installers, maintainers and influencers.

When reading this issue of environmental SCIENTIST, it is worth keeping that in mind. There is no point in creating a perfect technical solution to our energy problems with minimal impact on the wider environment and low costs unless people want to use it. Environmental scientists cannot sit in an ivory tower; they need to engage with people – politicians, engineers and, above all, consumers. Over the past few decades, interest in energy has swung between the corners of the trilemma: affordability, security of supply and environmental (generally low-carbon) responses. But these too must be about people.

Sending out the right message is important. It is not 'one size fits all'. For some, reassurance on affordability is key, sometimes needing to overcome an inherent distrust of the new, foreign or different. If a filament lightbulb was good enough for my father, why should I trust an LED? If I allow my energy supplier to manage my company's demand at peak periods, will I still be able to meet my production targets? And surely the energy used in making that shiny new solar panel must outweigh any trickle of power that it can capture under England's cloudy skies? There are a lot of urban myths about sustainable energy that need to be tackled with scientific rigour, and using plain English is essential; even among my friends I try not to talk too much about the benefits of BIPV in $kgCO_2e/m^2yr$* or why you will find ISO 14068 engraved on my tombstone.

Positivity is important too. We must promote the benefits of clean energy in terms of warmth and mobility for all, and not fall back on to seemingly negative phrases, such as climate crisis, low energy or zero carbon. A focus on carbon can introduce a level of remoteness to the discourse – when I switch on a light I see brightness, not some distant emissions of black carbon! So when thinking about the initiatives described in this issue, let's be positive about a clean, bright and bountiful energy future (and only incidentally note that it is zero carbon).

* BIPV = building integrated photovoltaics; $kgCO_2e/m^2yr$ = kilograms of carbon dioxide equivalent per square metre per year.

Editorial: Ian Byrne is a chartered environmentalist and chartered accountant who has promoted sustainable energy solutions for 33 years. He is the IES's Treasurer, runs IBECCS – a carbon and energy-saving consultancy working mainly with smaller public sector clients – and convenes the ISO working group writing the international standard on Carbon Neutrality (ISO 14068).

Cover design: Ricardo Santos is a graphic designer and illustrator from Lisbon. He uses the language and juxtapositions of collage to help clients big and small around the world. dat-rs.com

CONTENTS >

environmental SCIENTIST
The journal of the Institution of Environmental Sciences
Volume 32 No 1 | ISSN: 0966 8411

The environmental SCIENTIST provides a platform to discuss key issues within the environmental sciences, hosting original articles written by professionals, academics and experts working across the sector.

The views expressed in the journal are those of the authors and do not necessarily reflect IES views or policy.

INTRODUCTION

Energy: in what direction and at what speed towards a greener system

Yacob Mulugetta puts the journey into a technological, sustainability and geopolitical context.

Energy is a critical enabler for economic transformation and social wellbeing. It is needed for heat, light and services at home and in the workplace, for entertainment and transport, and to support education and health services. The energy story is also about the deep inequality of access to energy and how the benefits and costs of energy services are distributed across social groups and geographies. Furthermore, the industrial era driven by fossil fuels has come with considerable environmental and social costs. Fuel resources are often mined and converted into energy to bring ostensibly clean electricity and gas into the homes of affluent citizens while the waste generated by the production and conversion of fuel into energy is absorbed by upstream communities and made invisible to end users.[1]

© xmentoys | Adobe Stock

The current energy production and consumption model is complex, with inherently contradictory features. Proposed transitions will need to navigate the contextual factors underlying the different pathways to a sustainable energy future.

GEOPOLITICS AND ENERGY

The race to control energy resources led to a series of energy crises. Fifty years ago, Edward Heath's Three-Day Week – a policy designed in response to the 1973 oil crisis and industrial action by coal miners and railway workers – limited commercial electricity consumption by non-essential services and businesses.[2] At the time, the UK's electricity was generated by coal-burning power stations, and conserving energy and reducing electricity demand were seen as a sensible solution to help the country weather the energy crisis. A few years later, similar calls were made by US President Jimmy Carter on the importance of energy independence through conservation and investment in clean energy.

The early 1980s brought the defunding of renewable energy programmes in the USA, a watering down of standards, and more notably the transfer of ownership of energy assets such as power plants, transmission and electricity-distribution networks from public to private control. Environmental and social concerns were cast aside in the interest of the singular focus on economic growth and prosperity, policies which won the day. Demand for energy rose rapidly, as did the profligate consumption of materials, expanding beyond industrialised countries into other parts of the world. The world economy is now over five times the size it was in 1990 and 20 times larger than in 1970, a trend expected to endure as emerging economies continue to grow and new economic players such as China and India are drawn into the ambit of the global economic order.[3]

Today's global energy crisis, which began in the aftermath of the Covid-19 pandemic and was exacerbated by the Ukraine war, has come against a background of the growing threat of climate change to livelihoods and ecosystems everywhere. While the need to take action on reducing emissions and protecting the environment is self-evident, the pathways to delivering both climate and energy security solutions are fraught with difficulties. Political forces are polarised on policy directions and where to prioritise efforts. But with the immediate concerns of the rising cost of living – with energy prices contributing considerably to the problem – nearly three-quarters of Britons say that the cost of living should be prioritised over the environment and climate change, a significant drop from 2021.[4] Part of the challenge is that tackling climate change is often pitched head-to-head with other issues and against an enduring narrative that going green costs.

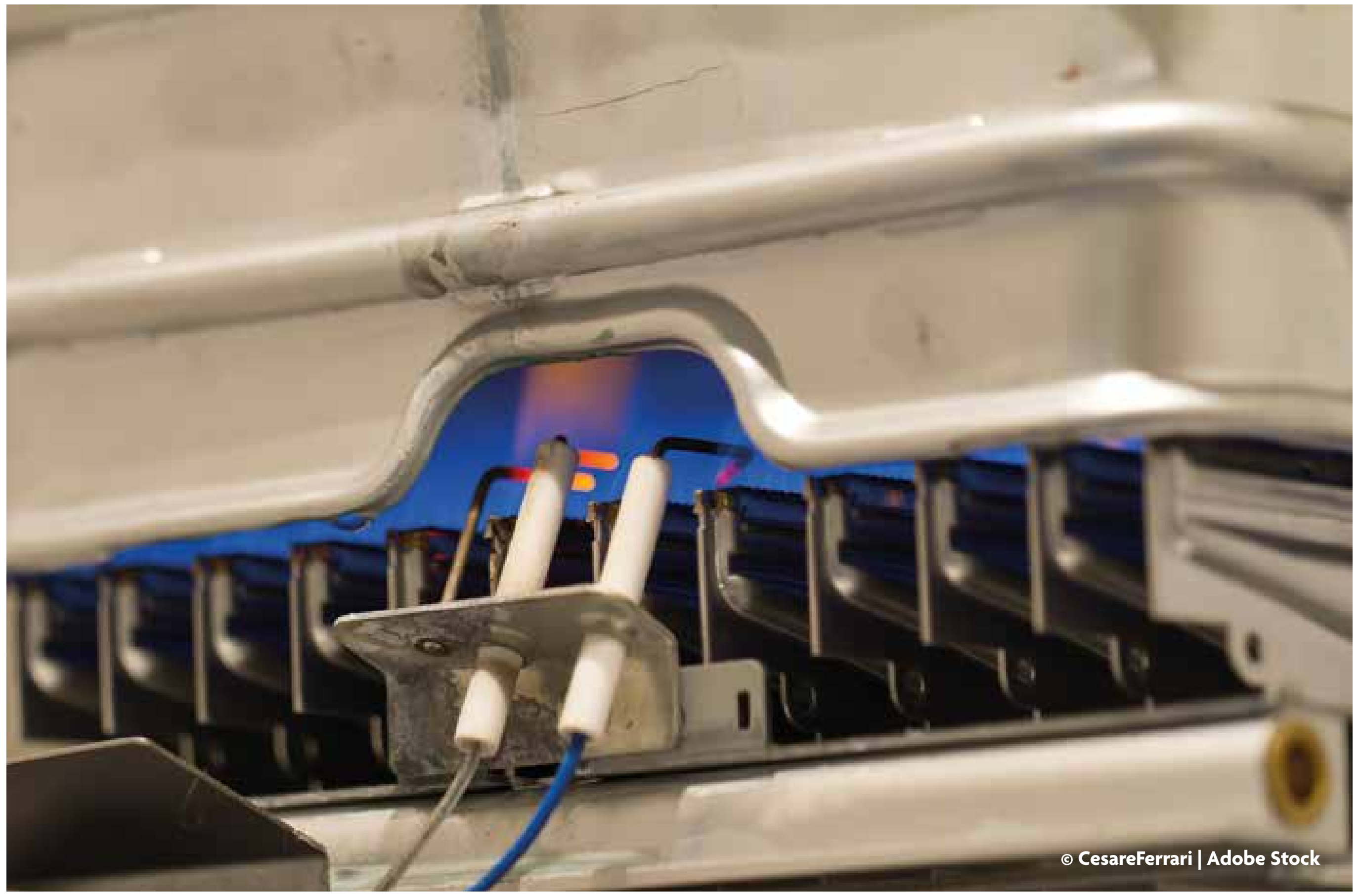
At the upstream end of the energy chain, soaring gas prices have led to huge profits for the five major oil companies, amounting to US$190 billion in 2022.[5] Downstream from fossil fuel extraction, energy network organisations in the UK, such as National Grid and the distribution network operators, have maintained high profit margins for several years while the public sees increasingly higher energy bills. This extractive model, which is at the heart of the energy system, has direct implications on the current challenges of tackling the high cost of living and taking positive climate action. Certainly, the war in Ukraine has been a major contributor to spiralling energy prices over the past year, but the problem is rooted in how the UK's energy system is organised.

CLIMATE CHANGE AS A KEY CONSTRAINT

Today, discussions about energy often take place in the shadow of climate change and development discourses. Scarcely a day passes without climate change being raised as an issue in energy policy debates. This is hardly surprising given the sobering assessment by climate scientists of the state of the global response to climate change. The Intergovernmental Panel on Climate Change Working Group 3 report notes that responses fall far short of what is required in terms of scale and speed to meet the Paris Agreement target of preventing the rise in global temperatures from reaching 1.5C above pre-industrial levels.[6] To make matters worse, total net greenhouse gas emissions have continued to rise during 2010–19, with 17 per cent of historical cumulative net CO_2 emissions since 1850 occurring during this period. Current policies, based on the voluntary pledges in the Paris Agreement's nationally determined contributions, put the world on track for a central estimate of around 3C warming above pre-industrial levels by 2100. This is clearly well above the 1.5C widely considered to be the threshold for dangerous levels of warming.

"Nothing short of a paradigm shift will do to make such a global energy transition possible across production and consumption systems."

Given that energy accounts for a significant share of greenhouse gas emissions, what the world does in response is central to the effort of achieving global net-zero emissions. Ending any further significant extraction of fossil fuels from existing reserves will be fundamental to limiting emissions – hence, no new oil and gas fields or coal mines should be approved for development.[7] Parallel to this, the rapid deployment



© CesareFerrari | Adobe Stock

of low-emissions energy sources and switching to alternative energy carriers, as well as energy efficiency and conservation, will be critical. For this to happen, a profound transformation of our economies, lifestyles and energy systems will be required at all scales. Nothing short of a paradigm shift will do to make such a global energy transition possible across production and consumption systems. Technology will play a crucial role in this endeavour, as will the deployment of new business models that are specifically designed to enhance wellbeing and limit pressure on ecosystems.[8] Lifestyle changes are also vital to anchoring this energy transition into our values and social practices.

TECHNOLOGICAL INNOVATION AS A CRITICAL DRIVER

In recent decades human development has been accompanied by rapid changes in technology.[9] This is shared by innovations in clean energy, where the pace of change seems to be progressing faster than policies are able to keep up. Innovations across a broad portfolio of options – such as integrating systems and increasing energy storage, smart grids, sustainable biofuels, low-carbon hydrogen and derivatives, and others – are currently taking place. The continued development of these technologies will be critical in accommodating large shares of renewables in energy systems, helping to deepen innovation and progressively reduce technology costs.

Already, a sharp reduction in the unit cost of key technologies has been achieved, notably wind and solar power and energy storage, enhancing the economic attractiveness of energy sector transitions through to 2030.[6] It is becoming increasingly evident that maintaining emissions-intensive systems may, in some regions and sectors, be more expensive than switching to low-emissions systems. Furthermore, there are unaccounted multiplier co-benefits that changes towards a low-emissions energy sector will bring, such as improvements in air quality, health and better access to education and energy (in regions such as Africa, for example).

Some 35 years ago the historian Melvin Kranzberg wrote that 'technology is neither good nor bad; nor is it neutral', acknowledging that humans, their values and worldviews play a role in shaping the development, application and uses of technology.[10] In line with this, technical developments in energy generation have environmental and social consequences (often unforeseen), and the same technology can have quite different results when introduced into different contexts or under different circumstances. For example, as the world pursues its low-emissions ambitions, the demand for critical minerals (including lithium, cobalt and nickel) needed for the green transition is expected to increase significantly by 2040.[11] Much of

INTRODUCTION

© Aleksandra | Adobe Stock

the mineral extraction will come from poorer and developing countries. A new arrangement based on shared benefits that allows poorer countries to capture some of the manufacturing value chain would go some way towards creating better partnerships. The world should be prepared for a managed transition that is fair and just.

SUSTAINABLE LIFESTYLES AND LIVELIHOODS

There are two broad stories for framing energy inertia. On the one hand are societies in industrialised countries where basic services are met but locked into high-consumption lifestyles that are based on carbon-intensive infrastructure. The average per capita energy consumption ranges from around 7,000 kg of oil equivalent (kgoe) in North America to about 3,500 kgoe in Europe.[12] In contrast, regions such as sub-Saharan Africa face major obstacles to accessing energy and widespread energy poverty problems, with an average per capita energy consumption of under 500 kgoe. Focusing policy interventions on *lifestyle change* in industrialised countries and *livelihood improvements* coupled with avoided future emissions in much of the global south would address context- and region-specific challenges.

Finally, a reformed and improved energy pathway will need to be directed by principles of equity and a recognition of true cooperation. The massive transformation required calls for a revolution of values that recognise the world faces a collective action problem and which challenge entrenched practices and power dynamics that perpetuate existing structural inequalities between and within countries and social groups. We already have the technical solutions to meet the energy challenge of the future. What is missing are the political will and imagination that recognise the social relations, cultural contexts and environmental limits that allow us to do so.

This edition hosts an eclectic collection of articles that investigate different parts and aspects of the energy system. This issue's articles focus on the complex technical and policy challenges we face as we aim to incorporate environmental and climate action into technological development and decisions on energy futures.

In the first article in this issue, Catherine Butler and Christina Demski demonstrate the pivotal role of public perceptions in energy policy, accentuating the need for inclusive decision-making.

Richard Heap then analyses the potential place of hydrogen in future energy systems, giving an overview of its complex set of benefits and drawbacks. Next, in a bioenergy case study, Rachel Smolker questions whether wood pellets should be considered a renewable fuel, investigating supply chains and the definition of carbon-neutral in the process. Pas Pallawela follows with a technical rundown of energy efficiency and storage, summarising a variety of methods and how these are important when looking at whole energy systems.

The pandemic proved that drastic action in the face of crisis is feasible. The same measures can – and must – be taken to ensure that clean and secure energy can be deployed at scale, says an analysis by Layla Sawyer. Continuing, Emily Wallace inspects the need for safe, climate-resilient energy generation, highlighting the importance of predicting and mitigating adverse weather.

Community cooperation and resource pooling has felt particularly important over the last year. Caitlin Mackesy Davies focuses in on a London borough creating local energy. Adrian Friday then looks at emissions embodied in everyday actions of modern life, revealing the true consumption of energy across information communication technologies.

Looking beyond hydropower as a purely positive form of renewable energy, Mark Everard weighs up 'the good, the bad and the ugly' dimensions of hydroelectric dams, accounting for wider social and environmental impacts. Finally, guest editor Ian Byrne sets out his road map to a green transition, underscoring the need for swift change. ES

Yacob Mulugetta is Professor of Energy and Development Policy at University College London. He has 30 years of research, teaching and advisory experience, specialising on the links between energy infrastructure provision and human welfare. He served as a Coordinating Lead Author of the Intergovernmental Panel on Climate Change (IPCC) 5th Assessment Report's (Working Group III on Mitigation) Energy Systems chapter and lead author of the IPCC 6th Assessment Report (Demand, Services & Social Aspects of Mitigation).

REFERENCES

1. Kapp, K.W. (1950) *The Social Costs of Private Enterprise.* Cambridge, MA: Harvard University Press.
2. UK Public General Acts (1973) Fuel and Electricity (Control) Act. https://www.legislation.gov.uk/ukpga/1973/67/contents/enacted (Accessed: 7 February 2023).
3. World Bank (no date) *GDP (current US$).* https://data.worldbank.org/indicator/NY.GDP.MKTP.CD (Accessed: 8 February 2023).
4. Smith, M. (2022) *What impact is the cost of living crisis having on support for tackling climate change?* https://yougov.co.uk/topics/politics/articles-reports/2022/10/12/what-impact-cost-living-crisis-having-support-tack (Accessed: 14 March 2023).
5. Common Wealth (2023) *Explainer: How Britain's energy system works — and why it needs an overhaul,* 31 January. https://www.common-wealth.co.uk/publications/explainer-how-britains-energy-system-works (Accessed: 25 February 2023).
6. Intergovernmental Panel on Climate Change (2022) *Climate Change 2022: Mitigation of Climate Change*. Contribution of Working Group III to the Sixth Assessment Report. P.R. Shukla, J. Skea, R. Slade, A. Al Khourdajie, R. van Diemen, D. McCollum, M. Pathak, S. Some, P. Vyas, R. Fradera, M. Belkacemi, A. Hasija, G. Lisboa, S. Luz and J. Malley (eds.). doi: 10.1017/9781009157926.
7. International Energy Agency (2021) *Net Zero by 2050. A Roadmap for the Global Energy Sector.* https://iea.blob.core.windows.net/assets/deebef5d-0c34-4539-9d0c-10b13d840027/NetZeroby2050-ARoadmapfortheGlobalEnergySector_CORR.pdf (Accessed: 25 February 2023).
8. Ribera, T. and Sachs, J. (eds) (2015) *Pathways to Deep Decarbonization. Executive Summary*. https://www.iddri.org/sites/default/files/import/publications/ddpp_exesum.pdf (Accessed: 25 February 2023).
9. United Nations Conference on Trade and Development (2022) *Technology and Innovation Report 2021.* Geneva: United Nations. https://unctad.org/system/files/official-document/tir2020_en.pdf (Accessed: 25 February 2023).
10. Kranzberg, M. (1986) Technology and history: 'Kranzberg's Laws'. *Technology and Culture*, 27 (3), pp. 544–560. https://doi.org/10.2307/3105385 (Accessed: 25 February 2023).
11. International Energy Agency (2022) *The Role of Critical Minerals in Clean Energy Transitions.* https://iea.blob.core.windows.net/assets/ffd2a83b-8c30-4e9d-980a-52b6d9a86fdc/TheRoleofCriticalMineralsinCleanEnergyTransitions.pdf (Accessed: 14 March 2023).
12. Data Commons (2023) *Place explorer.* https://datacommons.org/place/ (Accessed: 13 February 2023).

© Tony Baggett | Adobe Stock

FEATURE

Public perceptions of energy technologies: how do they influence energy policy?

Catherine Butler and **Christina Demski** examine the role of public opinion in shaping UK policies.

Energy policy is at the core of multiple contemporary environmental and social issues, including climate change, energy security and affordability, environmental degradation, health, and wellbeing more broadly. There is widespread recognition of the importance of public perceptions for energy policy but there is also significant debate about how to understand their influence and inclusion within decision-making.

There are many instances where public perceptions can be seen as pivotal in policy decisions, transforming existing approaches and even curtailing policies before they are implemented. Two key examples in the UK include shifts in the policy landscape for onshore windfarms and the abandonment of proposed changes to building regulations as part of energy efficiency policies. In a third example, the 2011 nuclear disaster in Fukushima, Japan, saw policy responses in Europe shaped by the nature of public opinion and debate within respective countries. In Germany, for instance, the decision was taken to accelerate the phase-out of nuclear energy, removing it from the system entirely by 2022.

In each of these cases, policy could be characterised as having been driven, to some extent, by public perceptions about these forms of energy system development. However, connecting with wider debates about public participation, it is possible to see how each example offers insights into a more complex set of relationships between public attitudes or perceptions and energy policy.

ONSHORE WIND AND ENERGY EFFICIENCY POLICY

The UK policy landscape for onshore wind has long been contentious, with analysts highlighting apparent differences between widespread public support for renewable energy technologies[1,2] and localised opposition

FEATURE


© Wirestock Creators | Adobe Stock

to specific developments.[3] This observation has in the past led some to conclude there is a nimby (not in my back yard) effect, but many have critiqued this as failing to account for the nature and complexity of public opposition to energy developments.[4] For example, Devine-Wright highlights how place-protective actions often arise from pre-existing emotional attachments and place-related identities that are threatened by new infrastructure developments such as wind farms.[5] In addition, empirical investigations have found only limited support for nimbyist responses, instead highlighting the need for more meaningful engagement in decision-making with diverse public values and concerns.

Though research has deepened understanding of public engagement with wind technologies, the UK policy landscape has reflected ongoing concern about local public consent and opposition particularly among rural communities. In 2015 changes to planning rules were introduced that meant an effective ban for onshore wind, with a 94 per cent decline in new projects and only two onshore wind turbines built in 2022.[6] This de facto ban has been the subject of contentious debate since its introduction given the relative low cost and effectiveness of onshore wind energy.[7] A reversal of the ban is currently under consultation with proposals that allow for planning applications to be submitted for new onshore wind by developers. Local community consent will still be required but is expected to be less restrictive than current regulations that mean opposition from one person can block a project.

All this appears to reflect an ongoing concern with the nature of public perceptions and support for onshore wind. However, it is important to highlight that the same principles have not been applied to the context for offshore wind. Major developments in offshore wind energy around the UK have been ongoing despite underpinning a fundamental reconfiguration of access to coastal resources and opposition from industries and groups such as fisheries and marine conservationists.[8] The nature of this opposition, however, is broadly constructed as coming from specific affected stakeholders and groups rather than from the wider local public that is invoked in the case of onshore wind.

The legitimacy created by and afforded to different interest groups in policy has been a topic of ongoing academic debate, with some arguing that dominant views of the public create closures around 'who gets to speak about energy transitions and how their visions will be interpreted and publicised' and, for this analysis, used in policy.[9] This first example can be utilised to highlight that, while there are clear and important relationships between public perceptions and policy, they are not always direct or straightforward. Instead, some ideas about public views are afforded greater legitimacy than others, with evidence of either support

© lazyllama | Adobe Stock

or opposition not always influencing policy-making. Rather, different interpretations of public perceptions relating to energy systems, and the legitimacy they are afforded, are heavily mediated by political and economic relations.

Much public perception research has focused on energy supply technologies, but the so-called demand-side of the energy system represents an equally important area for analysis. In the UK, in 2010, a flagship energy efficiency policy (named the Green Deal) was proposed and implemented based on a pay-as-you-save principle, whereby the upfront cost of works undertaken would be recouped through the savings on energy bills from efficiency measures. Alongside this, a consultation on building regulations was launched with proposals to extend existing regulation on energy efficiency to all properties. A media campaign subsequently conflated the policy and regulatory proposals coining the headline-grabbing phrase 'the conservatory tax' to characterise them.[10]

Though there were wider factors that contributed to the ultimate failure and withdrawal of the Green Deal policy and regulatory proposals, the media depiction and political perception of the public's response is generally regarded as a part of the story.[11] Here too, then, public attitudes played a role in shaping energy policy but with the focus on the news media perceived as a defining factor in shaping or characterising the public mood. This example showcases, once again, the complex relationship between public perception and policy, with alternative and diverse views of 'the public' and people's perceptions at play and, in this case, with the media cast as having a significant role.

NUCLEAR ENERGY

Turning to the final example and contrasting the UK's response with those of other nations, significant shifts in nuclear policy unfolded in the wake of public opposition following the Fukushima nuclear disaster. This is an interesting example to explore because different national contexts saw divergent responses despite this

© Paipai | Adobe Stock

being a global event. Some countries, such as Germany, announced an immediate phase-out of all nuclear power, while others, like the UK, adopted a narrative of enhanced safety and security.[12] In Germany's case, a pre-existing context of widespread public opposition saw plans for a nuclear power phase-out – which had been attenuated to support low-carbon targets – significantly ramped up with changes to the law that instituted a complete end to nuclear energy by 2022. This has subsequently required an extension, but the phase-out is on course for 2023.

By contrast, UK Government policy solidified plans for new nuclear development and contextualised the major accident within a message of continuous learning and improvement.[12] The current UK policy context sees continued support for and development of nuclear energy capacity, including smaller modular reactors, replacement of existing power stations, and innovation in nuclear fusion.[13,14] In this case, public opposition is, arguably, often cast as confined to specific interest groups and not afforded the legitimacy of an aggregate public perception, with no requirement for local support in the context of new developments as in the case of onshore wind energy. This suggests that policy responses may be reflective of entrenched policy trends and logics that are shaped more by existing political conceptions of public perceptions than they are by attentiveness to the shifting and emergent engagement with nuclear energy that followed the major accident.

HOW DO PUBLIC PERCEPTIONS INFLUENCE POLICY?

These examples all signify the importance of public attitudes and perceptions around energy policy but also paint a complex picture of what informs policy understanding about public views (e.g. media reporting, politics, polling and social research) and the roles they play in decision-making. Rather than seeing these relationships as straightforwardly characterised by translations of objectively measurable public views into policy, the examples give insight into the ways that constructions of public perceptions are highly political and brought into play or utilised in different ways within evolving energy policy contexts. Critical engagement with the ways in which public voices are used is likely to be an important precursor to developing governance processes that better support recognition and understanding of diverse public perspectives, which are crucial to sustainable, inclusive and socially just energy-system transitions. ES

Dr Catherine Butler is Senior Lecturer in Human Geography at the University of Exeter. Her research examines environmental governance including public engagement with energy and climate issues.

c.butler@exeter.ac.uk

@drcbutler

Dr Christina Demski is Reader in Psychology at the University of Bath. Her research examines public attitudes and acceptability towards environmental and energy issues as well as low-carbon futures.

cd2076@bath.ac.uk

@drcdemski

REFERENCES

1. Department for Business, Energy and Industrial Strategy (2021a) *BEIS public attitudes tracker.* https://www.gov.uk/government/collections/public-attitudes-tracking-survey (Accessed: 5 March 2023).
2. Demski, C., Butler, C., Parkhill, K.A., Spence, A. and Pidgeon, N.F. (2015) Public values for energy system change. *Global Environmental Change*, 34, pp. 59–69. https://doi.org/10.1016/j.gloenvcha.2015.06.014 (Accessed: 6 March 2023).
3. Boudet, H.S. (2019) Public perceptions of and responses to new energy technologies. *Nature Energy*, 4 (6), pp. 446–455. https://doi.org/10.1038/s41560-019-0399-x (Accessed: 6 March 2023).
4. Devine-Wright, P. (2005) Beyond NIMBYism: towards an integrated framework for understanding public perceptions of wind energy. *Wind Energy*, 8 (2), pp. 125–139. https://doi.org/10.1002/we.124 (Accessed: 6 March 2023).
5. Devine-Wright, P. (2009) Rethinking NIMBYism: the role of place attachment and place identity in explaining place-protective action. *Journal of Community & Applied Social Psychology*, 19 (6), pp. 426–441. https://doi.org/10.1002/casp.1004 (Accessed: 6 March 2023).
6. Renewables UK (2022) *UK's pipeline of onshore wind projects grows by 12% in last 12 months*, 7 September. https://www.renewableuk.com/news/616002/UKs-pipeline-of-onshore-wind-projects-grows-by-12-in-last-12-months-.htm (Accessed: 6 March 2023).
7. Department for Business, Energy and Industrial Strategy (2020) *Electricity generation costs (2020).* https://www.gov.uk/government/publications/beis-electricity-generation-costs-2020 (Accessed: 6 March 2023).
8. Haggett, C., ten Brink, T., Russell, A., Roach, M., Firestone, J., Dalton, T. and McCay, B.J. (2020) Offshore wind projects and fisheries: conflict and engagement in the United Kingdom and the United States. *Oceanography*, 33 (4), pp. 38–47. https://www.jstor.org/stable/26965748 (Accessed: 6 March 2023).
9. Chilvers, J., Pallett, H. and Hargreaves, T. (2018) Ecologies of participation in socio-technical change: the case of energy system transitions. *Energy Research & Social Science*, 42, pp. 199–210. https://doi.org/10.1016/j.erss.2018.03.020 (Accessed: 6 March 2023).
10. Richards, P. and Ares, E. (2012) *The 'Conservatory Tax'*. House of Commons Library. https://researchbriefings.files.parliament.uk/documents/SN06301/SN06301.pdf (Accessed: 6 March 2023).
11. Rosenow, J. and Eyre, N. (2016) A post mortem of the Green Deal: austerity, energy efficiency, and failure in British energy policy. *Energy Research & Social Science*, 21, pp. 141–144. https://doi.org/10.1016/j.erss.2016.07.005 (Accessed: 6 March 2023).
12. Butler, C., Parkhill, K.A. and Pidgeon, N.F. (2011) Nuclear power after Japan: the social dimensions. *Environment: Science and Policy for Sustainable Development*, 53 (6), pp. 3–14. https://doi.org/10.1080/00139157.2011.623051 (Accessed 6 March 2023).
13. Department for Business, Energy and Industrial Strategy (2021b) *Net Zero Strategy: Build Back Greener*. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1033990/net-zero-strategy-beis.pdf (Accessed: 6 March 2023).
14. Department for Business, Energy and Industrial Strategy (2022) *Site of UK's first fusion energy plant selected.* https://www.gov.uk/government/news/site-of-uks-first-fusion-energy-plant-selected (Accessed: 6 March 2023).

The role of hydrogen in decarbonising the energy sector

ANALYSIS

Richard Heap analyses the challenges and benefits of hydrogen in a future energy system.

HYDROGEN IS NOT NEW TO THE ENERGY SYSTEM

Hydrogen has been part of the energy system for over 150 years. Now, the drive towards decarbonisation has given it new impetus, attracting considerable investment and support from government research, demonstration and deployment programmes.

Until the 1970s, domestically, hydrogen was a major component of town gas – an artificial gas comprised of equal parts hydrogen and carbon monoxide that was used for cooking, heating and lighting. Produced primarily from coal in local and regional facilities, this highly toxic fuel was phased out following the discovery of natural gas fields in the North Sea in the mid-1960s and the subsequent development of a methane-based national gas network.[1]

© Hand Robot | Adobe Stock

ANALYSIS

Hydrogen as a fuel has been proposed for use in a range of applications across the energy system, including transport and heating in buildings, but it has struggled to compete against existing, more widely used technologies. Despite this, hydrogen is still a major global industry, used in oil refining and chemicals production, such as ammonia and fertilisers. About 94 million tonnes of hydrogen are produced globally each year.[2]

Hydrogen is being considered for a wide range of uses within the energy system and offers many appealing characteristics. However, its potential is contentious, particularly in some applications where it competes with alternative technologies and approaches. Numerous factors must be considered in determining the extent to which hydrogen will be used in our future energy system.

PHYSICAL ATTRIBUTES

Hydrogen is an abundant element, but to become a usable fuel it requires energy to extract it from a variety of possible feedstocks. Fossil fuel hydrocarbons supply most current hydrogen production although biomass options are being developed. Alternatively, hydrogen can be extracted from water, primarily through electrolysis.

Hydrogen is versatile and flexible, offering potential uses across the energy system (as well as a possible feedstock for the chemical industry). It can have characteristics similar to electricity or be used like a fuel, such as natural gas. It can be either burned for heat and power, including in a gas turbine or an internal combustion engine, or converted to electricity using a fuel cell. Like natural gas, hydrogen can be stored at a range of volumes, allowing fluctuations in production and demand to be separated to provide a valuable service for intermittent renewable generation. Hydrogen can also be piped long distances, although its chemical nature and small molecular size mean research is needed to test its compatibility with the existing pipe system and to develop new standards where necessary.[3]

One of hydrogen's big appeals for decarbonisation is that, like electricity, it is clean at the point of use, producing only water (although it burns at a high temperature and could produce nitrogen oxides, which are powerful greenhouse gases). However, not all hydrogen production options are clean.

THE APPEAL OF HYDROGEN

Hydrogen technologies offer attractive benefits, providing the convenience and familiarity of current systems, such as domestic heating controls and rapid vehicle refuelling. For transport, hydrogen vehicles could deliver the same clean, low-noise benefits as a battery electric vehicle (BEV) but with faster refuelling to address the challenges of battery recharging, particularly for long-distance journeys. Several countries (e.g. China, Korea, Germany, USA) are rolling out refuelling stations to support deployment. This may prove attractive, but it is competing against the diverse range of charging locations, including at home, that are being rolled out for BEVs. Globally by the end of 2021, there were about 51,000 hydrogen fuel-cell vehicles on the road, compared to over 16 million BEV or plug-in hybrid EVs.[4]

Hydrogen fuel-cell trains are being deployed on railway lines where electrification would be expensive or technically difficult.[5,6] In warehouses, fuel-cell trucks deliver improved duty cycles, as rapid refuelling avoids the downtime needed for battery recharging. In buildings, fuel cells provide clean, quiet combined heat and power, replacing gas boilers. On-site hydrogen storage is also capable of acting as a back-up power system.

Projects such as the UK's HyNet North West,[7] Zero Carbon Humber[8] and H100 Fife[9] are currently exploring the potential to distribute hydrogen through the gas network with the aim of decarbonising domestic, commercial and industrial heat. Initially this could be through blending hydrogen with the existing fuel: natural gas. Most domestic appliances could tolerate up to a 20 per cent blend. Higher percentages would require modifying or replacing equipment, as hydrogen burns differently to natural gas. Older parts of the gas network composed of iron would need to be upgraded or replaced with plastic pipes to reduce hydrogen leakage and bring the safety risks to the same level as for the current natural gas network.[10] A domestic hydrogen boiler could provide heat and hot water in the same way as an existing gas boiler while maintaining resilience for householders by retaining the diversity of energy forms.[11]

Developments are underway to use hydrogen in aviation.[12] Similarly, hydrogen is being considered as a fuel in shipping . In both cases, the storage of sufficient hydrogen for the fuel to be practically and commercially viable is a major challenge , although it is likely to be more feasible than using batteries alone. To overcome this, hydrogen could be combined with other compounds to make synthetic fuels. One option is to use atmospheric carbon dioxide (CO_2) to produce fuels that are almost identical to current hydrocarbons. These fuels could

▼ **Table 1. Hydrogen colour codes determined by feedstock, process and associated carbon emissions. There is some variation in the exact definitions, particularly for biomass feedstocks and for yellow hydrogen, which some define as electricity from a variety of renewable and fossil fuel sources. Data derived from National Grid[15] and Ricardo[16]**

Colour	Feedstock	Process	Greenhouse gas emissions
White	Naturally occurring geological		
Green	Renewable electricity	Electrolysis	Minimal
Yellow	Solar	Electrolysis	Minimal
Pink	Nuclear power	Electrolysis	Minimal
Red	Nuclear power	Catalytic splitting	Minimal
Turquoise	Biomass	Biomass conversion	Dependent on feedstock, process and use of carbon capture and storage
	Natural gas	Pyrolysis	Solid carbon
Blue	Natural gas (some include other fossil fuels)	Carbon capture and storage & steam-methane reforming or gasification	Low
Grey	Natural gas	Steam-methane reforming	Medium
Brown	Brown coal (lignite)	Gasification	High
Black	Black coal	Gasification	High

be tailored to specific needs and dropped into existing fuel systems. The additional cost of producing synthetic fuels, however, would have to offset their utility benefits.

A hydrogen system can also provide services to the electricity grid, improving the potential of intermittent renewable energy and balancing out shortfalls. Electrolysers can soak up surplus electricity from renewables when generation exceeds demand. This hydrogen could be stored and called upon to generate electricity when wind or solar resources are unavailable. The flexibility of hydrogen means that any surplus could be used by other parts of the energy system. However, while much has been made of the potential of this surplus electricity, modelling suggests that the percentage generated may only amount to about 10 per cent of the potential demand from passenger vehicles.

IS HYDROGEN A GREEN FUEL?

Determining whether hydrogen is green requires consideration of a wide range of aspects that go beyond how it is produced. Like electricity, hydrogen is clean at the point of use, producing only water, but the impacts of how both are produced and the feedstock that is used in the production of hydrogen vary greatly. Consideration should also be given to the effects that each production method has on the overall energy system, and implications for supplying the different

© Alexey Rezvykh | Adobe Stock

feedstocks, whether it be sustaining fossil fuel use or enlarging the electricity supply system, as well as the new international trade routes that might develop.

An array of methods can be used to produce and distribute hydrogen. Not all are low-carbon, and a rainbow of colours is being used to illustrate the carbon emissions associated with different production methods (see **Table 1**). Hydrogen can be extracted from various feedstocks, each requiring the establishment of new supply chains and infrastructure.

The huge scale of the new energy infrastructure and supply chains required for decarbonised energy means the efficiency of the systems need to be considered against the service they provide.

PRODUCTION

About 50 per cent of current hydrogen production uses natural gas as a feedstock; the rest uses oil and coal, with only 4 per cent produced using electricity. Using a mature process, steam-methane reforming produces low-cost hydrogen. The hydrogen it produces is classified as grey since the process emits CO_2 during the splitting of the hydrocarbon and from the natural gas used to power it. The result is that the emissions are higher per unit of energy than from using natural gas directly. The carbon impact could be reduced to produce blue hydrogen by adding carbon capture and storage (CCS). However, this is only expected to capture 90 per cent of emissions because of the high cost of reaching 100 per cent.[17] CCS itself adds inefficiencies to the system and carries the risk of CO_2 leakage. Concerns have been raised about the use of CCS particularly where viable alternatives exist, although developing the infrastructure now may prove valuable for enabling the growth of technologies that remove carbon directly from the atmosphere.[18] A further upstream source of emissions is from the gas wells, which could amount to 15 per cent of emissions from the resulting hydrogen.[19] While these emissions can be reduced through best practice, they are hard to eliminate.

Fossil fuels, particularly natural gas, are likely to be the main source of early hydrogen supplies. With the additional energy input to fuel the process, the effect will be to increase overall demand for natural gas, with implications for energy security. Ongoing development is seeking to improve the efficiency of the production process and increase CO_2 capture rates, but the feedstock dependency remains.

Biomass is being explored as an alternative source of hydrocarbons.[20] While various biomass feedstocks present technical challenges, the inefficiencies in the process will increase demand for biomass compared to using it for electricity generation. Research is underway[21] as to whether CCS can be added to biomass-produced hydrogen to deliver negative emissions.[22] However, the environmental and land impacts are highly debated, with concerns raised about the use of forest biomass and whether it can be used sustainably for extensive energy production.[23]

Green hydrogen produces minimal greenhouse gas emissions. The main production technology is electrolysis, which uses renewable electricity to split water into hydrogen and oxygen. Electrolysers have been around for decades but the hydrogen produced is more expensive than that from fossil fuel feedstocks. Improvements in efficiency and industry scale-up will reduce costs, with some analysis suggesting it will be cost competitive with blue and grey hydrogen by 2050,[24] although others think it will remain higher over the next three decades.[25] A significant part of the cost is the electricity used. Using surplus electricity from renewables will make green hydrogen from electrolysis more competitive, but there are competing uses for this cheap electricity, such as batteries and demand-side response, which will limit its availability for hydrogen production. Analysis suggests this is likely to be limited because much of the surplus comes in surges, which are expensive to capture.[26]

Using electrolysis for large-scale production of hydrogen will therefore require a dedicated renewables-fed generation capacity. The ability to store hydrogen means production can be separated from demand, allowing it to easily accommodate the inherent variability in the output from wind and solar power.

Hydrogen can also be produced through thermochemical processes, using high temperatures to split water. Research projects are also exploring the potential of using high-pressure steam from nuclear power stations to produce hydrogen as a by-product.

IMPORTING HYDROGEN

Another option is to import hydrogen instead of producing it locally, potentially developing an international trade in the gas, similar to that for oil and gas. This would allow hydrogen to be produced efficiently in fixed locations using dedicated renewables, such as solar power, and then be shipped or piped to meet demand. Long-distance pipe networks have been proposed.[27] There are two constraints to this: the small size of hydrogen molecules leads to higher losses compared to natural gas, and the required operating pressures means the potential to store energy in the pipes is reduced.

Alternatively, hydrogen can be shipped. Liquifying hydrogen increases the energy density, and therefore the amount of fuel that can be moved per vessel, although it is considerably lower than can be achieved using a comparable volume of liquified natural gas. Hydrogen liquefaction also requires high pressures and sustained very low temperatures that create a significant energy penalty, which could be as much as 30–40 per cent of its energy content compared to 10 per cent for liquified natural gas. Even with insulation to keep storage tanks cold during transit about 3–5 per cent of the hydrogen is lost per voyage to boiloff.[19] These factors could double the cost of hydrogen.

Converting hydrogen into a more stable form, such as ammonia, or combining it with CO_2 taken from the atmosphere to create synthetic hydrocarbon fuels are being explored to improve energy density, reduce transport loses and lower costs.[28] However, the benefits and savings must be balanced with the additional energy input that these processes require, which reduces the overall energy efficiency and raises the cost of hydrogen.[29]

EFFICIENCY

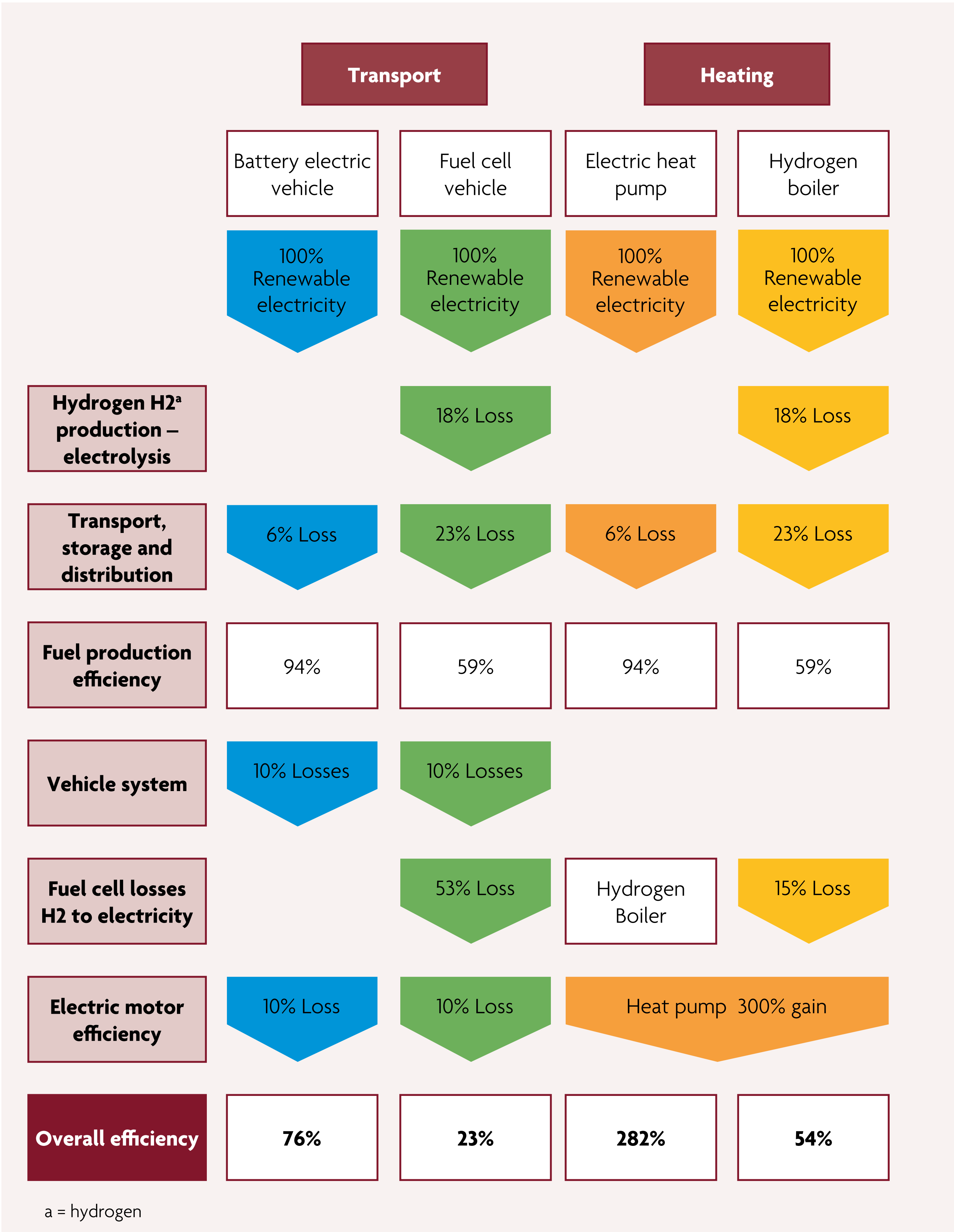
While hydrogen offers a range of favourable services, at a system level it is inherently inefficient compared to other decarbonisation options, particularly electricity. This inefficiency raises operating costs and leads to upstream impacts on infrastructure and feedstock supplies. While technology developments and investment are leading to improvements, the additional conversion stages limit what can be achieved.

The main loses come from hydrogen production stages, but there are also losses during storage and transmission (see **Figure 1**). The end-use technology can lead to further losses. While a hydrogen electric vehicle might be lighter than a BEV, the energy loss from the onboard conversion of hydrogen to electricity offsets the benefits. Burning hydrogen for heat has similar efficiencies to natural gas at the point of combustion. However, a fully electric heating system uses a heat pump that can deliver 3–4 times the heat output for each unit of energy consumed. A limitation of a heat pump system is that the temperature output may be lower, although this can be compensated for through modifications to the heating system's operation.

INFRASTRUCTURE DEMANDS

The impact of the inherent inefficiency of hydrogen compared to other fuels is that it increases the upstream energy demand and associated energy infrastructure. If hydrogen were to replace natural gas there is a risk of increasing dependence on fossil fuel consumption. This may be necessary in the short term to enable the hydrogen sector to develop. Allowing investment in gas-based hydrogen production assets beyond the short-term risks locking in long-term dependency on natural gas consumption, upstream emissions and dependency on the CCS industry to dispose of the resulting CO_2 emissions.

ANALYSIS



▲ **Figure 1. Comparison of fuel system efficiencies for heat and transport. Additional fuel conversion steps for hydrogen in both transport and heat reduce its overall efficiency. Hydrogen and natural gas boilers have similar efficiencies, whereas heat pumps provide substantial energy gains. (Source: Energy Research Partnership[30])**


© Pavel Kašák | Adobe Stock

Producing green hydrogen from renewables requires the construction of a dedicated generation capacity. To complicate matters, the systemic inefficiencies of hydrogen would require the construction of additional capacity compared to an all-electric system.

THE FUTURE FOR HYDROGEN

Hydrogen is expected to play a role in a future energy system, particularly in sectors that experience significant technical and commercial limitations, such as aviation and shipping. An all-renewable, electric energy system has many challenges to address including the need to tackle short and long-term intermittence from renewables. Hydrogen could play a critical role in providing services to the electricity grid, such as energy storage, particularly where very large volumes of energy need to be stored for long periods of time. The investment drive into hydrogen is leading to new production methods and could address current efficiency losses.

It is unclear whether hydrogen will become the future system fuel. In Japan, a major roll-out of hydrogen was planned, including a 2030 pathway with targets for volume and cost of production and for number of fuel cells deployed. Uptake has been substantially lower than expected; consumers prefer BEVs and homeowners have opted for cheaper and more efficient heat pumps rather than use fuel cells that provide heat and power.[31]

However, it is early days in the challenge to decarbonise the energy system, and the technical, economic, commercial, environmental and social challenges are beginning to emerge. The alternative decarbonisation routes are not without their own wider environmental and societal impacts. Although it is hard to predict how society will respond as the climate continues to change, weaning the economy off the existing gas- and oil-based energy systems presents substantial challenges. For example, converting homes to use heat pumps instead of gas-fed boilers raises significant economic and societal challenges. The timescales in which to accomplish decarbonisation are also demanding and achieving a wholly renewable energy system may be much harder to realise than decarbonisation. While a full hydrogen economy may be unlikely, hydrogen could still play an important role in achieving the long-term transition. **ES**

Richard Heap is an experienced analyst managing technical and cross-cutting projects. At the Royal Society he led projects on ocean acidification, biofuels, and geoengineering. At the Energy Research Partnership he produced reports on CO_2-Enhanced Oil Recovery, the heat transition, hydrogen and public engagement. His current freelance work uses futures techniques with public and stakeholder engagement to inform policy and regulatory development, with a specific focus on carbon removal.

ANALYSIS

REFERENCES

1. Thomas, R.C.S. (2014) Gas production over the last 200 years: friend or foe? *Environmental Scientist*, 23 (1), pp. 8–15. https://www.the-ies.org/sites/default/files/journals/env_sci_feb_14.pdf (Accessed: 10 March 2023).
2. International Energy Agency (2022) *Hydrogen*. https://www.iea.org/reports/hydrogen (Accessed: 10 March 2023).
3. National Gas (no date) *FutureGrid*. https://www.nationalgas.com/insight-and-innovation/transmission-innovation/futuregrid (Accessed: 10 March 2023).
4. International Energy Agency (2022) *Global EV outlook 2022*. https://www.iea.org/reports/global-ev-outlook-2022 (Accessed: 13 March 2023).
5. Szondy, D. (2018) *World's first hydrogen fuel cell-powered train enters service*. https://newatlas.com/worlds-first-hydrogen-fuel-cell-train-service/56372/?itm_source=newatlas&itm_medium=article-body (Accessed: 10 March 2023).
6. Blain, L. (2023) *China launches 100-mph hydrogen/supercapacitor train.* https://newatlas.com/transport/china-hydrogen-supercapacitor-train/ (Accessed: 10 March 2023).
7. HyNet North West (no date) Home page. https://hynet.co.uk (Accessed: 10 March 2023).
8. Zero Carbon Humber (no date) Home page. https://www.zerocarbonhumber.co.uk (Accessed: 10 March 2023).
9. H100 Fife (no date). Home page. https://www.h100fife.co.uk (Accessed: 10 March 2023).
10. H21 (no date) *H21 NIC – Phase 1*. https://h21.green/projects/h21-nic-phase-1/ (Accessed: 10 March 2023).
11. Worcester Bosch (no date) *Hydrogen-fired boiler.* https://www.worcester-bosch.co.uk/hydrogen (Accessed: 10 March 2023).
12. Department for Transport (2022) *Jet zero strategy: delivering net zero aviation by 2050*. https://www.gov.uk/government/publications/jet-zero-strategy-delivering-net-zero-aviation-by-2050 (Accessed: 13 March 2023).
13. Committee on Climate Change (2019) *Letter: International aviation and shipping and net zero.* https://www.theccc.org.uk/publication/letter-international-aviation-and-shipping/ (Accessed: 13 March 2023).
14. Hilderman, V. (2022) *Comment: Addressing the challenges of hydrogen-based aviation.* https://www.theengineer.co.uk/content/opinion/comment-addressing-the-challenges-of-hydrogen-based-aviation (Accessed: 13 March 2023).
15. National Grid (no date) *The hydrogen colour spectrum.* https://www.nationalgrid.com/stories/energy-explained/hydrogen-colour-spectrum (Accessed: 10 March 2023).
16. Ricardo (2021) *Cracking hydrogen colour codes*. https://www.ricardo.com/en/news-and-insights/insights/hydrogen-colour-codes-explained (Accessed: 10 March 2023).
17. Department of Business, Energy and Industrial Strategy (2018) *Hydrogen supply chain: evidence base*. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/760479/H2_supply_chain_evidence_-_publication_version.pdf (Accessed: 10 March 2023).
18. Lomax, G., Lenton, T.M., Adeosun, A. and Workman, M. (2015) Investing in negative emissions. *Nature Climate Change*, 5 (6), pp. 498–500. doi: 10.1038/nclimate2627.
19. International Energy Agency (2022) *The Role of Low-Carbon Fuels in the Clean, Energy Transitions of the Power Sector*. https://iea.blob.core.windows.net/assets/01ca16c8-e493-475c-81c4-04ac5d3b9882/Theroleoflow-carbonfuelsinthecleanenergytransitionsofthepower-sector.pdf (Accessed: 10 March 2023).
20. Lepage, T., Kammoun, M., Schmetz, Q. and Richel, A. (2020) Biomass-to-hydrogen: a review of main routes production, processes evaluation and techno-economical assessment. *Biomass and Bioenergy,* 144 (105920). doi:10.1016/j.biombioe.2020.105920.
21. Department of Business, Energy and Industrial Strategy (2022) *Government launches new scheme for technologies producing hydrogen from biomass.* https://www.gov.uk/government/news/government-launches-new-scheme-for-technologies-producing-hydrogen-from-biomass (Accessed: 10 March 2023).
22. Committee on Climate Change (2018) *Biomass in a Low-Carbon Economy.* https://www.theccc.org.uk/wp-content/uploads/2018/11/Biomass-in-a-low-carbon-economy-CCC-2018.pdf (Accessed: 10 March 2023).
23. European Academies Science Advisory Council (2017) *Multi-functionality and Sustainability in the European Union's Forests.* https://easac.eu/publications/details/multi-functionality-and-sustainability-in-the-european-unions-forests/ (Accessed: 10 March 2023).
24. Simon, N., McCurdy, M. and Larson, H.M. (2021) *Examining the current and future economics of hydrogen energy*. https://www.icf.com/insights/energy/economics-hydrogen-energy (Accessed: 10 March 2023).
25. Department of Business, Energy and Industrial Strategy (2021) *Hydrogen production costs 2021.* https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1011506/Hydrogen_Production_Costs_2021.pdf (Accessed: 10 March 2023).
26. Boston, A. and Thomas, H. K. (2015) *Managing Flexibility whilst Decarbonising the GB Electricity System.* Energy Research Partnership. https://erpuk.org/project/managing-flexibility-of-the-electricity-sytem/ (Accessed: 10 March 2023).
27. International Energy Agency (2023) *Energy Technology Perspectives 2023.* https://iea.blob.core.windows.net/assets/a86b480e-2b03-4e25-bae1-da1395e0b620/EnergyTechnologyPerspectives2023.pdf (Accessed: 10 March 2023).
28. Collins, L. (2022) Why shipping pure hydrogen around the world might already be dead in the water. *Recharge*, 27 January. https://www.rechargenews.com/energy-transition/special-report-why-shipping-pure-hydrogen-around-the-world-might-already-be-dead-in-the-water/2-1-1155434 (Accessed: 10 March 2023).
29. El Kadi, J., Smith, C. and Torrente-Murciano, L. (2020) H2 and NH3 – the perfect marriage in a carbon-free society. *The Chemical Engineer,* 948. https://www.thechemicalengineer.com/features/h2-and-nh3-the-perfect-marriage-in-a-carbon-free-society/ (Accessed: 10 March 2023).
30. Heap, R.J. (2016) *Role of Hydrogen in the Future Energy System.* https://erpuk.org/project/hydrogen/ (Accessed: 10 March 2023).
31. Renewable Energy Institute (2022) *Re-examining Japan's hydrogen strategy: moving beyond the 'hydrogen society' fantasy*. https://www.renewable-ei.org/en/activities/reports/20220922.php (Accessed: 10 March 2023).

CASE STUDY

Wood pellets for industrial bioenergy

Rachel Smolker asks whether burning wood should continue to be supported as a renewable fuel.

Traditional bioenergy – the use of wood for cooking and heat, for example – remains important to the livelihoods of many people. Modern bioenergy, however, bears little resemblance to that and includes liquid biofuels such as ethanol from corn and sugar cane, biodiesel made from fats and oils and biomass, primarily wood.

Burning wood is an ancient practice, used to provide heat and fuel for cooking, for charcoal production and for forging metal. With growing recognition of climate change and the role of fossil fuel combustion, there is a booming new trend: burning wood pellets and chips (also known as biomass) at industrial scale for heat and power. This is often referred to as modern bioenergy and is subsidised through climate policies as a renewable, low-carbon or carbon-neutral practice.

Pinnacle/Drax Pellet Plant. (© STAND.earth)

For policy-makers and others working to transition away from fossil fuels, wood bioenergy is often promoted as the alternative, both explicitly and implicitly (i.e. by failing to exclude it as an option). Wood combustion, including in partially or fully converted coal-fired power plants, is classed as a renewable fuel alongside wind and solar, and is almost entirely dependent on subsidies linked to climate and renewable energy policies, including exemption from carbon taxes.

Industry spokespeople claim that they only use 'residues' from pre-existing forestry practices, such as limbs, sawdust or mill ends for example.[1] But that claim can be challenged by looking at the pellet facilities, where whole trees are laid out in stacks prior to chipping and processing. Logging practices have intensified to accommodate the new demand. Now in many places trees that are not suitable for timber production or other higher-value uses are harvested for biomass and classed as residue. Diversion of true residues from logging and sawmills to biomass in some cases displaces pre-existing uses, ultimately, if indirectly, driving more logging. Industrial-scale wood bioenergy is gaining traction around the globe under increasing pressure on nations to reduce their greenhouse gas emissions. But does it achieve this goal?

THE IMPACTS OF BURNING WOOD FOR POWER

The EU provides a good case study given its early adoption of wood combustion subsidisation policies. A recent analysis concluded that the treatment of biomass as a preferred, subsidised, zero-carbon fuel has driven a steep increase in wood pellet use by 239 per cent in 2020 from a 1990 basis. At the same time, the use of wood within the energy sector for heat and power has increased by over 1,000 per cent, within industry by 185 per cent and in residential and commercial heating by 167 per cent. Most of these increases have taken place since 2002, when the EU first introduced policies promoting biomass as a renewable fuel.[2]

Where does all this wood come from? Much of it is imported, hence a rapidly expanded international trade in wood pellets. A case in point is Drax Group, which operates the UK's largest power station and has converted four of its six units to burn wood, making it the world's largest wood burner. In 2021, Drax burned pellets from some 16.6 million tonnes (wet weight) of green wood, most of which was shipped from the south-eastern USA, Canada and Baltic states. In return, Drax received almost £1 billion in direct subsidies, derived from a surcharge to ratepayers.[3]

The scale of Drax's biomass plant may be unique, but the model is not. Germany, the Netherlands, Denmark, Portugal, Finland and Sweden among others all have major biomass heat and power facilities or plans to develop them, with many relying on wood imports.

▲ **US Southeast: Dogwood Alliance has documented transport of logs from these clearcuts to an Enviva pellet manufacturing plant. (© Dogwood Alliance)**

Europe is not alone. Japan and South Korea have rapidly emerging biomass power industries and are importing large quantities of pellets from Canada, Vietnam and elsewhere in Asia.

Industry analysts report that global pellet trade grew by 50 per cent between 2017 and 2021 to a record 29 million tonnes.[4] The International Energy Agency reports that bioenergy currently supplies about 10 per cent of global primary energy. This includes traditional use of wood for cooking and heat. Its assessment of how to achieve net-zero emissions suggests that modern industrial wood bioenergy would need to increase by 60 per cent by 2050 from current levels.[5]

Drax has established itself not only as a power company, but as the world's second-largest pellet producer, supplying its UK power station and exporting globally from pellet plants in the south-eastern USA and Canada's British Columbia and Alberta provinces. The world's leading wood pellet manufacturer is Enviva Pellets, with 10 manufacturing facilities across the south-eastern USA. These facilities, often located in low-income communities, are noisy, prone to fire outbreaks and explosions, and repeatedly violate their emissions to air permit limitations set out under the Clean Air Act.[6]

Vast areas of the south-east USA have been converted by the pulp industry from formerly biodiverse forest ecosystems to industrial-scale pine-tree monocultures. Current estimates are that about one-third of the forest area in the south-east now consists of pine plantations.[7] The pulp industry has largely shifted elsewhere, leaving behind these plantations, which are now viewed as a source of wood pellets for European power plants. An investigation by environmental organisations and investigative reporters as well as a recent Enviva whistle-blower revealed that the company is sourcing wood not only from pine plantations but also from clear-cuts in areas of rare remaining forests in the North Atlantic Coastal Plains, one of only two recognised global biodiversity hotspots in the USA.[8,9]

Canada also has become a major exporter of pellets to Europe and more recently to Asia, where demand is growing fast. Investigations in Canada revealed that pellet facilities source wood supplies from areas identified as primary old-growth forests and endangered species habitats.[10] These old-growth forests are rare temperate rainforests – one of the world's most important major carbon sinks – which are being cut and turned into pellets. Another significant source of pellets is the Baltic states, where Graanul Invest operates. Here, pellet production has been linked to an overall increase in logging, including in high conservation value forests, watersheds and peatlands. Logging in Estonia is so intense that, according to Government figures, the forest has become a net source of carbon emissions.[11]

In short, where bioenergy is classed as renewable, the new demand for renewable energy, and the subsidies provided for it, are creating a major new driver of forest degradation, destruction of wildlife habitats and loss of carbon sinks.

CLIMATE IMPACTS

Wood bioenergy is falsely assumed to reduce emissions relative to fossil fuels. This is due to a carbon accounting error, first detailed in 2009.[12] Concerns were raised that emissions from bioenergy might be double counted if reported under both the land use sector (where crops or trees are grown and harvested) and the energy sector (where they are burned to produce energy). As policies for accounting were developed under the United Nations Framework Convention for Climate Change, and the policies that followed, this concern ultimately resulted in a failure to account for bioenergy emissions under *either* energy *or* land sector. Ultimately, this led to a broadly accepted misrepresentation that greenhouse gas emissions from bioenergy are nonexistent.

However, debates over the climate impacts of biomass energy have been ongoing. Industry interests and policy-makers continue to claim that wood bioenergy is carbon neutral: in their models, they claim that when a tree is cut and burned for power, it releases carbon into the atmosphere; however, a new tree will replace it, absorbing the same amount of carbon from the atmosphere, thus making the process neutral.

This simplistic model is fraught with error. The reality is that logging removes trees that would otherwise continue to sequester carbon. Furthermore, additional carbon is released at various stages of the process, including:

- By the harvesting equipment;
- From soil disturbance during harvesting;
- When the wood is transported to a processing facility;
- From the processing energy used to dry, chip and compact pellets;
- When pellets are shipped overseas; and
- As pellets are transported from port to power station and burned.

Even when measuring only the smokestack emissions where the pellets are burned, ignoring all other sources, more carbon is emitted per unit of energy produced than from coal.

Meanwhile, new trees may or may not grow. Degradation of forests and soils where harvesting has occurred often limits potential regrowth, as can the escalating impacts of climate change itself. If trees do grow back, it may take decades or even centuries to re-absorb an amount of carbon that is roughly equivalent to what was released. The carbon neutrality myth has been repeatedly refuted by scientists over many years. In February 2021, over 500 scientists wrote an open letter to world leaders stating that:

> 'Regrowing trees and displacement of fossil fuels may eventually pay off the carbon debt, but regrowth takes time the world does not have to solve climate change. As numerous studies have shown, this burning of wood will increase warming for decades to centuries. That is true even when the wood replaces coal, oil or natural gas.'[13]

We have long been taught about the key roles of forests as the planet's lungs, carbon sinks, essential elements in maintaining freshwater resources and the hydrological cycle, and life-supporting habitats for much of the Earth's biodiversity. Protecting and restoring forests has been prominently emphasised in climate policy. For example, carbon markets very often feature forests and tree planting as offsets for carbon emissions (though they have been shown to be ineffective, or worse).[14] The concept of nature-based solutions including the potential role of forest protection has gained attention. Yet simultaneously, pressure is mounting to expand biomass power, increasing rather than decreasing deforestation and forest degradation, under the guise of providing a climate solution that is based on a well-known carbon accounting error.

Burning wood biomass has been attractive in part as a way of preventing existing infrastructure like the Drax coal-fired plant from becoming a stranded asset. It is also favoured because it is not as vulnerable to intermittency in the same way as wind and solar, and can provide baseload energy, smoothing supply to the grid as needed.

Burning wood is often referred to as clean energy. But its emissions are comparable to those from burning coal, with one important difference: small particulates are emitted at much higher rates from burning wood.[15] Particulates are especially damaging to human health, and are linked to a wide variety of health problems from asthma to cardiovascular disease, premature births, neurodegenerative diseases, cancers etc.

In cold climates, wood is increasingly promoted as a climate-friendly alternative to gas and oil for residential and commercial heating, adding yet more demand. A growing push for electrification is creating more impetus for biomass power. Recently proposed legislation in the USA would extend the Renewable Fuel Standard to subsidise biomass power for charging electric vehicles. Converting wood to liquid biofuels on a commercial scale has failed so far. But if a successful process is developed, that would create yet another substantial subsidised demand for wood.

IS CERTIFICATION THE ANSWER?

Industry and policy-makers have long countered statements of concern claiming that they operate sustainably, that they practise sustainable forestry and comply with sustainability standards. What does that mean? Does it work? The term 'sustainable' is used widely to refer to a balance between supply and demand that does not deplete resources or otherwise have negative impacts. Standards have been developed for many practices, including for forestry and biomass power.[16] While sound in principle, these standards have been shown to be largely ineffective for a variety of reasons.

Certification to demonstrate compliance with standards has itself become a profit-making industry. Independent auditing and verification is generally lacking, indirect impacts are not accounted for, and even concerns

Enviva, Southampton, Virginia plant. (© Dogwood Alliance)

CASE STUDY

Drax Power station, Selby. (© Cut Carbon Not Forest)

about potential conflicts that could arise under trade agreements can undermine their implementation.[17]

Experience has shown that standards cannot prevent harm, especially when lucrative subsidies for renewable energy are on offer. A case in point is the certification of wood pellets by the Sustainable Biomass Program (SBP). Dutch authorities embraced SBP certification on the assumption that doing so would meet their own criteria for sustainability and thus eligibility for Dutch subsidies. Yet an investigation found a lack of credible auditing of supply chains or verification of the claims made by the pellet producers that SBP largely relied on. For example, pellets that had been certified by SBP were sourced from Estonian forests that have been so heavily logged as to be deemed a source rather than a sink for carbon. The basis for certification by SBP assumed hypothetical carbon sequestration modelled over a 70-year future horizon.[18]

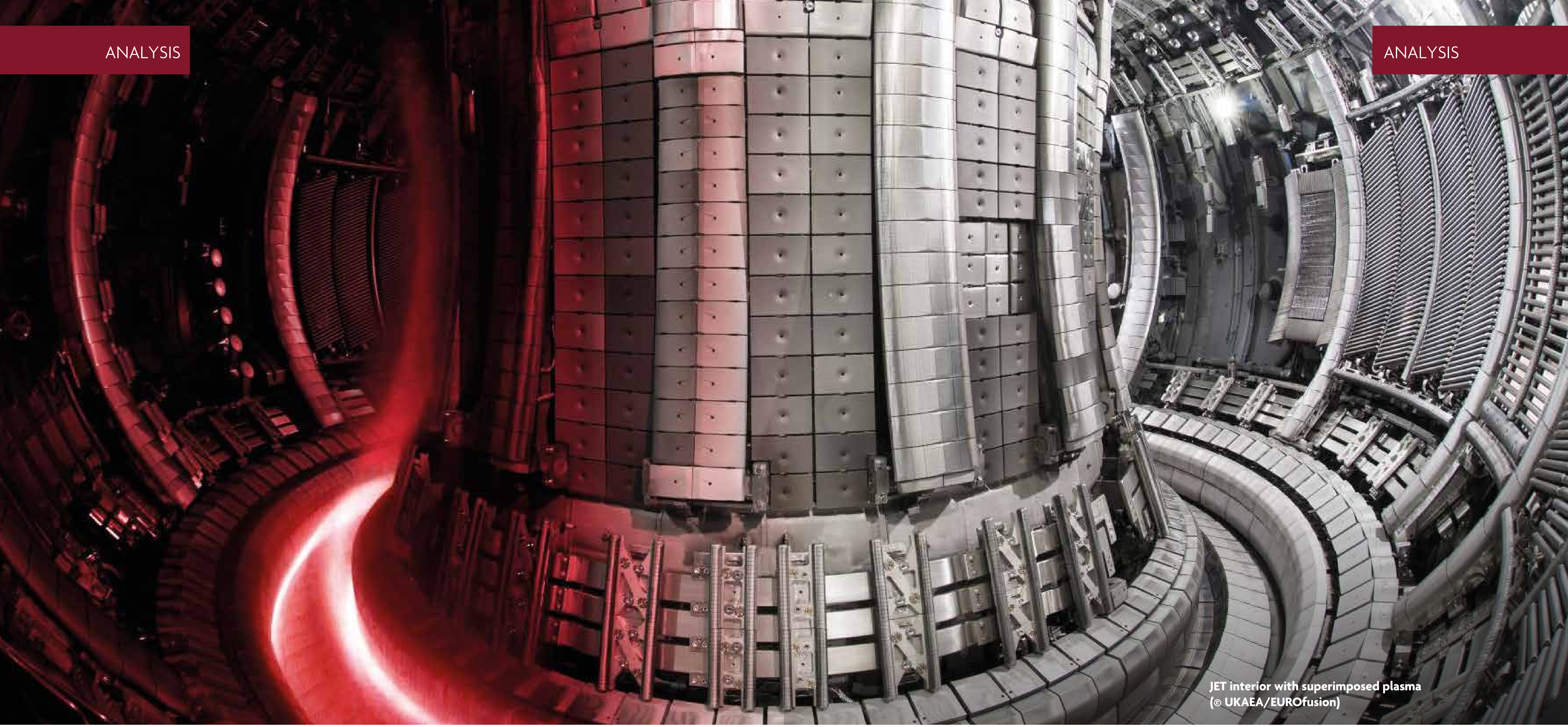
Standards cannot fix the problem. An unsustainable scale of demand cannot be made sustainable by use of standards. Ultimately, the removal of wood combustion from the definitions of renewable energy upon which subsidy distributions are based is essential if we are to protect and restore our forests and ecosystems and effectively reduce greenhouse gas emissions. A reality check is long overdue. The liveable climate we experience on Earth is in large part a result of the miraculous evolution of photosynthesis and the proliferation of plant life. We cannot supply insatiable appetites for energy and materials by harvesting the biosphere. **ES**

Rachel Smolker PhD is Co-director of Biofuelwatch and works internationally on addressing the climate, biodiversity and human rights impacts of large-scale industrial bioenergy.
✉ **rsmolker@riseup.net**

REFERENCES

1. Drax (no date) *Biomass – frequently asked questions*. https://energy.drax.com/support/biomass-faq/ (Accessed: 13 March 2023).
2. Booth, M.S. (2022) *Burning up the Carbon Sink: How EU's Forest Biomass Policy Undermines Climate Mitigation, and How It Can Be* Reformed. Partnership for Policy Integrity. https://forestdefenders.eu/wp-content/uploads/2022/11/PFPI-Burning-up-the-carbon-sink-Nov-7-2022.pdf (Accessed: 24 February 2023).
3. Drax (2021) *Annual Report 2021*. https://www.drax.com/investors/announcements-events-reports/annual-reports-and-accounts/ (Accessed: 10 March 2023).
4. Forest to Market (2022) *Global wood pellet trade reached record-high 29 million tons in 2021*, 26 April. https://www.forest2market.com/blog/global-wood-pellet-trade-reached-record-high-29-million-tons-in-2021 (Accessed: 7 March 2023).
5. International Energy Agency (2021) *Net Zero by 2050: A Roadmap for the Energy Sector*. https://www.iea.org/reports/net-zero-by-2050 (Accessed: 10 March 2023).
6. Environmental Integrity Project (2018) *Dirty Deception: How the Biomass Industry Skirts the Clean Air Act*. http://www.environmentalintegrity.org/wp-content/uploads/2017/02/Biomass-Report.pdf (Accessed: 13 March 2023).
7. Fagan, M.E., Morton, D.C., Cook, B.D., Masek, J., Zhao, F., Nelson, R.F. and Huang, C. (2018) Mapping pine plantations in the southeastern U.S. using structural, spectral, and temporal remote sensing data. *Remote Sensing of Environment*, 216, pp. 415–426. https://www.sciencedirect.com/science/article/abs/pii/S0034425718303341 (Accessed: 30 March 2023).
8. Catanosa, J. (2022) *Whistleblower: Enviva claim of 'being good for the planet... all nonsense'*, 5 December. https://news.mongabay.com/2022/12/envivas-biomass-lies-whistleblower-account/ (Accessed: 24 February 2023).
9. Natural Resources Defense Council, Dogwood Alliance and Southern Environmental Law Center (2019) *Global Markets for Biomass Energy Devastating U.S. Forests*. https://www.nrdc.org/sites/default/files/global-markets-biomass-energy-devastating-us-forests-202209.pdf (Accessed: 7 March 2023).
10. Stand.earth (2021) *Canada's Growing Wood Pellet Export Industry Threatens Forests, Wildlife and Our Climate*. https://old.stand.earth/sites/stand/files/report-canada-wood-pellet-industry.pdf (Accessed: 24 February 2023).
11. Estonian Fund for Nature (2022) *Logging and Carbon Storage in Estonia and What Can Be Done*. https://media.voog.com/0000/0037/1265/files/LULUCF%20background%20paper_Estonian%20Fund%20For%20Nature%20(May%202022).pdf (Accessed: 24 February 2023).
12. Searchinger, T.D., Hamburg, S.P., Melillo, J., Chameides, W., Havlik, P., Kammen, D.M., Likens, G.E., Lubowski, R.N., Obersteiner, M., Oppenheimer, M., Robertson, G.P., Schlesinger, W.H. and Tilman, G.D. (2009) Fixing a critical accounting error. *Science*, 326, pp. 527–528. https://www.pfpi.net/wp-content/uploads/2011/03/Searchinger-et-al-2009.pdf (Accessed: 7 March 2023).
13. Raven, P. *et al.* (2021) *Open letter regarding use of forests for bioenergy*, 11 February. https://www.documentcloud.org/documents/22252792-scientist-letter-to-biden-von-der-leyen-michel-suga-moon-re-forest-biomass-february-11-2021 (Accessed: 7 March 2023).
14. Tin Fisher, V. and Knuth, H. (2023) Phantom offsets and carbon deceit. *Die Ziet* Nr 4, 18 January. https://www.zeit.de/wirtschaft/2023-01/co2-certificates-fraud-emissions-trading-climate-protection-english (Accessed: 24 February 2023).
15. UK National Atmospheric Emissions Inventory (no date) *Emissions maps 2020*. https://naei.beis.gov.uk/data/map-uk-das (Accessed: 13 March 2023).
16. Sustainable Biomass Program (no date) *The promise of good biomass*. https://sbp-cert.org (Accessed: 10 March 2023).
17. FERN, ClientEarth, Biofuelwatch, Estonian Fund for Nature, Canopee and ZERO (2021) *Unsustainable and Ineffective: Why EU Forest Biomass Standards Won't Stop Destruction*. https://www.fern.org/fileadmin/uploads/fern/Documents/2021/Unsustainable_and_ineffective_EU_Forest_Biomass_Standards.pdf (Accessed: 24 February 2023).
18. Biofuelwatch, Estonian Fund for Nature, Dogwood Alliance, Comité Schone Lucht NL and Leefmilieu (2023) *Sustainable Biomass Program: Certifying Paperwork Without Looking at the Forest*. https://www.biofuelwatch.org.uk/2023/sbp-report/ (Accessed: 24 February 2023).

ANALYSIS



JET interior with superimposed plasma (© UKAEA/EUROfusion)

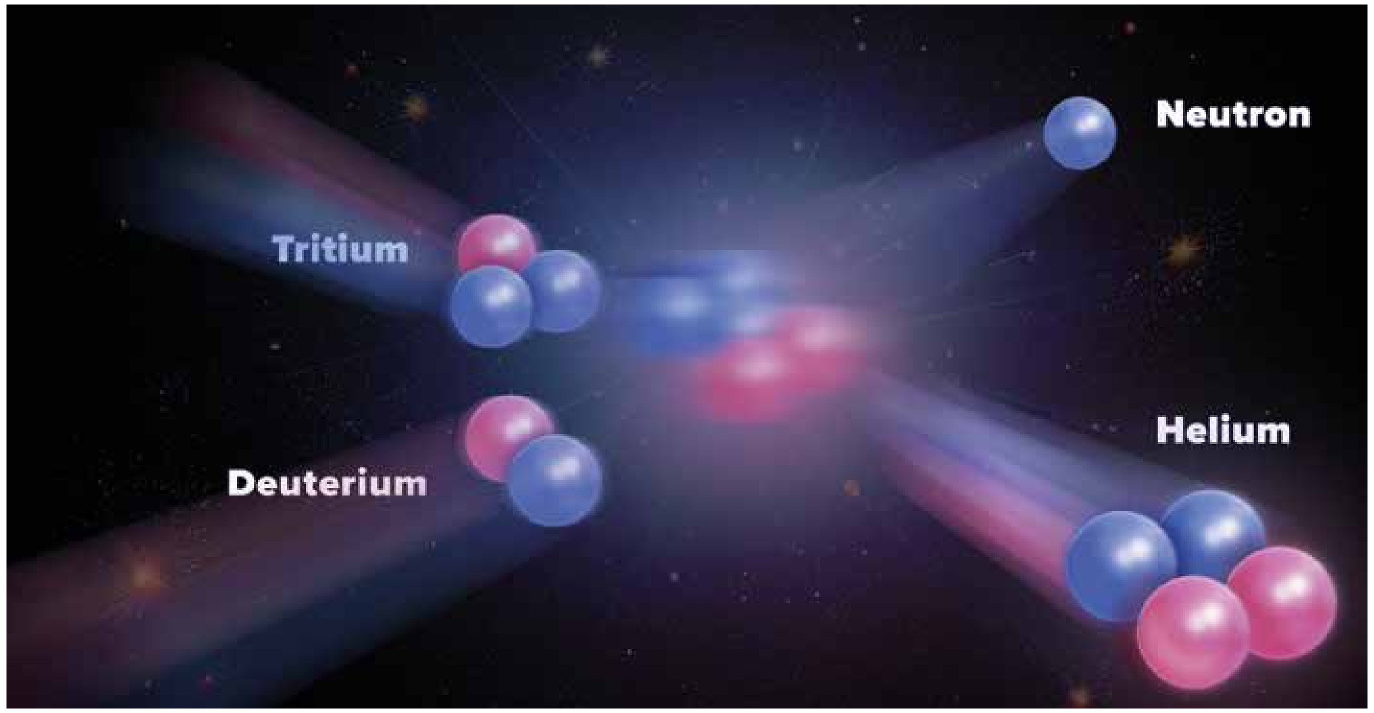
Star power: the potential of fusion energy

Mark Shannon delves into the world of fusion physics to set out the case for a new and promising form of energy.

Fusion is the process that powers the sun and stars. The rewards for recreating what many consider the ultimate energy source here on Earth are enormous, with the potential for low-carbon and near-limitless energy for generations to come. However, achieving it is one of the greatest scientific and engineering challenges of our time.

The first fusion experiments were conducted in the 1950s, and since then activity has predominantly taken place in a small number of national laboratories. But our world is changing, and it is clear now more than ever that new power solutions are required for a sustainable future. The commercial opportunity for delivering fusion energy is significant; investment and interest have spiked across the globe, and competition is driving innovation and progress like never before.

ANALYSIS



▲ **Fusion process: A combination of hydrogen gases, deuterium and tritium, are heated to very high temperatures to create a plasma. Energy is released during this process when deuterium and tritium atoms fuse together to form a helium atom and a neutron. (© UKAEA).**

Fusion has been in the spotlight recently following multiple significant breakthroughs. Last year, the United Kingdom Atomic Energy Authority (UKAEA) announced a new record for sustained fusion energy, and December saw US scientists demonstrate net energy gain from a fusion reaction – two world firsts for fusion. More recently, EUROfusion and UKAEA scientists revealed they have found a way to boost the performance of fusion inside tokamaks – machines that use a magnetic field to confine plasma – through the demonstration of a 'heat barrier'. This heat barrier prevents the machine's tungsten walls from contaminating the plasma created in the fusion process.[1] These developments take us one step closer to harnessing what could be the ultimate energy source, and it is worth examining at a high level what it is we are working towards.

WHAT IS FUSION ENERGY?

Fusion is the process that takes place in the heart of stars. When lighter nuclei fuse to form a heavier nucleus, they release bursts of energy. This is the opposite of nuclear fission – the reaction used in nuclear power stations today, in which energy is released when a nucleus splits apart to form smaller nuclei.

When a mix of two forms of hydrogen – deuterium and tritium – are heated to form a plasma at extreme temperatures – around 10 times hotter than the sun's core – they fuse to create helium, releasing significant amounts of energy. There are multiple approaches to creating fusion. The UKAEA approach involves using strong magnets to hold hot plasma in a ring-shaped machine called a tokamak. This magnetic confinement method is used in UKAEA's Joint European Torus (JET) facility in Oxford and the Mega Amp Spherical Tokamak Upgrade (MAST-U) device and will be used in the Spherical Tokamak for Energy Production (STEP), the UK's prototype fusion power plant to be built at West Burton A in Nottinghamshire.

RECENT DEVELOPMENTS

In December 2022, the team at the US National Ignition Facility (NIF) at Lawrence Livermore National Laboratory achieved landmark results, in which scientists demonstrated a scientific energy gain – meaning more energy was produced than put in.[2] The calculation did not factor in the energy it took to power the lasers used in the process, but these results are overwhelmingly positive for fusion research. They confirm in practice what has been theorised by fusion researchers for decades.

The approach taken by the NIF to create a fusion reaction uses the inertial confinement method. This involves rapidly compressing a small capsule containing fusion fuel using high-energy lasers to create a plasma and, thus, fusion conditions. As evidence of technical progress, last year, UKAEA announced record results from the JET experiment. EUROfusion researchers more than doubled the previous world record for fusion energy: 59 megajoules of sustained fusion energy was produced over a five-second period, demonstrating power plant potential.[3,4]

The scientific data from these crucial experiments are a major boost for ITER, the larger and more advanced version of JET. ITER is a fusion research mega-project supported by seven members – China, the EU, India, Japan, South Korea, Russia and the USA – based in the south of France, to further demonstrate the scientific and technological feasibility of fusion energy. In the UK, a major infrastructure project is underway to transform an old coal-fired power station in Nottinghamshire into a prototype fusion energy power plant, known as STEP. It is anticipated that STEP will pave the way for future commercial plants, with first operations expected by 2040. These developments sit alongside rapidly increasing commercial interest and are concrete milestones on the path to developing fusion as a potential and viable part of the world's energy mix.

There is more than one approach to achieving fusion. In addition to magnetic and inertial confinement, other techniques being pursued worldwide include:

- Magnetised target fusion, where magnetic confinement and inertial compression are combined to create fusion conditions with less onerous performance extremes;
- Field-reversed configuration devices, which attempt to create a magnetically contained plasma volume with no central tube or solenoid; and
- Stellarators that employ complex coil configurations to apply magnetic containment to a twisted hoop-shaped plasma volume.

MEETING CHALLENGES, DEVELOPING CAPABILITIES

Each approach to fusion is supported by its own range of technologies and involves multiple technical challenges. Some are unique to each approach and others are shared. There is still much work to be done before fusion can generate electricity on a commercial scale.

Putting fusion electricity on the grid – economically and reliably – using a tokamak requires finding and integrating technological solutions to several major challenges. These include:

- Creating a sustained and controlled plasma;
- Using structural materials that withstand high-energy neutrons and operate at high temperatures (for thermal efficiency);
- Deploying plasma-facing materials that can withstand intense heat;
- Designing and manufacturing robust fusion components with these materials;
- Breeding, storing and supplying tritium fuel in sufficient quantities for continuous operation;
- Perfecting robotics systems and robotics-friendly designs that minimise time taken for inspections and maintenance; and
- Building plants with high energy efficiency that make best use of the life of the materials and components.

UKAEA is undertaking innovative work with academia, the industrial supply chain and private sector fusion companies in all these areas as fusion pivots from science to real-world applications.

These developments come with challenges. Taking materials as an example, engineers must carefully select which ones they use to shield a tokamak's components. This shielding is needed because neutrons produced by fusing nuclei are highly energetic, and it is this energy that will ultimately generate electricity. Kinetic energy of this nature, however, first needs to be converted into heat while minimising the energetic damage imparted on the machine's structures the neutrons pass through. The shielding function is to protect components, such as magnets, that are more sensitive to this neutronic damage. The materials selected for shielding therefore need to avoid alloying elements that become activated for extended periods of time. Space in a tokamak is also limited due to competing needs for shielding, services, breeding volume and magnet structures, so shielding needs to balance cost, size and efficacy.

STIMULATING INDUSTRY

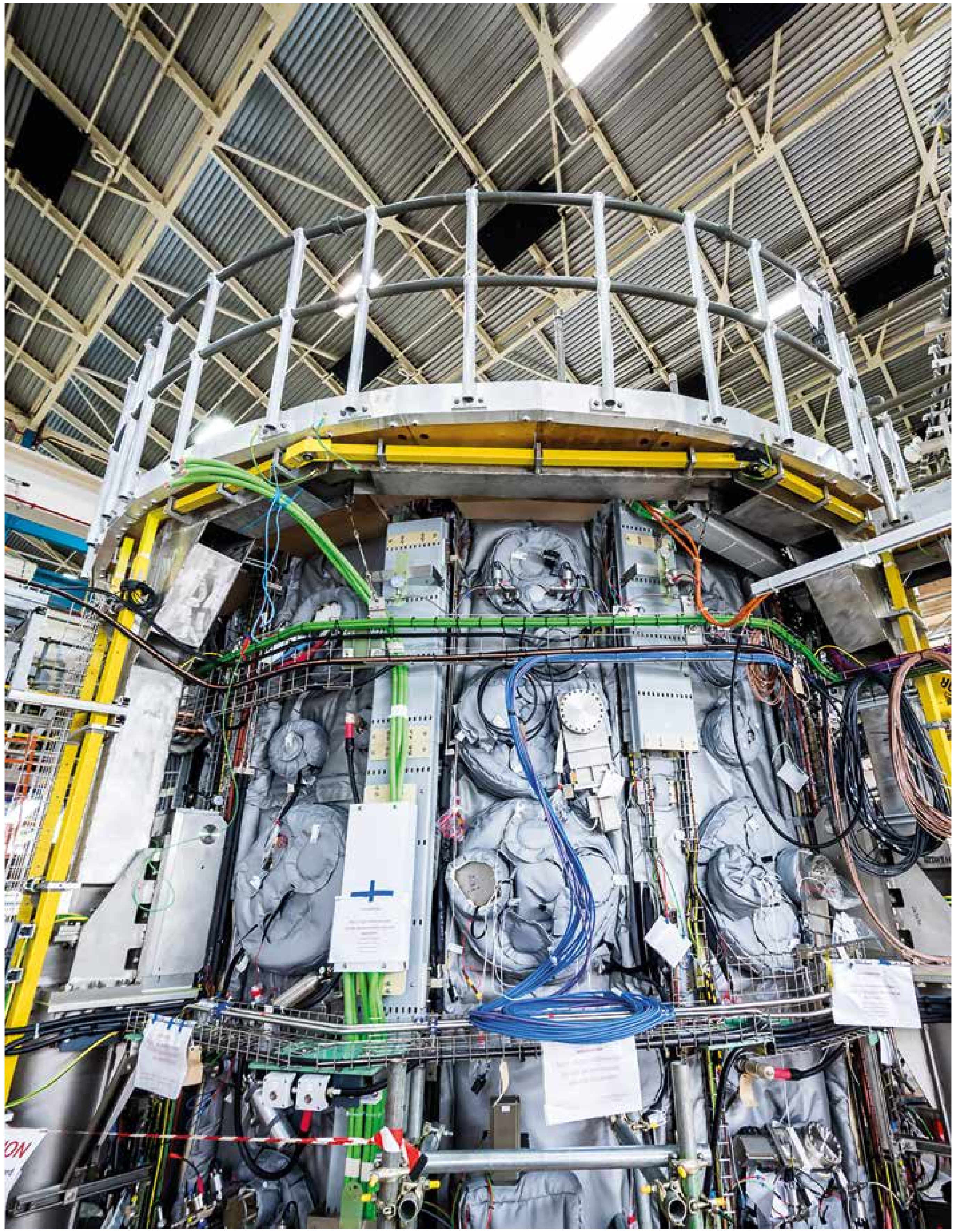
UKAEA is supporting fusion energy organisations – including private companies and academia – in several ways to commercially develop fusion energy. Eighteen organisations have recently secured contracts with UKAEA to demonstrate how their innovative technologies and proposed solutions can help make fusion energy a commercial reality.

The contracts – from £50,000 up to £200,000 for feasibility studies – are funded by the UKAEA's Fusion Industry Programme (FIP) and awarded through the UK Government's Small Business Research Initiative platform. The latest contracts are the second FIP cycle, following the first that was held in 2021. The projects aim to tackle specific challenges linked to the commercialisation of fusion energy, from novel fusion materials and manufacturing techniques through to innovative heating and cooling systems, all necessary elements of future fusion power plants.

FIP engages organisations and industrial partners to stimulate growth of the fusion ecosystem and prepare the UK for the future global fusion power plant market. It does this through a combination of three schemes:[1]

- A challenge fund to engage organisations to meet technical challenges;
- A voucher scheme for businesses to make use of specialist fusion facilities; and
- An education scheme to increase the supply of skilled students into the fusion sector.

In addition to FIP, there are various funding mechanisms for fusion, including the UK Innovation & Science Seed Fund.



▲ **MAST-U - a fusion energy machine at UKAEA's Culham Campus vital for the delivery of fusion power plants. (© SMD Photography)**

With a growing number of private fusion companies and research at universities and the UKAEA, the UK has a thriving fusion energy scene. The UKAEA's Culham Campus in Oxfordshire is at the heart of a growing UK fusion cluster, not limited to other fusion companies but looking at organisations that develop all the technologies that make fusion happen. For example, UKAEA and First Light Fusion recently signed an agreement for the design and construction of a new purpose-built facility at Culham Campus to house the latter's Machine 4 demonstrator.

Like NIF in the USA, First Light Fusion is pursuing an inertial-confinement approach to fusion. Its method leverages the same physics proven by NIF but combines it with a unique approach that involves firing a projectile at a fuel pellet to force it to fuse and produce energy. Although Machine 4 will not generate power, it will be used to demonstrate net energy gain and to develop the technology needed for future inertial-confinement fusion power.

UKAEA is also working with General Fusion on a hybrid device, also to be constructed at Culham Campus, which uses both compression and magnetic confinement, and with Tokamak Energy to build a protype with power plant-relevant magnet technology.

In all cases, the technology being developed by these organisations will need to overcome shared challenges to ensure fusion energy realises its power plant potential.

LOOKING AHEAD

Commercialisation also needs to consider how fusion can be deployed at scale to provide a low-carbon source of power to address global demand. Plans for the governance and regulation of fusion energy will be a key part of this transformation. The UK is in an ideal position as the first country worldwide to publish plans for regulating fusion energy.[2,3] The UK Fusion Strategy will apply to all technological approaches used to generate fusion energy. These initiatives are designed to support the sector and grow the industry's capability to make the UK a global hub for fusion innovation.[4]

The overarching goals of the UK Fusion Strategy are for the UK to:

- Demonstrate the commercial viability of fusion by building a prototype fusion power plant in the UK that puts energy on the grid; and
- Build a world-leading fusion industry that can export fusion technology around the world in subsequent decades.

To achieve these goals, the strategy focuses on international, scientific and commercial leadership. Delivering fusion energy requires the very best scientists and engineers in many disciplines working together. No organisation can achieve sustainable fusion on its own. Together we are stronger. **ES**

Mark Shannon is Director of Integrated Engineering at the UKAEA. He joined in 2005 following a career in the oil and gas sector and has worked with various plasma-heating systems and in engineering management roles on JET, MAST-U, International Thermonuclear Experimental Reactor and DEMO (demonstration power plant) machines before heading up UKAEA's Project Management Office. He returned to engineering in 2019 as Engineering Department Manager before becoming Division Director in 2022.

REFERENCES

1. Field, A.R., Casson, F.J., Fajardo, D., Angioni, C., Challis, C.D., Hobirk, J., Kappatou, A., Kim, H-T., Lerche, E., Loarte, A., Mailloux, J. and JET Contributors (2023) Peripheral temperature gradient screening of high-Z impurities in optimised 'hybrid' scenario H-mode plasmas in JET-ILW. *Nuclear Fusion*, 63 (016028). doi: 10.1088/1741-4326/aca54e.
2. United States Department of Energy (2022) *DOE National Laboratory Makes History by Achieving Fusion Ignition*, 13 December. https://www.energy.gov/articles/doe-national-laboratory-makes-history-achieving-fusion-ignition (Accessed: 16 March 2023).
3. Gibney, E. (2022) *Nuclear-fusion reactor smashes energy record*. https://www.nature.com/articles/d41586-022-00391-1 (Accessed: 16 March 2023).
4. Science Daily (2022) *JET fusion facility sets a new world energy record: European joint experiment prepares transition to large-scale ITER project*, 10 February. www.sciencedaily.com/releases/2022/02/220210085048.htm (Accessed: 16 March 2023).
5. UK Atomic Energy Authority Culham Centre for Fusion Technology (2023) *The Fusion Industry Programme (FIP) is stimulating growth of the UK fusion ecosystem and preparing it for future global fusion power plant market*. https://ccfe.ukaea.uk/programmes/fusion-industry-programme/ (Accessed: 16 March 2023).
6. Department of Business, Energy and Industrial Strategy (2021) *UK set to be first country to legislate for safe and efficient rollout of fusion energy*, 1 October. https://www.gov.uk/government/news/uk-set-to-be-first-country-to-legislate-for-safe-and-efficient-rollout-of-fusion-energy (Accessed 16 March 2023).
7. UK Atomic Energy Authority (2022) *Regulation decision to help 'accelerate' fusion energy process*, 20 June. https://www.gov.uk/government/news/regulation-decision-to-help-accelerate-fusion-energy-progress (Accessed: 16 March 2023).
8. Department for Energy Security and Net Zero and Department of Business, Energy and Industrial Strategy (2021) *Towards fusion energy: the UK fusion strategy*. https://www.gov.uk/government/publications/towards-fusion-energy-the-uk-fusion-strategy (Accessed: 16 March 2023).

© wolandmaster | Adobe Stock

TECHNICAL

How to improve the efficiency of energy-storage systems

Pasidu Pallawela examines the energy efficiencies of different green energy-storage systems

Electricity grids and transportation systems will change significantly in the future due to increasing levels of electrification in everyday life. Greater deployment of renewable energy is required to decarbonise the grid, and the wider adoption of electric vehicles will result in large amounts of electricity being drawn from the grid, often at times that do not align with renewable energy generation. The intermittent nature of wind and solar resources means that energy storage is a fundamental requirement in the transition to net-zero energy systems; with that, efficiency is one of the most important factors in a system's economic viability, as it directly affects the levelised cost of storage. So how can we get the most out of our energy-storage systems (ESS)?

ENERGY-STORAGE TECHNOLOGY OPTIONS

The choice of energy-storage technology for a particular application can have a significant impact on ESS efficiency. For example, pumped hydro and compressed-air storage are more efficient over long periods of time, while others, such as lithium–ion batteries, are better at providing quick bursts of power. Choosing the right technology for an application can therefore improve overall system efficiency.

There are several ESS technologies, each with unique characteristics and efficiencies, including:

- **Rechargeable electrochemical batteries.** Batteries are one of the most common forms of energy storage and are used in a wide range of applications, from portable electronic devices to large-scale grid-energy ESS. Battery efficiency can vary: most lithium–ion batteries have an efficiency of around 80–90 per cent,[1] while for new technologies such as lithium–polysulphide flow batteries this can reach 98 per cent (see **Figure 1**).[2] When it comes to large-scale stationary or grid-scale storage, high efficiency is important. An efficiency level lower than 70 per cent can be disadvantageous for this type of storage.

- **Mechanical energy storage.** There are three types of mechanical energy storage: pumped hydro, compressed-air energy storage (CAES) and flywheel or gravity-based. Pumped hydro involves pumping water from a lower to an upper reservoir using excess electricity then releasing it as needed through a turbine to generate power. This method has an efficiency of 75–90 percent.[3] CAES involves using excess electricity to compress air that is then stored in an underground cavern or tank to be released at a later date through a turbine to generate power. The efficiency of CAES methods can vary, with a typical range of around 50–60 percent.[4] Flywheel or gravity-based systems use mechanical methods such as a spinning flywheel or lifted weights to store excess energy as kinetic energy. This can then be recovered by slowing down the flywheel or lowering the weight and using the

TECHNICAL

▲ Figure 1. A novel battery bank of lithium–polysulphide single liquid flow battery cells. (© StorTera)

resulting kinetic energy to generate electricity. All these technologies are capital intensive, best suited to large-scale applications, and most require specific geographical conditions, such as hills or mountains.

- **Thermal energy storage**. Thermal ESS uses excess energy to heat a medium, such as water or molten salt, which can be stored and later used to generate electricity through a heat engine. Its efficiency can vary depending on the specific technology used and the temperature difference between the hot and cold reservoirs, with typical efficiencies of 50–70 per cent.[5] These systems are also best suited to large-scale applications and are capital intensive.

Electrochemical batteries, such as lithium–ion, are more efficient compared to other ESS technologies because they utilise an electrochemical reaction to store and release energy. These storage systems can directly convert chemical into electrical energy, resulting in high energy-conversion efficiency and performance. Importantly, the materials used in such batteries are well suited for this type of reaction. In contrast, other technologies use indirect methods to store and release energy, which can result in lower energy-conversion efficiencies. Furthermore, electrochemical batteries have a relatively low internal resistance or impedance, allowing for efficient energy transfer between the storage system and power electronic converter. This, combined with their high energy density, makes them an attractive option for a variety of energy-storage applications.

The efficiency of a battery depends on numerous factors including the type of chemistry used, battery design and operating conditions. The approximate direct current to direct current (DC–DC) efficiencies of common battery chemistries provide some context (see **Table 1**).

METHODS OF IMPROVING EFFICIENCY

There are a number of techniques and technologies that can be applied to improve ESS efficiency.

Optimising charging and discharging. Optimisation of the charging and discharging process is one method that will affect ESS efficiency. This can be achieved in one of three ways:

- Advanced or intelligent control systems. These can analyse real-time data on energy demand, supply and renewable energy generation as well as factors such as energy pricing and grid conditions. This information can be used to optimise the operation of ESS charging and discharging processes. Advanced control systems can be used to determine the optimal times to charge or discharge an ESS – for example, considering the availability of excess solar generation and the cost of electricity. The ability to use onsite renewable energy increases ESS efficiency by not having to draw alternating current (AC) energy from the grid, converting it to DC energy and then converting back to AC when electricity is needed (see **Figure 2**).

- Battery management systems (BMS). An important aspect of ESS efficiency is the management of the individual cells within a battery module. BMS can monitor and balance the amount of energy stored in battery cells to minimise the energy lost through cell balancing. Cell balancing is the activity of bringing the voltage of all cells down to the same level by discharging those cells with higher voltage levels when the battery pack is in a resting period. This function is necessary to maintain the design capacity of the battery pack. Optimising battery charging and discharging based on the specific needs of the application will aid efficiency. For example, for a battery that is used once a week, the BMS can be programmed to fall into deep sleep mode after detecting a period of inactivity.

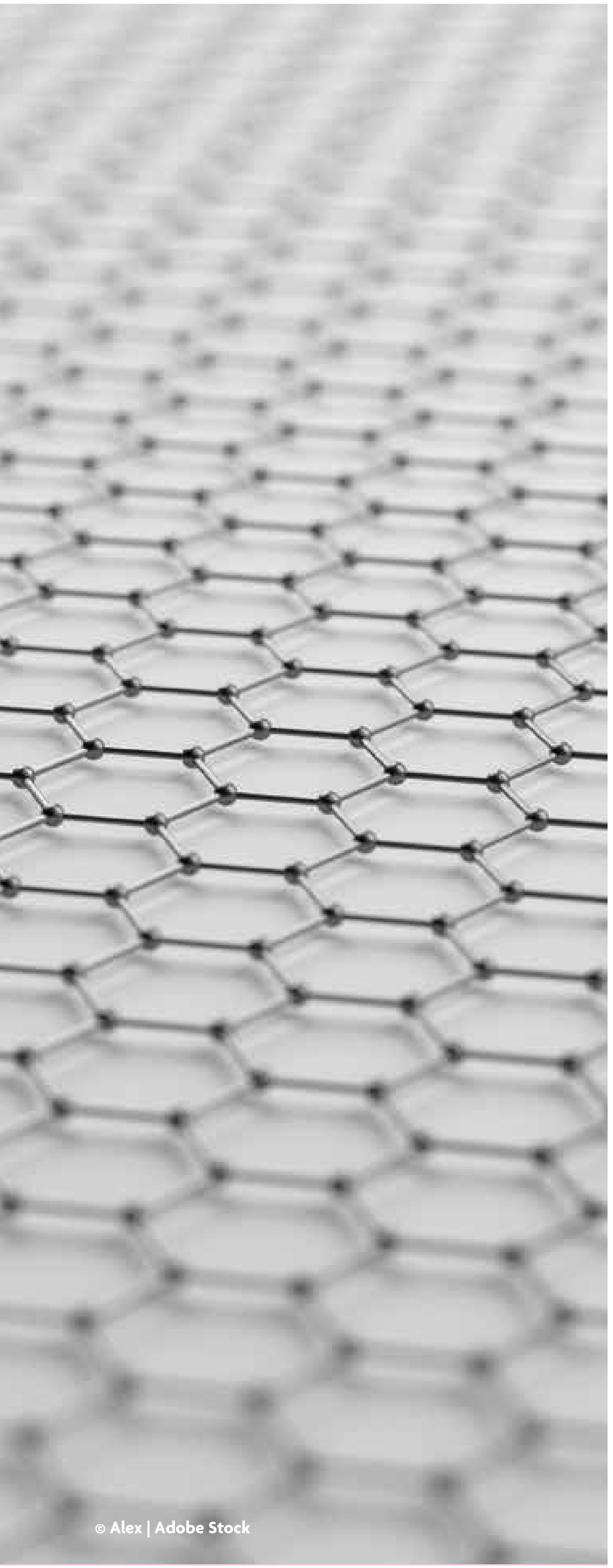
- Efficient power-conversion systems. Using only highly efficient power electronics – an important requirement for a modern and efficient ESS – such as DC–AC inverters and DC–DC converters will also play a role in the efficiency of the charging–discharging process.

Using advanced materials. Researchers have developed new types of batteries that use novel materials, such as graphene and lithium–sulphur, which have improved efficiencies compared to traditional batteries. These advanced materials can potentially increase the amount

▲ Figure 2. Energy-storage units use advanced controls to optimise charging and discharging. (© StorTera)

▼ Table 1. DC–DC efficiency for a range of battery types

Battery chemistry	Efficiency (%)
Lithium–ion	80–90[6]
Lead–acid	50–75[7]
Nickel–metal hydride	60–80[8]
Nickel–cadmium	70–80[9]
Lithium–sulphur single liquid flow	96–98[2]


© Alex | Adobe Stock

of energy that can be stored, thus leading to a more efficient ESS. Graphene, for example, is used in many electrochemical batteries to lower internal resistance and increase efficiency. Lithium–polysulphide single liquid flow battery (SLIQ) uses dissolved lithium–polysulphide in a liquid medium to eliminate the disadvantages of standard lithium–sulphur pouch-cell batteries, such as polysulphide shuttling, that can cause corrosion and volume expansion.[10] These material innovations have enabled the SLIQ to achieve DC–DC efficiencies in the order of 96–98 per cent.

Waste energy capture and utilisation. Waste energy recovery refers to the process of capturing and using energy that would otherwise be wasted or lost. In ESS, low-grade heat is generated during operation, which is usually considered to be waste energy. Recovery and use of this low-grade thermal energy is a valuable tool that can improve overall ESS efficiency. For example, a large ESS integrated with a district-heating network could use the recovered heat energy for homes and businesses, increasing overall efficiency.

Improving plant efficiency and quality. An important factor in ESS efficiency is the quality of the components used since they can reduce losses and improve overall system efficiency. For example, high-quality inverters can reduce losses from inverter inefficiencies, while high-quality materials and manufacturing methods can reduce losses due to battery degradation.

Regular maintenance and cleaning. Regular ESS maintenance and cleaning also improve efficiency since dirt and debris can accumulate on components, reducing their performance and efficiency. In the case of electrochemical batteries, these slowly degrade when operated over numerous cycles. One of the common degradation mechanisms is the formation of unwanted chemical compounds affecting the battery's active area or exfoliation of film-coated active chemicals into the electrolyte. Removing this debris or solid precipitates can improve efficiency. For example, the SLIQ flow battery's patented flushing mechanism flushes the stack, reducing internal resistance by removing resistive elements such as precipitated solid chemical compounds.

Appropriate sizing. Sizing an ESS appropriately is crucial. Over-sizing or under-sizing can reduce efficiency, as the system may not be used to its full capacity. Sizing is determined by considering factors such as energy-demand data, energy usage patterns, environmental data and onsite energy generation data.

Use of hybrid systems. A hybrid system could be created by combining a fast-response battery, such as lithium–ion, with a gravity-based or CAES system. This could potentially increase overall system efficiency by taking advantage of the strengths of each technology.

Using artificial intelligence (AI) algorithms. More recently, AI algorithms have been used to optimise operations for maximum efficiency, such as regulating charging and discharging. For example, an AI algorithm could predict when electricity demand is likely to be high and instruct the ESS to discharge a certain amount of stored electricity. This could have potentially significant energy savings for customers, as it reduces the need for expensive peak generation capacity. Some of the ways in which AI is used to improve overall ESS efficiency include:

- Predictive maintenance. Analysing ESS data to predict when maintenance or repairs are needed, thus preventing unexpected failures.
- Load forecasting. Forecasting the energy demand of a system and optimising ESS charging and discharging to meet it.
- Fault detection and diagnosis. Detecting and diagnosing ESS faults, allowing for quick and accurate repairs.
- System optimisation. Optimising ESS operation by selecting the most efficient charging and discharging strategies or by finding the optimal mix of storage technologies.
- Demand response. Optimising the user demand in response to available energy stored in the ESS can help to significantly increase efficiency.

Various organisations have developed AI systems to optimise and increase ESS efficiency. One AI system for use in optimising ESS is the tri-layer AI controller (TRAICON). TRAICON implements AI in three different application layers within an ESS: battery-cell management, power converter and control system, and cloud-based control and optimisation. These are known as vertically integrated AI controllers and can access large amounts of external data such as weather conditions, electricity network demand data and renewable energy generation data in a given geographical area. This information is then transferred to battery-cell and power-control layers to optimise the battery systems and connected loads and thus increase overall ESS efficiency.

POLICY AND REGULATORY MEASURES

In addition to technological approaches, there are also policy and regulatory measures that can improve ESS efficiency. These could include financial incentives by governments that can assist with the development and deployment of advanced high-efficiency energy-storage technologies, as well as incentives to increase existing ESS efficiency. Governments can also introduce regulations to encourage continuous improvements.

Improving ESS efficiency is a critical step towards realising the full potential of renewable energy and future smart grids. By utilising advanced materials, hybrid storage systems and supportive policy measures and incorporating AI algorithms the efficiency and adoption of energy-storage technologies can be increased, leading to a more sustainable and secure energy future. ES

Pasidu Pallawela is the founder and Chief Technology Officer of StorTera. Pasidu is a multi-skilled engineer, inventor and a green entrepreneur who focuses on developing novel smart-battery storage technologies. He holds several energy-storage patents. **pas@stortera.com**

REFERENCES

1. Schimpe, M., Naumann M., Truong, N., Hesse, H.C., Santhanagopalan, S., Saxon, A. and Jossen, A. (2018) Energy efficiency evaluation of a stationary lithium-ion battery container storage system via electro-thermal modelling and detailed component analysis. *Applied Energy*, 210 (C), pp. 211–229. doi: 10.1016/j.apenergy.2017.10.129.
2. Sims, R. and Ayyadi, S. (2022) *Power Network Demonstration Centre Energy Storage Test Report*. In press.
3. Rehman, S., Al-Hadhrami, Luai M. and Mahbub, A. (2015) Pumped hydro energy storage system: a technological review. *Renewable and Sustainable Energy Reviews*, 44 (April), pp. 586–598. https://doi.org/10.1016/j.rser.2014.12.040 (Accessed: 5 March 2023).
4. Brian, E. and Brix, W. (2011) *Efficiency of Compressed Air Energy Storage*. 24th International Conference on Efficiency, Cost, Optimization, Simulation and Environmental Impact of Energy Systems. https://backend.orbit.dtu.dk/ws/portalfiles/portal/6324034/prod21323243995265.ecos2011_paper%5B1%5D.pdf (Accessed: 5 March 2023).
5. Alva, G., Lin, Y. and Fang, G. (2018) An overview of thermal energy storage systems. *Energy*, 144 (C), pp. 341–378. doi: 10.1016/j.energy.2017.12.037.
6. Ananthachar, V. and Duffy, J.J. (2005) Efficiencies of hydrogen storage systems onboard fuel cell vehicles. *Solar Energy*, 78 (5), pp. 687–694. https://doi.org/10.1016/j.solener.2004.02.008 (Accessed: 5 March 2023).
7. Rand, D.A.J. and Moseley, P.T. (2015) 'Energy storage with lead–acid batteries', in *Electrochemical energy storage for renewable sources and grid balancing*. https://doi.org/10.1016/B978-0-444-62616-5.00013-9 (Accessed: 5 March 2023), pp. 201–222.
8. Aktas, A. and Kirçiçek, Y. (2021) 'Solar hybrid systems and energy storage systems', in *Solar hybrid systems*. https://doi.org/10.1016/B978-0-323-88499-0.00005-7 (Accessed: 5 March 2023), pp. 87–125.
9. Breeze, P. (2018) *Power System Energy Storage Technologies*. London: Elsevier.
10. Han, Y., Duan, X., Li, Y., Huang, L., Zhu, D. and Chen, Y. (2015) Effects of sulfur loading on the corrosion behaviors of metal lithium anode in lithium–sulfur batteries. *Materials Research Bulletin*, 68, pp. 160–165. https://doi.org/10.1016/j.materresbull.2015.03.042 (Accessed: 5 March 2023).

New members and re-grades

Associate is for individuals beginning their environmental career or those working on the periphery of environmental science.

Alyazya Alshehhi – Data Ecology Analyst
Matthew Batchelor – Air Quality Consultant
Matthew Bradnam – Assistant Air Quality Consultant
Li Xing Alex Chan – Student
Esme Chappell – Assistant Environmental Scientist
Hei Lam Cheung – Air Quality Consultant
Andrew Cuff – Graduate
Abbie Davies – Graduate Geo-Environmental Consultant
Matthew Dean – Environmental Consultant
Ahmed Eldessouky – Environmental Specialist
Michael Ella – Project GIS Analyst (ESIA)
Hannah Fleming – Air Quality Environmental Scientist
Jade Flenley – Air Quality Technician
Ruth Frost – Environmental Specialist - Modelling & Mapping
Matthew Goldsmith – Environmental Consultant
Bethany Graham – Graduate Geo-Environmental Consultant
Ryan Guppy – Project Consultant - Air Quality
Steven Hart – Project Manager
Stephen Himson – Environmental Consultant
Aiden Humphries – Environmental Engineer
Truce Jack – Graduate Environmental Consultant
Marie-Claire Jalaguier – Graduate Environmental Scientist
Ruari Kaylor – Environmentalist
Matthew Kinkaid – Environmental Scientist
Olivia Maxwell – Senior Geo-Environmental Consultant
Rishad Maynard – Graduate
Kerith McClung – Environmentalist
Charlotte Mould – Graduate Environmental Engineer
Louisa Osei – Graduate Air Quality Consultant
Danniella Page – Geo-Environmental Engineer
Brendan Parry – Sales & Watch Consultant
Liam Pickles – Graduate
Agnes Richard – Environmental Consultant
Henry Robins – Air Quality Consultant
Joshua Roye – Crew Member
Liam Shelmerdine – Senior Air Quality Consultant
Edward Smith – Environmental Economist
Rachel Stephenson – Graduate Consultant
Charlotte Stephenson – Project Environmental Scientist
Micha Stuart – Geo-Environmental Consultant
Sorina Sulitau – Graduate Geo-Environmental Consultant
James Tew – Environmental Consultant
Sai Turlapati – Geo-Environmental Engineer
Thomas Vaughan – Graduate Air Quality Consultant
Natasha Weekes – Environmental Consultant
Iwan Williams – Graduate
Eunice Wong – Graduate Environmental Scientist

Affiliate is for individuals with an interest in environmental issues but who don't work in the field, or for students on non-accredited programmes.

Henry Brown – Apprentice Environmental Consultant - AECOM
Zack Dresner Barnes – Student and Environmental Practitioner Apprentice
Mia Fraser – Student
Arif Fuzzaman – Operation Officer
Elspeth Grace – Environmental Consultant
Kelly Greener – Environmental Consultant
Helena Januszewski – Student
Lynsey Marie Little – Student
Adam Livesey – Student
Michael Loyns – Asset Engineer
Nigel Martin – Damp & Mould Surveyor
Rowan Mataram – Sustainable Cities Strategy & Project Lead
Iain Miller – Head of Air Quality
Chris George Rajan – Air Quality Technician
Harriet Sleight – Graduate Teaching Assistant
Charles Townsend – Student

Member is for those individuals who have substantial academic and work experience within environmental science.

Thomas Adams – Principal Consultant
Faraz Ahmed – Environmental Specialist
Lovemore Amidu – Head of Environmental Management
Katy Andrews – Environmental Advisor
Neil Balderstone – Principal Environmental Consultant
Claire Barrett-Mold – Principal EIA Consultant
Thomas Bartle – Senior Air Quality Consultant
Benjamin Beaton – Director and Environmental Consultant
Michael Bell – Air Quality Consultant
Joshi Bhargav – Senior Environment Engineer
Louisa Bindi – Senior Geo-Environmental Consultant
Rebecca Booley – Environmental Consultant
Matthew Buckler – Head of Wilder Landscapes
Desiree Carolus – Senior Consultant
Peter Chesney – Senior Technical Advisor
Rachel Cossins – Environmental Scientist
Lai Han Natalie Cunningham – Principal Environmental Consultant
Pierangelo Di Stefano – Principal Consultant
Stuart Dunlop – Sustainability & Accessibility Manager
Michael Emery – Geo-Environmental Engineer
Thomas Fisher – Senior Oil Spill Response Specialist
Matthew Forman – Senior Environmental Scientist
Maria Fuhrmann – Consultant
Jamie Gordon – Principal Consultant
Joanna Hall – Senior Consultant
Tatenda Hanyani – Environmental & Climate Specialist
Laura Harpham – Agricultural Consultant
Harrison Hazell – Principal Sustainability Consultant
Yessika Hernandez – Senior Technical Advisor
Ohione Ilavbare – Environmental Manager
Zeeshan Ismail – Senior Executive Officer
Rachel Jackson – HSE Representative
Jovish John – Environmental Engineer
Kerry Jones – Principal Consultant
Richard Jones – Senior Environmental Consultant
Abigail Juggins – Senior Environmental Consultant
Anuraj Kaimal – Terrestrial Ecologist
Freddie Kennedy – Head of Geo-Environmental
Susan Kenworthy – Senior Investigations Officer
Paul Kimber – Technical Services Manager
Charlotte Main – Associate - Land Quality
Raquel Martin Trivino – Team Manager & Principal Consultant
Lauren Massingham – Principal Air Quality Consultant
Diane McGuigan – Environment Specialist
Scott Milligan – Carbon Consultant
Oliver Milliner – Head of Sustainability
Remya Mohan – Senior Environmental Engineer
Ciara Nolan – Senior Air Quality Consultant
Deo Okure – Air Quality Scientist & Programme Manager
Olufunminire Onamuti – Quality Control Analyst
Chrysoula Pantsi – Lecturer
Daniel Peters – Geo-Environmental Engineer
Alice Pooley – Senior Geo-Environmental Consultant
Erica Powell – Senior Environmental Consultant
Rama Gowri Shankar Robbi – Senior Air Quality Scientist & Engineer
Andrew Robertson – Environmental Consultant
Drew Smith – Senior Environmental Advisor
Ross Smith – Principal Consultant
Amanda Sterkenburg – Marketing Manager, Europe
Richard Swailes – Safety & Environmental Consultant
Ikediashi Umuodum – Environment & Safety Manager
Anthony Vine – Technical Manager
Katherine Ward – Consultant
Vicky Warren – Senior Environmental Consultant
Jonathan Weston – Senior Environmental Consultant
Alexandrea White – Ecological Consultant
Aled Williams – Geo-Environmental Engineer
Gareth Wood – Principal Environmental Scientist

Not a member?

Whatever stage of your career you are at, the IES has membership services that will help you gain recognition and progress to the next level. Members come from all areas of the environmental sector, wherever their work is underpinned by science.

Time for a re-grade?

If your career has progressed recently it could be time for a re-grade to reflect your success.

Re-grading can take place at any time of the year. Re-grading from Associate to Full Member means that you can apply for Chartership. There's never been a better time to take the next step in your career.

Eligible for chartership?

If you have been building your career for four years or more, now could be the right time to become Chartered.

Chartered status is a benchmark of professionalism and achieving this will see you join the ranks of the best environmental scientists in the sector. The IES awards two Charterships: Chartered Scientist and Chartered Environmentalist. We also offer the REnvTech register.

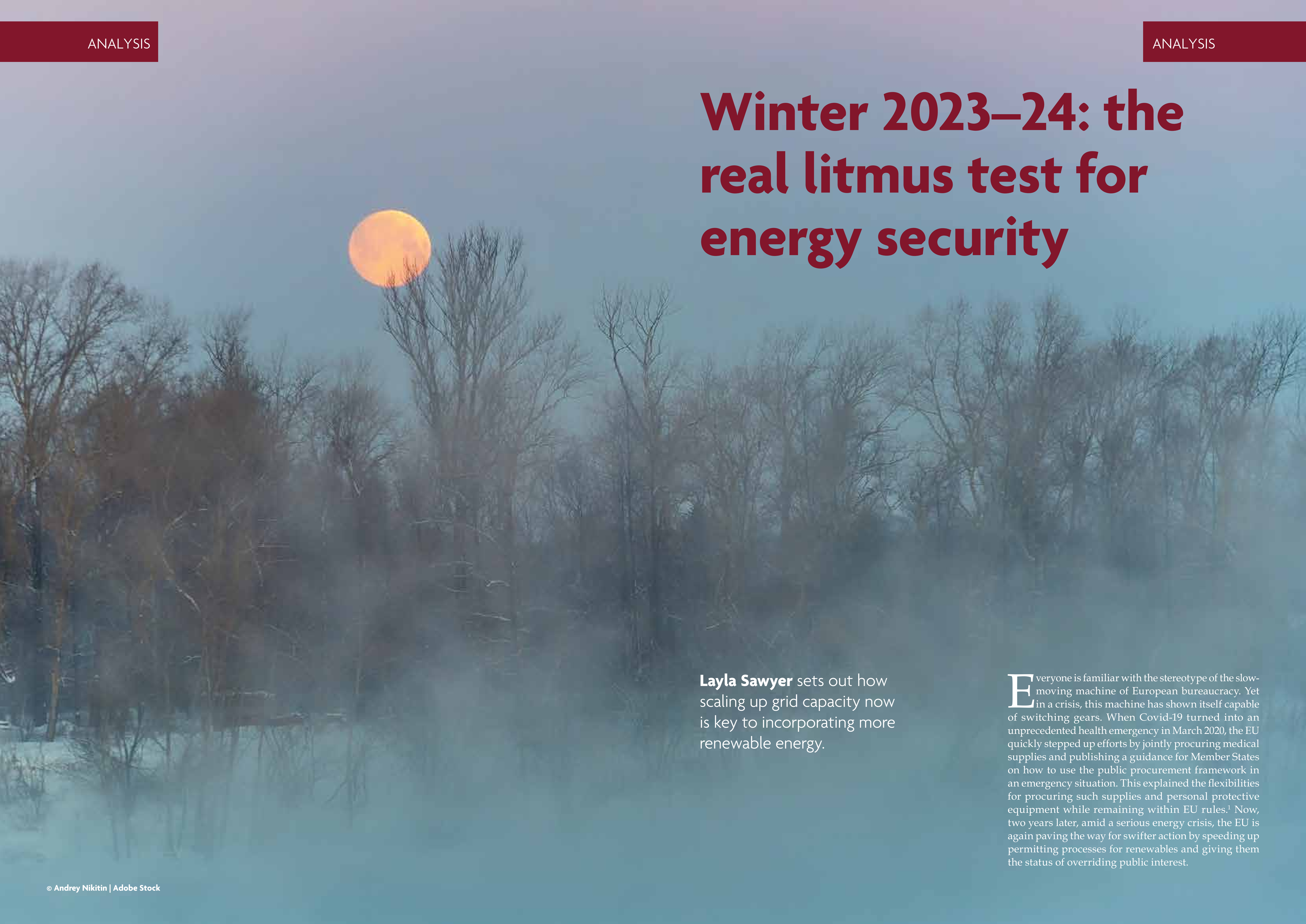
Contact Us

To find out more about membership or chartership, get in touch.

info@the-ies.org
+44 (0)20 3862 7484
www.the-ies.org
@IES_UK

ANALYSIS

Winter 2023–24: the real litmus test for energy security



© Andrey Nikitin | Adobe Stock

Layla Sawyer sets out how scaling up grid capacity now is key to incorporating more renewable energy.

Everyone is familiar with the stereotype of the slow-moving machine of European bureaucracy. Yet in a crisis, this machine has shown itself capable of switching gears. When Covid-19 turned into an unprecedented health emergency in March 2020, the EU quickly stepped up efforts by jointly procuring medical supplies and publishing a guidance for Member States on how to use the public procurement framework in an emergency situation. This explained the flexibilities for procuring such supplies and personal protective equipment while remaining within EU rules.[1] Now, two years later, amid a serious energy crisis, the EU is again paving the way for swifter action by speeding up permitting processes for renewables and giving them the status of overriding public interest.


© mahout | Adobe Stock

However, now that Europe has made it through the first winter of the energy crisis, it is time to switch to the highest gear yet. Spring is in the air, but next winter is just around the corner – and that may prove to be the real litmus test for European energy security. The International Energy Agency has already issued stark warnings and published reports highlighting the gas demand–supply gap for the forthcoming winter, even with all the extra measures that have been announced.[2]

Scaling up renewables is a crucial part of the EU's strategy to wean itself off Russian fossil fuels, as outlined in the European Commission's REPowerEU plan, and powerful electricity grids will be needed to integrate them.[3] By all measures, Europe is not moving fast enough to increase the electricity grid's capacity at the rate required. While the EU has already demonstrated that the regular rules do not apply in emergency situations – as with Covid-19 and phasing out of Russian fossil fuels – this same level of resolve has not yet been seen around scaling up grid capacity before next winter and the ones to come after that.

It seems obvious that the fastest way to scale up and reduce curtailment of renewables is to make better use of existing infrastructure. In addition to well-known solutions behind the meter (i.e. smart charging, virtual power plants, demand response), there is a whole range of less-mediagenic technologies on the network side, many of which are already widely commercially available. While these technologies can optimise the use of the network and free up available line capacity, they are often overlooked or under-incentivised in the European regulatory framework.

Grid capacity challenges are not unique to Europe. Many regions across the globe have faced comparable challenges and have developed different approaches to quickly increase capacity without breaking the bank. While no solution is perfect, there is much that Europe can learn from the regulatory approaches developed elsewhere.

SPEEDING UP QUICK WINS IN AUSTRALIA

On the other side of the world, the Australian regulator is encouraging utilities to pursue smaller, faster projects via the Network Capability Incentive Parameter Action Plan (NCIPAP) as part of a scheme to incentivise efficient investment in infrastructure.[4] In order to qualify for this streamlined process, a project must cost less than AU$6 million, must increase network capability and provide net market benefits (e.g. lowering consumer energy costs or deferring the need for more capital-intensive projects). As an incentive, NCIPAP projects also receive a 50 per cent greater return. This scheme has resulted in a significant amount of funding for smaller projects that can be delivered much faster than building new transmission lines.

COMPETING FOR THE BEST SOLUTIONS IN COLOMBIA

Another strategy to increase grid capacity quickly and cost effectively is to introduce a certain amount of competition into the natural monopoly of the electricity grid. In Colombia, for example, the central planning agency – Unidad de Planeación Minero Energética (UPME) – plans the transmission system, which includes both the long- and short-term needs of the entire national network. All transmission operators are then invited to propose solutions to UPME in a highly competitive process that favours solutions that utilise existing right-of-way corridors. Transmission operators compete for projects across the country, resulting in more efficient solutions to meet the network's needs. This competitive process provides an incentive to propose the most cost-efficient solution, which inherently prioritises optimising and upgrading the existing network.

NETWORK OPTIONS ASSESSMENT IN THE UK

In the UK, the Network Options Assessment is designed to evaluate multiple options to resolve an identified network need in a transparent and technology-neutral way. Every year, the electricity system operator (ESO) predicts the future requirements of the power system based on future energy scenarios and extensive stakeholder engagement. Transmission owners then submit project proposals that meet those identified needs. These network options are then transparently evaluated under a 'least worst regrets' analysis to assess the benefits under each scenario, and the ESO recommends which options should receive investment and when.

The process is repeated every year, which reduces the risk of oversized solutions or bad investment decisions, as each network option is re-assessed based on how the system evolves over time. This incentivises the use of solutions that can be quickly delivered to provide benefits earlier than alternatives and can be adapted over time. This enables the transmission owners to defer some investment decisions for large infrastructure until more certainty of the network need exists while still meeting the near-term network needs with alternative solutions.


© Ingo Bartussek | Adobe Stock

ANALYSIS


© finecki | Adobe Stock

MANDATORY HOURLY CAPACITY UPDATES IN THE USA

A big part of optimising the use of the existing electricity grid comes from measuring how much electricity can pass through the transmission lines at any given moment. In the past, line ratings have been based on conservative estimates that would ensure electricity can be transferred safely on the hottest day of the year with no cooling wind at all. Modern sensor technologies, as well as more accurate modelling software, can provide more precise insight into how much capacity is actually available on the grid based on the weather conditions at any point in time, and is a simple way of increasing grid capacity in the very short term. In December 2021, the US Federal Energy Regulatory Commission issued Order No. 881, which requires transmission operators to update grid capacities hourly based on air temperatures and solar radiation.[5] While this still does not take all factors into effect (e.g. wind cooling), it is a step forward in making more efficient use of the transmission system and keeping the costs of energy transition as low as possible.

CONCLUSION

Europe can and must go much faster in scaling up the electricity grid and increasing energy security for next winter and beyond. While none of these regulatory approaches is likely to be the silver bullet for solving Europe's energy crisis, it is important to find the right incentives to increase grid capacity quickly and cost effectively in order to integrate as many renewables as possible, as quickly as possible. ES

Layla Sawyer is the Secretary General of currENT, the voice of innovative grid technology companies in Europe. She was previously Head of Business Development at smartEn, where she worked on demand-side flexibility, digitalisation and the future of prosumer models. She studied sustainable business and innovation at the University of Utrecht in the Netherlands.

REFERENCES

1. European Union (2020) Communication from the Commission. Guidance from the European Commission on using the public procurement framework in the emergency situation related to the COVID-19 crisis 2020/C 108 I/01. *Official Journal of the European Union*. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52020XC0401(05)&from=EN. (Accessed: 22 March 2023).
2. International Energy Agency (2022) *How to avoid gas shortages in the European Union in 2023.* https://www.iea.org/reports/how-to-avoid-gas-shortages-in-the-european-union-in-2023 (Accessed: 22 March 2023).
3. European Commission (2022) *REPowerEU Plan.* https://eur-lex.europa.eu/resource.html?uri=cellar:fc930f14-d7ae-11ec-a95f-01aa75ed71a1.0001.02/DOC_1&format=PDF (Accessed: 22 March 2023).
4. ElectraNet (2022) *Network Capability Incentive Parameter Action Plan: Revenue Proposal 2023–2024 to 2027–2028.* https://www.aer.gov.au/system/files/ENET012%20-%20ElectraNet%20-%20Attachment%2010%20-%20Appendix%20A%20NCIP%20Action%20Plan%20-%2031%20January%202022.pdf (Accessed: 22 March 2023).
5. United States Federal Energy Regulatory Commission (2021) *Managing transmission line ratings.* https://www.ferc.gov/media/e-1-rm20-16-000 (Accessed: 22 March 2023).

FEATURE

The value of understanding the weather in a changing energy sector

Emily Wallace investigates the importance of forecasting for resilient low-carbon energy generation.

Our energy system is changing. Understanding weather variability is becoming critical to ensuring safe, efficient and resilient infrastructure operation and for medium- and long-term planning. Energy generation is moving from being primarily fossil fuel powered to becoming increasingly reliant on weather-driven renewables. In what is known as the energy transition, how we use energy is also changing, with electric heating, air conditioning and electric vehicles becoming more widespread and new energy-storage technologies coming online.

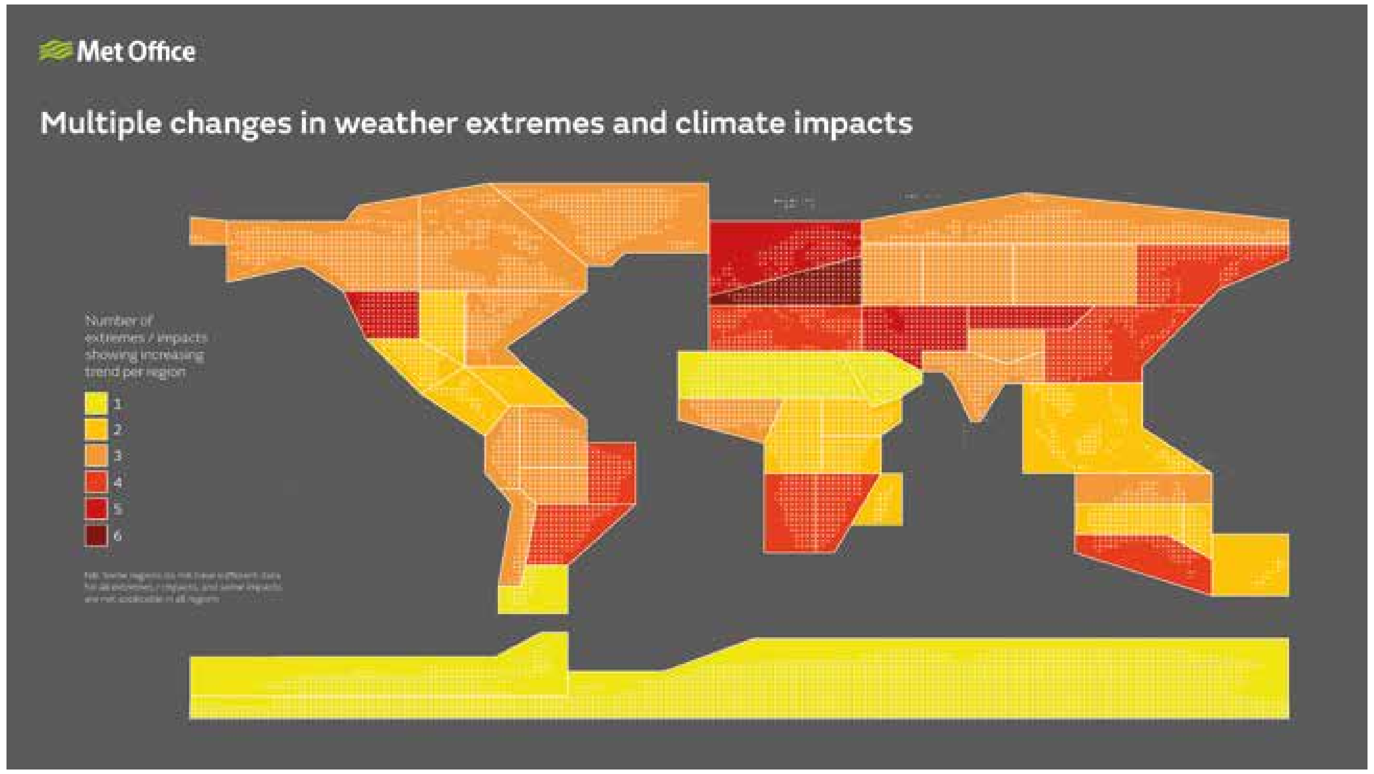
This energy transition is vital if we are to meet our global ambitions to lower greenhouse gas emissions, which is necessary if we are to limit the impacts of extreme weather on humans and the systems we rely on. However, the combination of this energy transition and the increasing threat from climate change will expose our energy system even more to hazardous weather. Even without climate change the energy transition means that energy generation is inherently less predictable and energy networks and renewable energy-generation infrastructure are more exposed to weather than the conventional system. This causes challenges in ensuring a reliable and sufficient supply of energy to those who need it. At the same time, increasingly hazardous weather from our changing climate is already causing damage to infrastructure, compounding these challenges.

It is therefore necessary for the energy industry to place a much greater focus on the link between weather and energy. From all parts of the energy sector, new questions are emerging of how to manage and exploit the risk, and opportunity, this brings. These questions need urgent consideration to support a cost-effective, low-carbon and resilient energy transition.

MAKING BEST USE OF FORECASTS TODAY

Significant weather exposure is not a problem for the distant future. The energy-generation network has already undergone dramatic change: since 2012 there has been a twofold increase globally in installed renewable energy capacity and a further increase of 75 per cent is expected over the next five years.[1] This means that network operators around the world are already dealing with balancing energy generation that fluctuates, sometimes abruptly, depending on wind speed, cloud cover, fog and temperature extremes.

To manage this variable generation and optimise the use of clean renewable energy, rather than rely on fossil fuels to plug the gap, forecasts of the highest quality are required. This necessitates investment in weather forecast techniques, in the algorithms used to convert these weather forecasts into estimates of energy generation and in understanding how to use this information to make good decisions. Weather and energy-generation forecasts can never provide perfect predictive information, and the level of certainty varies between scenarios. An ongoing dialogue is needed within the forecasting community and users of these forecasts, while a focus on scenario-based techniques can help to make the most of predictive information and large data volumes. Coupled with a collaborative approach to the development of energy predictions to promote accuracy and usefulness, this will allow network operators and users to reduce reliance on fossil fuels.



▲ **Figure 1. Observed trends in climate extremes and impacts. The map shows the number of extreme weather-related indices with an increasing trend over recent decades. The indices relate to observed occurrences of extreme high temperatures, heavy rainfall and flooding, river flows, agricultural drought, fire weather and glacier mass. Evidence for increases or decreases in indices was taken from peer-reviewed studies. An indicator of 6 on the map designates all extremes/impacts increasing; this means that somewhere in the region has experienced increases in extremes of all six indices. Areas with an indicator of 1 demonstrate evidence that only one of the indices is increasing; this can be because the other indices are decreasing, have no clear trend, do not have sufficient data for analysis, or are not relevant to that region. (Source: Met Office[3])**

Our present-day energy system is at the mercy of the weather when it comes to managing energy generation. Our existing energy infrastructure is also exposed to damage from extreme weather in our already warmed climate. Over the past decade, global temperatures have fluctuated around approximately 1.1C above pre-industrial levels.[2] This has increased instances of extreme high temperatures, wildfire conditions, coastal and inland flooding and drought in many regions,[3] and there is some evidence of changes in storminess.[4] These extreme events can damage infrastructure – for example, by trees falling on equipment, heat causing the dangerous sagging of overhead lies, and coastal flooding leading to salt ingress and corrosion (see **Figure 1**).

In all seasons there are key weather scenarios that can impact the safe and efficient operation of energy networks or repair of damaged infrastructure. These impacts can come from direct and indirect risks. Examples of direct risks include storms damaging the power network and exposing personnel to dangerous conditions, while indirect risks could result from a lack of telecommunications connectivity due to heat-related faults or flooding on transport networks preventing access to assets.

With modern forecast systems it is possible to detect an enhanced probability of these risk scenarios weeks and even months in advance. A key example was seen in February 2022 when three storms (named Dudley, Eunice and Franklin) hit the UK in quick succession. The second of these, Eunice, was the most severe and damaging in almost a decade. As well as loss of life, these three storms caused major disruption to road and rail infrastructure and port operations. Power cuts were widespread and lengthy, partly due to the string of storms hampering clean-up operations.

The increased risk of stormy weather during this period was identified as early as November 2021. The detail around expected conditions increased over time, with warning of the specific storms pinpointed with six days' notice. This allowed emergency responders to prepare and communicate the danger to the public, without which the impacts would undoubtedly have been greater. However, more can still be done to determine and monitor other cross-sectoral scenarios that would put pressure on and ultimately impact the public and industry.

Despite advances in predictability, total certainty in high-impact events occurring and the exact nature of an event – such as precise location of snow drifts, strongest wind gusts or lightning – remains impossible. Therefore, a scenario-based approach, considering a range of potential outcomes is essential if we are to create system resilience. Information that puts these scenarios in the context of the past and future can support decision-making in the short and longer term. For example, in our changing climate we will encounter hazardous scenarios, the severity of which we have never encountered before. Highlighting the unprecedented nature of an event can promote appropriate action from individuals who may otherwise not understand the seriousness of the weather conditions. Historical and future context are also important for longer-term planning – organisations often have short memories.

© galitskaya | Adobe Stock

When deciding how to invest it can be very valuable to use recent impactful scenarios as a baseline to describe future challenges.

> **"When high-risk scenarios emerge, a multi-agency approach can help to ride out the storm."**

When high-risk scenarios emerge, a multi-agency approach can help to ride out the storm. Sharing knowledge and planning the response between sectors, including operators, regulators and relevant government departments, can ensure that impacts from the weather and other system stressors can be appropriately managed. Following an extreme weather event, a review of the chain of information provision, decision-making and outcomes can improve our response over time.

KEEPING PACE WITH A CHANGING CLIMATE

Building standards and regulations is the responsibility of international agencies and industry bodies, and they are vital to promoting the safe design of infrastructure in all sectors, including energy. Much of the infrastructure built today will need to continue to function safely into the 2050s, 2060s and beyond. By this time, even under the most ambitious greenhouse gas reduction pathways, it is very likely that we will be experiencing significantly more warming than we already are. Climate projections indicate that globally there will be a higher chance of heatwaves and wildfires and more intense rainfall leading to increased flooding even while there is greater water scarcity in many parts of the world. Additionally, in some regions there may be changes to wind speeds and storminess and increased storm surges associated with rising sea levels. All these changes will provide challenges to the safe and efficient operation of energy infrastructure. While we can limit the extent of these impacts by reducing greenhouse gas emissions, some changes are inevitable.

In some parts of the energy sector standards and regulations have kept pace with our shifting climate and explicitly require consideration of the changes we expect to see in weather hazards. For example, the UK's Office for Nuclear Regulation specifies that licences for the design, planning, construction, operation and decommissioning of nuclear facilities will only be issued where duty holders (the facility owners) have used information from the latest authoritative UK Climate Projections (currently UKCP18)[5] 'for an appropriate timeframe'.[6] The onus is on the duty holder to make a case that they have done so in a manner which constitutes relevant best practice. This also means updating the case when new information comes to light, such as more detailed projections. However, other areas of the energy sector are bound to regulation that is out of date in terms of the referenced climate, does not account for future climate conditions and has not kept up with the pace of scientific expertise that allows for much better characterisation of weather-related risks.

Out-of-date regulations do not only put the public and maintenance crews at risk from the infrastructure itself. Where assets are not designed to operate efficiently under future climate conditions, there will be a cost to consumers in terms of lack of supply and cost of energy. Furthermore, in some instances, over-design is promoted by some standards and regulations. This has financial implications for network operators and increases the carbon cost of new infrastructure.

These problems have wider impacts than on the energy sector alone. Regulators should be encouraged to work together to solve similar problems and recognise the interdependencies between sectors. This was recently acknowledged in the UK in the Joint Committee on National Security Strategy's report, which called for the creation of a forum to link regulatory bodies between sectors and better address the cascading risks that occur when one or more sectors is impacted.[7]

PLANNING AND POLICIES FIT FOR THE FUTURE

Sophisticated real-time weather monitoring and appropriate use of regulations and standards can help energy networks remain resilient. The final essential element to securing future energy resilience is to have the right technologies in place in the right geographies, which can only be achieved through well-evidenced planning and policy.

Conventionally, much energy-system planning has been relatively simplistic, often only considering average conditions and making significant assumptions about the geographical distribution of energy generation. For our future world this is no longer appropriate. Our future energy system will need to cope with conditions that historically would have appeared relatively benign. For example, in the northern mid latitudes (Northern Europe, North America, Canada) low winds frequently coincide with particularly cold weather conditions during winter; these conditions often have a very large spatial scale, covering many hundreds of kilometres at a time.

The Met Office worked to quantify these and provide a resource for energy modellers to stress-test their plans.[8] The resulting report described how these events are already challenging within our current system and could present an even greater risk in the future. Demand for electricity will be greater, since the energy transition will have to meet increased demand for electric heating and electric vehicles, and in cold, low-wind scenarios, low-carbon generation will be reduced because it relies much more heavily on wind energy. Furthermore, the large spatial scales will mean that neighbouring countries may be unable to meet the energy shortfall since they will be suffering from similar problems.

Policy-makers must consider these high-impact scenarios and understand the technologies that could plug this gap. To do this, they must understand the frequency and duration of these phenomena, the role of energy storage and how other energy generation-relevant weather is likely to behave at the same time (e.g. solar output, wave activity, precipitation levels). Even technologies that can appear to have a small role in terms of total generation or storage could be critical if they extend across periods of significant challenge and help to maintain energy security.

Energy transition and climate change are upon us. They have already created greater exposure of our energy system to weather conditions, around both less-predictable generation and demand and network maintenance. To ride out the storm the sector must recognise the risks and opportunities that weather brings, and plan to design, build and operate the system appropriately by integrating weather and climate expertise into every aspect. ES

Dr Emily Wallace is a Fellow in Weather and Climate Extremes and Impacts at the Met Office. Throughout her career she has championed the transition to resilient, low-carbon energy by improving the way the sector uses weather and climate information for planning, building, operating and decommissioning energy infrastructure.

energy@metoffice.gov.uk

www.linkedin.com/in/emily-wallace-48a62827/

REFERENCES

1. International Energy Agency (2022) *Renewables 2022. Analysis and Forecast to 2027*. https://iea.blob.core.windows.net/assets/ada7af90-e280-46c4-a577-df2e4fb44254/Renewables2022.pdf (Accessed: 25 February 2023).
2. Met Office Climate Dashboard (no date) *Tracking the changing climate with Earth observations*. https://climate.metoffice.cloud/ (Accessed: 25 February 2023).
3. Met Office (2022) *Observed Climate Extremes/Impacts Trends*. https://www.metoffice.gov.uk/binaries/content/assets/metofficegovuk/pdf/research/climate-science/impacts/observed-climate-extreme_impact-trend-maps_07112022.pdf (Accessed: 25 February 2023).
4. Intergovernmental Panel on Climate Change (2021) *Sixth Assessment Report. Summary for policymakers*. Working Group 1. https://www.ipcc.ch/report/ar6/wg1/chapter/summary-for-policymakers/ (Accessed: 25 February 2023).
5. Met Office (no date) *UK climate projections (UKCP)*. https://www.metoffice.gov.uk/research/approach/collaboration/ukcp (Accessed: 25 February 2023).
6. Office for Nuclear Regulation, Environment Agency, Natural Resources Wales and Scottish Environment Protection Agency (2022) *Use of UK Climate Projections 2018 (UKCP18) Position Statement*. https://www.onr.org.uk/documents/2022/ukcp18-position-statement-rev-2.pdf (Accessed: 25 February 2023).
7. Moore, C. (2022) UK's critical infrastructure deemed vulnerable to 'cascading' risks from climate change, *New Civil Engineer*, 27 October. https://www.newcivilengineer.com/latest/uks-critical-infrastructure-deemed-vulnerable-to-cascading-risks-from-climate-change-27-10-2022/ (Accessed: 25 February 2023).
8. Dawkins, L., Rushby, I. and Pearce, M. (2021) *Adverse Weather Scenarios for Future Electricity Systems: Developing the Dataset of Long-duration Events*. Devon: Met Office. https://nic.org.uk/app/uploads/MetOffice_NIC_CCC_Phase2bReport.pdf (Accessed: 25 February 2023).

CASE STUDY

Creating local energy in the Royal Borough of Kensington and Chelsea

Caitlin Mackesy Davies explains how Repowering London and community energy projects are helping one London council create a low-carbon borough.

In 2018, Councillor David Lindsay of the Royal Borough of Kensington and Chelsea (RBKC) shared these optimistic words: 'I believe this project represents a chance for the council … to make a real difference, inspire future generations and help tackle one of the biggest issues of our time.' The occasion was the launch of a community share offer supporting North Kensington Community Energy (NKCE), the first community-owned renewable energy project established in the borough.

◀ **North Kensington Community Energy members in front of the Dalgarno Community Centre. (© Joe Burrows)**

NKCE was developed thanks to a partnership between the RBKC's Climate Change team and community energy organisation Repowering London, which currently supports eight community energy co-operatives across London. Under the banner of Creating Local Energy, Repowering London's goal is to give London's communities 'the power to create, control and benefit from renewable energy, and play an active part in the transition to a low-carbon society' (see **Figure 1**). Following Repowering London's well-established model, NKCE embodies the organisation's core mission: to put people at the heart of the energy system.

The word 'active' is not just there for window-dressing. A vital first step in any Repowering London project is to build strong, collaborative relationships with local organisations and partners such as London councils so that every co-operative is well supported and working towards a clear, shared goal. In the RBKC that goal was to create a low-carbon borough in the heart of London. The initiative received support from across the council,

▲ **Figure 1. The Repowering London cooperative model. (© Repowering London)**

including assistance from the executive, Children's Services, Corporate Property and Housing teams. Other important partners bringing much-needed resources to the development process included the Mayor of London, blowUP Media, local charity Migrants Organise, and the Westway Trust – a local organisation working towards sustainable wellbeing in North Kensington.

BRINGING THE COMMUNITY ON BOARD

With the groundwork laid, it was time to bring the whole community on board so that the project would be led by it and produced in a collaborative environment. And although NKCE welcomed interest from across Kensington and Chelsea, its focus has been on the North Kensington area, which is surrounded by some of the wealthiest streets in the UK yet is home to some of the country's poorest people. This income imbalance was brought into sharp focus by the Grenfell Tower fire in 2017, which revealed the stark differences in the way people live in the borough and the services they receive. Making sure the voices of all residents are heard, as well as reducing energy costs and providing a path to green-industry training and employment, is therefore an important goal of the NKCE project.

A grassroots campaign was launched to explain to residents how community energy can help them and their neighbourhoods. This included distributing around 3,500 flyers and putting up 150 posters in local shops, cafes, libraries, markets and community spaces (see **Figure 2**). The community was invited to public meetings held across the borough to learn more about the project and how residents

▲ **Clockwise: Figure 2. Spreading the word about North Kensington Community Energy included postering and leafletting in the local area. Figure 3. Solar panels in place on the Thomas Jones Primary School. (© Joe Burrows) Figure 4. View of the Westway Sports Centre solar installation. (© Joe Burrows)**

▲ **Figure 5. North Kensington Community Energy's directors and members at the Westway Sports Centre installation, with Royal Borough of Kensington and Chelsea Deputy Mayor Janet Evans (fourth from left). (© Joe Burrows)**

could become involved. Consultation events were also organised for people to share their views and for decisions to be made by consensus. The sessions also helped to embed strong engagement principles, such as being positive, respectful, responsible, honest and responsive – values that have been crucial for keeping the group focused. In addition, information events were held at local schools, universities and community centres, including solar panel-making workshops and energy advice sessions.

RAISING FUNDS AND NURTURING LOCAL LEADERS

At the same time, the Community Benefit Society – a legal entity whose purpose is to serve the benefit of the greater community – was established to administer NKCE projects, and local volunteers were recruited to key leadership roles. Then came the launch of the community share offer to attract local investors, which included affordable share prices and the prospect of a 3 per cent annual return over 20 years. The society's 144 members – many of whom live in the borough's most-deprived north – successfully raised the £83,000 needed for the first NKCE solar installations and helped to put a total of 306 solar photovoltaic panels on North Kensington's Avondale Park Primary School, Thomas Jones Primary School (see **Figure 3**), and the Dalgarno Community Centre.

Since then, NKCE has worked with Westway Sports & Fitness Centre to install 138kWp (kilowatt peak power, a unit associated with solar installations) of solar panels on its roof. The panels, installed in October 2020, have already reduced the centre's carbon dioxide (CO_2) emissions by over 53 tonnes (see **Figure 4**). NKCE raised a total of £107,000 through a second community share offer for this project, involving over 100 investors.

In common with all Repowering London co-operatives, a Community Fund was also created for NKCE with the aim of using the money raised through energy sales to support local causes more widely. Through income generated by the (now discontinued) feed-in-tariff, the sale of energy at a discounted rate to the sites where solar panels were installed, and the sale of any excess electricity to the grid, it is estimated that around £70,000 will be raised for the fund over the project's 20-year lifetime.

To date, the fund has contributed towards the cost of installing solar panels on a nearby community centre (Edward Woods) and installing energy-saving upgrades at one of its existing sites, the Dalgarno Community Centre. The Dalgarno contribution activated further donations from the council and supported the centre at a time when it was looking for help to manage soaring energy costs.

CREATING A GREEN TALENT PIPELINE

Understanding that a low-carbon future will require a ready workforce, NKCE is also giving people in the borough the necessary tools to participate in the fast-growing green economy. As part of this effort, Repowering London delivered a paid youth training programme through which 42 young people aged 16–19 from the borough and surrounding area completed an AQA-accredited course (formerly known as the Assessment and Qualifications Alliance) while being paid the London Living Wage. The programme offers learning in subjects such as energy and solar power feasibility, solar panel-making workshops and in-person community engagement and includes work experience placements.

Meanwhile, NKCE's volunteers are learning transferable skills in marketing, project management and more. One community lead employed by Repowering London is using her deep neighbourhood network to create a bridge across the borough while building the skills she needs to participate in the environmental and co-operative economy. Co-operative events such as Greener Living Days (see **Figure 6** and **Figure 7**) offer opportunities for the whole community to be creative and collaborative, build practical knowledge around energy efficiency and imagine a low-carbon future.

The energy at such gatherings is palpable, and co-operative members have shared their own enthusiasm for NKCE and its aims. Feedback from one resident and NKCE member highlighted how 'becoming a shareholder allows residents to participate in something that moves things forward environmentally at a local level and give material form to values that matter', and also spoke of their excitement that 'community renewable energy is now up and running in the borough and is fully funded'.

So with visible evidence of energy-system change on its rooftops and a growing community of engaged citizens, NKCE is driving grassroots behaviour change and empowering local people to take positive climate action. Its community of over 200 members, volunteers, investors and supporters is spreading the message

BOX 1. SOLAR INSTALLATIONS IN BRIEF[a]

North Kensington Community Energy's solar installations to date include the following:

Dalgarno Community Centre Hosts 158 solar panels, representing an electricity capacity of 43kWp. Anticipated savings of 168.4 tonnes of CO_2 over the project's lifetime.

Thomas Jones Primary School Hosts 88 solar panels, representing an electricity capacity of 30kWp. Anticipated savings of 117.5 tonnes of CO_2 over the project's lifetime.

Avondale Park Primary School Hosts 60 solar panels, representing an electricity capacity of 14kWp. Anticipated savings of 54.8 tonnes of CO_2 over the project's lifetime.

Westway Sports Centre Hosts 500 panels, representing an electricity capacity of 138kWp. Anticipated savings of 540.5 tonnes of CO_2 over the project's lifetime.

[a] All lifetime CO_2 savings are based on the Department for Business, Energy and Industrial Strategy carbon conversion factor 2020 and assume a project lifetime of 20 years.

▲ **Figure 6. At a Greener Living Day in February 2023 children imagined what a solar-powered future might look like. (© Tran Phuc Hai)**

that everyone can play a part in the fight to maintain a liveable climate, create a fair energy future and make a just transition to a low-carbon society. It is inspiring individuals to move beyond roles as passive consumers in the energy system and to help build a system with tangible benefits for themselves and their neighbours – including reduced energy costs, opportunities for skill development and stronger community networks.

NKCE members have also shared practical tools and lessons on what works well for them, helping to build knowledge across other co-operatives with similar aspirations. Recently, for example, NKCE and Repowering London have supported the establishment of a new community energy co-operative in neighbouring Hammersmith and Fulham, providing mentoring, sharing expertise and building on shared links.

NKCE offers a successful model for building collaborative, low-carbon partnerships between councils and community stakeholders. For the community energy sector more widely, it is an example of a thriving and self-sufficient co-operative, offering inspiration for community energy groups at different stages of their development. ES

Caitlin Mackesy Davies is the Communications Officer for Repowering London. Caitlin has worked in the communications sector for over 30 years, with a particular focus on membership publishing and nurturing communities of interest. Over recent years, she has been heavily involved in environmental activism and community organising aimed at meeting the challenges of our changing climate. Repowering London welcomes interest from potential project partners and funders.

caitlin.mackesydavies@repowering.org.uk
www.repowering.org.uk

▲ **Figure 7. North Kensington Community Energy's Community Lead Nasri Ismael welcomed Greener Living Day participants in February 2023. The event included information on energy efficiency measures and a free meal made from rescued 'waste' food. (© Tran Phuc Hai)**

BOX 2. KEY ACHIEVEMENTS

North Kensington Community Energy's key achievements to date include:

- Establishment of the community solar co-operative, with residents taking leadership roles, including project directorship;
- Forty-two local young people taking part in a paid youth training programme;
- A total of 225kWp solar array installed on four buildings of community importance;
- Anticipated emissions reductions of over 880 tonnes of CO_2 over a 20-year time span;
- Around £190,000 in capital funds raised through community share offers; and
- Around £70,000 generated for the Community Fund.

© joon | Adobe Stock

FEATURE

Information communication technologies: infinite growth without environmental impact?

Adrian Friday makes the case for climate-proportional computing.

INTRODUCTION

Information communication technologies (ICT), including the internet and perhaps the device you are using to read this, are ubiquitous. Computational techniques such as machine learning, blockchain and cryptocurrencies, are rarely thought about in terms of their environmental impacts yet are becoming increasingly embedded into scientific endeavour. The case is often made that the value of these technologies to society outweighs their impacts, or even that such impacts are not growing but are offset by decarbonisation and the energy efficiency gains of ICT's application to other sectors. But what is the reality? And should environmental scientists concern themselves with this?

THE IMPACTS OF ICT

The environmental impact of any single ICT device alone may not be that significant. However, when considered in the wider context of the billions of devices, data centres, networks and hidden communication gadgets in our cars and buildings, it adds up to a substantial combined energy and greenhouse gas (GHG) footprint. Calculated at between 1.8 and 3.9 percent globally, it is roughly equivalent to annual air travel.[1]

Some of this comes from the electrical energy required to undertake computing tasks. Less obvious is the energy needed to operate ICT equipment (particularly significant for data centres and supercomputers) or in the ICT supply chain – from the extraction of raw materials, manufacturing and transport to the end-of-life emissions from disposal and hopeful recycling.

A simple factor combining these energy costs is often used when assessing computational tasks such as the cost of a text message or email or a simple web search. But this would be misleading because it focuses the debate on the work that is done without thinking about the growing service infrastructure and drivers of this growth. The embodied cost is important. For a data centre, the energy intensity of computation means the embodied cost could be around 25 per cent of the lifetime emissions. For a mobile phone, this could be as much as 50 per cent, reinforcing the need to maximise a device's usefulness for as long as possible – not a bad principle in general![1]

FEATURE

Advanced technology relies extensively on rare earths and complex supply chains. Some underpinning resources exist in tiny and diminishing quantities. There are non-trivial human rights and environmental impacts associated with who controls and profits from their extraction, sale and processing.[2] The emissions occur overseas and outside a nation's emissions targets, and the workers are out of sight. Similarly, e-waste is a growing environmental and human health problem with potentially toxic materials leaching into the soil and waterways.[3,4]

The location of large-scale data centres has implications for local energy supplies and water access for cooling. This is a complex balancing act involving land cost, energy, tax and network proximity to customers. Use of waste heat and the co-location of supply and demand could even be advantageous to integrating renewables and demand flexibility in energy grids. There are even geographical and geopolitical dimensions to clean energy generation and access to renewable power resources (e.g. latitude, sun, wind, waves etc.).

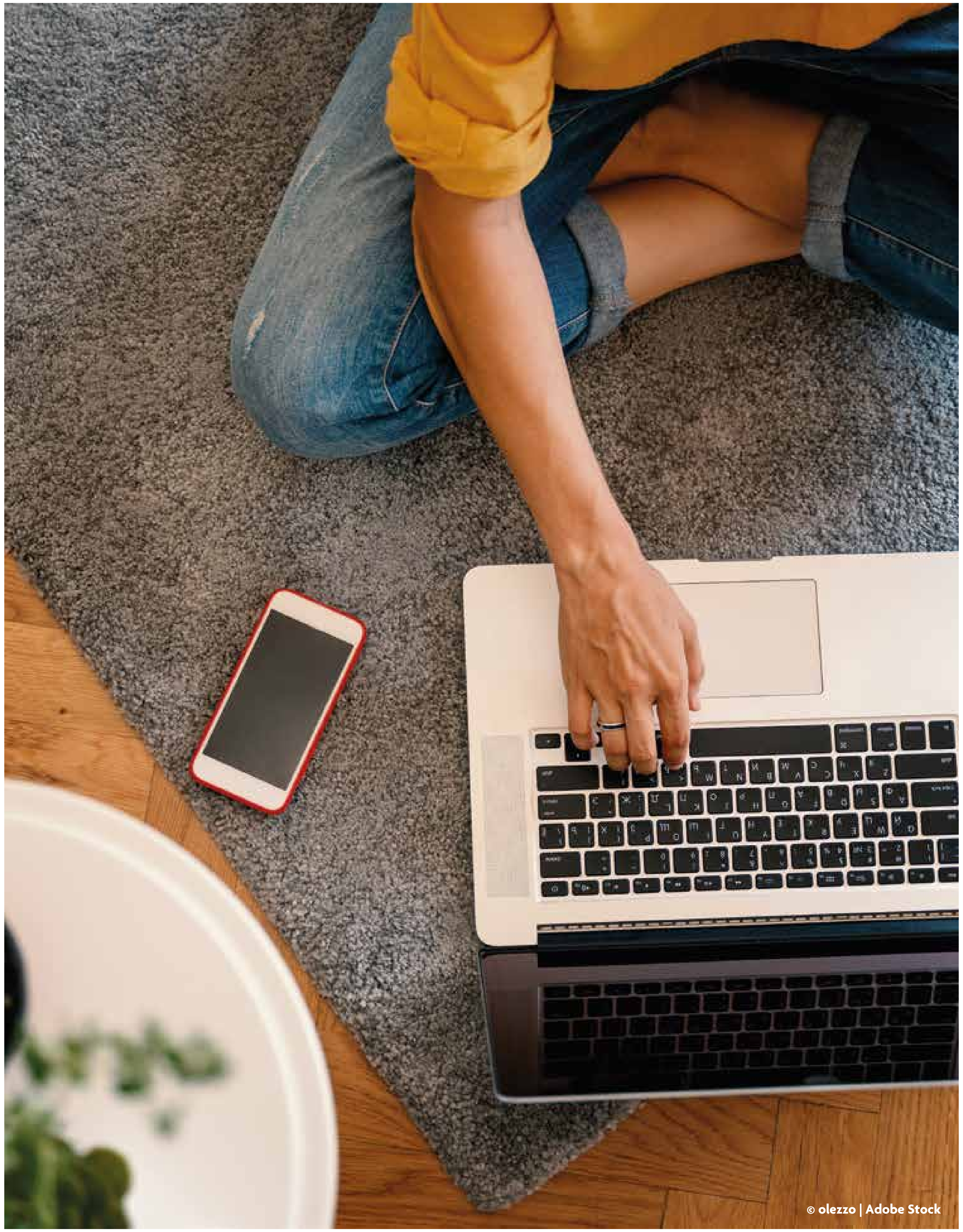
The composition of the energy mix and GHG externality of energy generation where the computation happens vary with both geography and time. A dark secret of the internet is its reliance on fossil fuels in many parts of the world, especially since much of the manufacturing is in countries with carbon-intensive energy mixes.[4]

GROWTH TECHNOLOGIES

Is the ICT sector's GHG footprint still growing? If yes, should there be a limit to this expansion?

Moore's Law stipulates that there will be a doubling of transistors every 18 months, which goes into creating each generation of increasingly powerful processors.[5,6] This progression has become the foundation for improved digital products and services. As computation is embedded into everything, so internet-related infrastructure such as networks and data centres must be expanded to meet demand. Offering faster services and greater interconnections to a growing array of devices in our homes and cities enables new digitally mediated businesses, and so on. This very pervasive application of ICT has even enabled compelling visions of addressing the environmental challenges of climate change through optimisation of ever smarter cities.[7,8]

Some suggest that artificial intelligence, the Internet of Things (i.e. internet-connected sensors and devices with processing capabilities) and autonomous vehicles (e.g. drones) might increase agricultural yields[9] and enable the sensing of soil conditions and development of 'digital twins' – digital models that could help us optimise, predict and control real-world phenomena.[10]



It is important to recognise that, once in place, this infrastructure also lays down a further dependence on ICT with more of the same energy, environmental and social impacts.

These technologies may themselves be computationally expensive by their very design. Machine-learning models require significant computation to train before they can be used. Deep learning (i.e. very large neural network models with millions of inputs), rely on large clusters of computers, making it feasible to compute ever larger models for applications such as natural language processing, speech and image recognition. These models are growing in size.[11] It is also noteworthy that OpenAI's impressive text-generating GPT-3 software took the equivalent of over 400 years of computing time to train.[12]

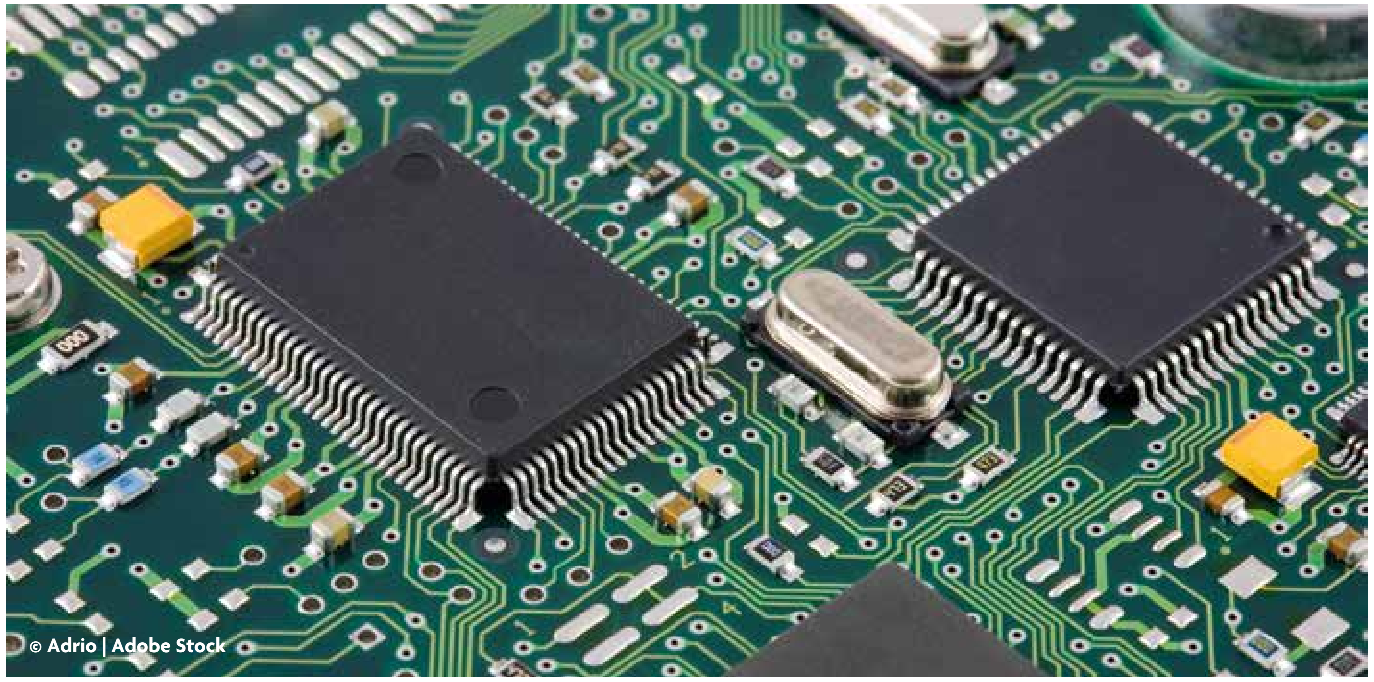
Blockchain is a 'distributed ledger', somewhat like a tamper-resistant virtual computer, with applications where decentralised control and trust are important, such as peer-to-peer energy trading.[13] Blockchain is underpinned by computational work, which needs expensive cryptographic processes to operate. This is significant not only because of the computational expense, but because of the potential scale at which it could be adopted.

Some researchers have suggested that one cryptocurrency alone, bitcoin, could drive us beyond 2C of global warming,[14] although this is contentious.[6] Etherium recently switched towards a computationally cheaper algorithm, reducing its estimated GHG emissions by 99.9 per cent.[15] But other cryptocurrencies have already been adopted as legal tender[16] and global collaborative environments such as the metaverse support trade using many existing cryptocurrencies[17] – the multiplier effect of locking in these technologies at scale – is potentially very significant.

ICT AND SUSTAINABILITY

A key question, and a barrier to concerted action, is whether ICT's global footprint has stabilised or will in the future.[18]

The Global e-Sustainability Initiative asserted that ICT could save 12.08 gigatonnes of carbon dioxide equivalent (CO_2e) by 2030 by applying ICT efficiency savings in domains such as health, education, buildings, agriculture, transport and manufacturing. This 20 per cent reduction in global CO_2e emissions if ICT-related emissions hold at 2015 levels is therefore net carbon negative. The ICT sector is accelerating the use of renewables and offsetting its emissions in some cases.[7, 12] Could virtual reality platforms such as the metaverse even promote sustainability by enabling the acquisition and social status of digital rather than physical goods?[19]


© Adrio | Adobe Stock

SHOULD WE WORRY?

It is perhaps easy to focus on headline technologies and large energy users. These same facilities underpin the pursuit of knowledge and innovation – including in the environmental sciences. So do we need to control ICT's growth?

Opinions are divided regarding future ICT-related emissions. On the one hand, it is anticipated that emissions are growing globally due to increases in data traffic and the number of end-user devices.[20,21] Conversely, some estimates have shown a decrease, recognising that data-centre overheads continue to drop and energy supplies are decarbonising.[1,22] GHG emissions from ICT may even have stabilised, while computation is starting to decouple from emissions as energy efficiency outstrips demand.[22]

At the core of these arguments are several assertions. Without good and transparent data, independently verifying these claims is certainly challenging. Almost irrespective of the result, there is a moral question here: should ICT not be subject to the same decarbonisation pressures as other sectors? If ICT has more spending power than other sectors, how much of the world's renewables should be set aside for ICT? If efficiency gains are decarbonising ICT, why do global emissions continue to rise?[23]

In the absence of downward pressure on growth or accountability, it would seem risky given the climate crisis to absolve ICT of due responsibility and place our trust in efficiency and renewables.[18] After all, efficiency gains have historically been shown to lead to surprising rebound effects – a phenomenon known as the Jevons paradox.

WHAT SCIENTIFIC COMMUNITIES CAN DO

Computation has become increasingly central to many disciplines. Computational models are arguably essential to our understanding of a changing climate.[23] But ICT and therefore this research has an environmental cost.[24] By considering this in our practices we can influence it. Environmental science might be especially well placed to consider ICT's true environmental impacts and to what extent it is (or not) addressing the climate crisis.

But we are more than just scientists. We are influential science communicators, leaders, advisers and citizens. In addition to looking at the computation and algorithms we embed in our work, we can create a culture and practice while cognisant of ICT's holistic impacts. ICT is having a global impact, reshaping systems and our relationship with the planet. As we set our grand challenges and research funding agendas, we should consider our relationship to ICT and help enable climate-proportional computing. ES

Adrian Friday is Professor of Computing and Sustainability at Lancaster University. His work focuses on energy and GHG emissions from technology in everyday life and whether these technologies can offer new and more sustainable pathways. His research has explored energy use in the home, thermal comfort, sustainable food shopping, logistics and the gig economy, and energy insights toward net zero.

Acknowledgements

This work benefits extensively from the hard work of my colleagues at Lancaster University and Small World Consulting: Charlotte Freitag, Mike Berners-Lee, Kelly Widdicks, Bran Knowles and Gordon S. Blair. My thanks also to Oliver Bates and Christian Remy for their thoughtful comments on an earlier draft of this article.

REFERENCES

1. Freitag, C., Berners-Lee, M. Widdicks, K., Knowles, B., Blair, G. and Friday, F. (2021) The real climate and transformative impact of ICT: a critique of estimates, trends and regulations. *Patterns*, 2 (9), 100340. https://doi.org/10.1016/j.patter.2021.100340 (Accessed: 12 March 2023).
2. Bardi, U. (2011) *The Limits to Growth Revisited*. Berlin: Springer Science & Business Media.
3. Geneva Environment Network (2023) *The Growing Environmental Risk of E-Waste.* https://www.genevaenvironmentnetwork.org/resources/updates/the-growing-environmental-risks-of-e-waste/ (Accessed: 27 March 2023).
4. Alorse, R.W. (2020) *Coal is still king for the internet.* https://nationalinterest.org/blog/buzz/coal-still-king-internet-124806 (Accessed: 12 March 2023).
5. Malmodin, J. and Lundén, D. (2018) The energy and carbon footprint of the global ICT and E&M sectors 2010–2015. *Sustainability*, 10 (9). https://www.researchgate.net/publication/327248403_The_Energy_and_Carbon_Footprint_of_the_Global_ICT_and_EM_Sectors_2010-2015 (Accessed: 12 March 2023).
6. Masanet, E., Shehabi, A., Lei, N., Vranken, H., Koomey, J. and Malmodin, J. (2019) Implausible projections overestimate nearterm bitcoin co_2 emissions. *Nature Climate Change*, 9 (9), pp. 653–654. https://www.nature.com/articles/s41558-019-0535-4 (Accessed: 12 March 2023).
7. Global e-Sustainability Initiative (2015) *#SMARTer2030. ICT solutions for 21st century challenges.* Technical report. https://smarter2030.gesi.org/downloads/Full_report.pdf (Accessed: 12 March 2023).
8. Department of Business, Energy and Industrial Strategy (2021) *Transitioning to a Net Zero Energy System: Smart Systems and Flexibility Plan 2021.* https://www.gov.uk/government/publications/transitioning-to-a-net-zero-energy-system-smart-systems-and-flexibility-plan-2021 (Accessed: 12 March 2023).
9. Blackmore, S. (1994) Precision farming: an introduction. *Outlook on Agriculture*, 23 (4), pp. 275–280. https://doi.org/10.1177/003072709402300407 (Accessed: 12 March 2023).
10. Tao, F. and Qi, Q. (2019) Make more digital twins. *Nature*, 573 (7775), pp. 490– 491. https://media.nature.com/original/magazine-assets/d41586-019-02849-1/d41586-019-02849-1.pdf (Accessed: 12 March 2023).
11. Schwartz, R., Dodge, J., Smith, N.A. and Etzioni, O. (2020) Green AI. *Communcations of the Association for Computing Machinery*, 63 (12), pp. 54–63. https://cacm.acm.org/magazines/2020/12/248800-green-ai/fulltext?mobile=false (Accessed: 12 March 2023).
12. Patterson, D., Gonzalez, J., Hölzle, U., Le, Q., Liang, C., Munguia, L-M., Rothchild, D., So, D.R., Texier, M. and Dean, J. (2022) The carbon footprint of machine learning training will plateau, then shrink. *Computer*, 55 (7), pp. 18–28. https://storage.googleapis.com/pub-tools-public-publication-data/pdf/3f06b8dbb0abc8ab6fbccde0bc37647ae012956c.pdf (Accessed: 12 March 2023).
13. Li, Z., Kang, J., Yu, R., Ye, D., Deng, Q. and Zhang, Y. (2017) Consortium blockchain for secure energy trading in industrial internet of things. *IEEE Transactions on Industrial Informatics*, 14 (8), pp. 3690–3700. doi: 10.1109/TII.2017.2786307.
14. Mora, C., Rollins, R.L., Taladay, K., Kantar, M.B., Chock, M.K., Shimada, M. and Franklin, E.C. (2018) Bitcoin emissions alone could push global warming above 2°C. *Nature Climate Change*, 9 (80). https://doi.org/10.1038/s41558-018-0353-0 (Accessed: 12 March 2023).
15. Sarkar, A. (2022) *The Merge brings down Ethereum's network power consumption by over 99.9%.* https://cointelegraph.com/news/the-merge-brings-down-ethereum-s-network-power-consumption-by-over-99-9 (Accessed: 27 February 2023).
16. CoinMarketCap (2023) *Countries which allow cryptocurrency as legal tender.* https:// coinmarketcap.com/legal-tender-countries/ (Accessed: 27 February 2023).
17. Nasdaq (2022) Home page. https://www.nasdaq.com/articles/10-best-metaverse-coins-to-buy-for-2022 (Accessed: 27 February 2023).
18. Knowles, B., Widdicks, K., Blair, G., Berners-Lee, M. and Friday, F. (2021) Our house is on fire: the climate emergency and computing's responsibility. *Communications of the Association for Computing Machinery*, 65 (6), pp. 38–40. https://cacm.acm.org/magazines/2022/6/261169-our-house-is-on-fire/fulltext (Accessed: 12 March 2023).
19. Townsend, S. (2022) *Could the metaverse & Web3 save sustainability?* https://www.forbes.com/sites/solitairetownsend/2022/09/29/could-the-metaverse--web3-save-sustainability/ (Accessed: 27 February 2023).
20. Belkhir, L. and Elmeligi, A. (2018) Assessing ICT global emissions footprint: trends to 2040 & recommendations. *Journal of Cleaner Production*, 177, pp. 448–463. https://doi.org/10.1016/j.jclepro.2017.12.239 (Accessed: 12 March 2023).
21. Andrae, A.S.G. and Edler, T. (2015) On global electricity usage of communication technology: trends to 2030. *Challenges*, 6 (1), pp. 117–157. https://doi.org/10.3390/challe6010117 (Accessed: 12 March 2023).
22. Malmodin, J. (2020) *Decarbonising Data.* Presentation at the Tech UK Conference, 29 September. YouTube video, 22:25. https://youtu.be/o2f9ms9Ynhk (Accessed: 16 March 2023).
23. McGrath, M. (2021) Climate change: IPCC report is 'code red for humanity', *BBC News*, 9 August. https://www.bbc.com/news/science-environment-58130705 (Accessed: 27 February 2023).
24. Intergovernmental Panel on Climate Change (2023) *AR6 Synthesis Report: Climate Change 2023.* https://www.ipcc.ch/report/sixth-assessment-report-cycle/ (Accessed: 27 February 2023).
25. Friday, F. (2022) *The academic machine: flying again.* https://medium.com/sigchi/the-academic-machine-flying-again-8dcdf1f333d (Accessed: 12 March 2023).

ANALYSIS

Hydropower: the good, the bad and the ugly

Mark Everard examines the benefits and repercussions of harnessing water for power.

People require energy for their daily needs and for development. In a climate-aware world, we know we need low-carbon energy. For decades, hydropower has been promoted as a strategic solution, and it is frequently a favoured resource where rivers are large and other energy-yielding resources are sparse. But is hydropower a panacea, or must we address wider considerations to pursue the goals of sustainability and meet universal human needs?

© chungking | Adobe Stock

ANALYSIS

A SHORT HISTORY OF HYDROPOWER

Harnessing energy from flowing water dates back millennia. Waterwheels for grinding wheat into flour were used in Greece over 2,000 years ago, with widespread global examples of water-powered mills, water pumps, saws and other tools used over the intervening centuries. The invention of the hydropower turbine in the mid-1700s is credited to the French engineer Bernard Forest de Bélidor.[1] Subsequent refinement and implementation of the technology has resulted in hydroelectric power generation across the world, particularly in nations with large rivers of reliable flow and steeper topography, such as widespread installations in China, India and Nepal that are fed by river systems originating in the Himalayas.

As society grapples with development challenges, including achievement of the 17 United Nations Sustainable Development Goals,[2] there remains a growing need for reliable energy in developing nations and increased energy efficiency and transition to renewable sources in the developed world.

THE GOOD

Hydroelectric power comes from the extraction of energy from water-cycle flows that are ultimately driven by solar radiation. Hydropower is classified as green in many parts of the world including the UK, and in the USA hydropower contributes to transition goals of 100 per cent clean electricity by 2035 and net-zero emissions by 2050.[3] Hydropower can provide a base load of power where water flows are reliable; alternatively, energy can be stored in reservoirs or in pumped storage units, providing service flexibility. Hydroelectric power generation also allows states to produce their own energy where suitable water resources are available, without relying on international fuel sources.

Reservoirs for hydropower generation also enable water to be directed to specific uses, including for urban and industrial supply and large-scale irrigation. They also offer recreational and tourism opportunities such as boating, fishing and swimming. Flood control is another commonly described benefit of hydropower installations, as they provide a buffer for flood events by storing surplus water for gradual release during drier periods.

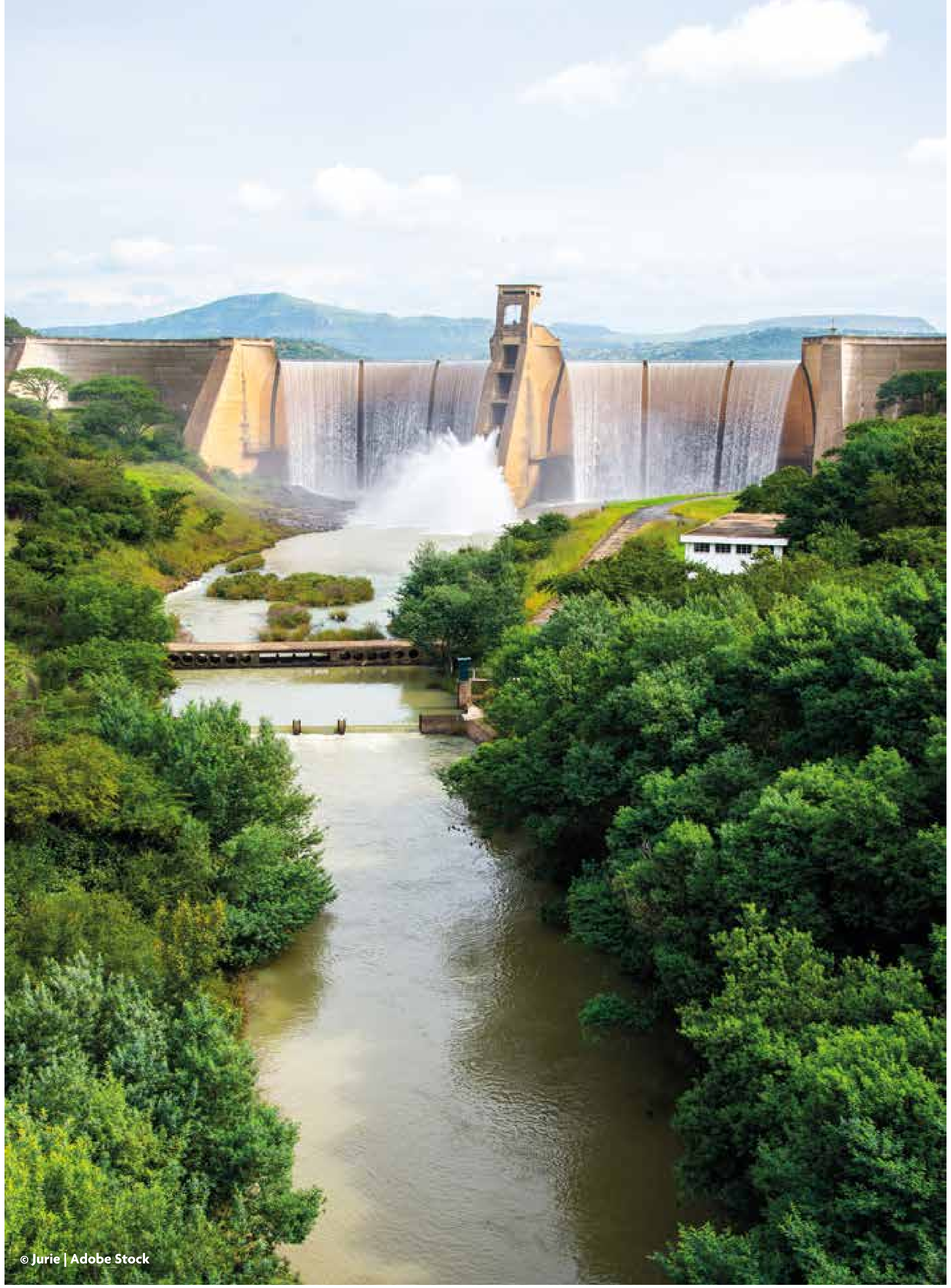
THE BAD

With all these benefits, what could possibly be considered bad about hydropower?

If our worldview is purely utilitarian – creating harvestable water and power with additional recreational benefits – all appears to be good. However, we thought the same about digging up carbon-rich fossil fuels to serve legitimate societal demands for energy. Yet despite global markets and governments still making use of fossil fuels as a cheap default option, we are increasingly aware of the existential threat and disruption posed by such an oversimplistic view of short-term interference with carbon cycles that naturally operate over geological timescales.

The reality, though, is that water is far more than a utility. The global water cycle carries solutes, suspended chemicals, aggregates, biota and energy. It is fundamental to human health, economic activities from food production to heavy industry and contributes to the security and fulfilment of human potential. Interventions in any ecosystem element – tilling a field, removing a keystone species, releasing substances sequestered over geological time back into the biosphere, rearranging atoms into molecular configurations alien to nature – has pervasive, systemic repercussions. Interventions in the water cycle are no different and are either done myopically or with foresight.

Water-cycle interventions have inevitable systemic influence not just on water and energy resources but across a broad swathe of water-vectored ecosystem services. Extensive reviews by the World Commission on Dams[4] and in *The Hydropolitics of Dams*[5] recognise many of these wider, systemic ramifications. In addition to storing water, dams trap up to 100 per cent of river sediment flows, often contributing to an unanticipated high rate of reservoir infilling and shortened design life. Critically, sediment entrapment also starves downstream



© Jurie | Adobe Stock

ANALYSIS

river catchments of the nourishing nutrients, minerals and particulate matter necessary to replenish floodplain and delta habitats. Instead, these downstream reaches of catchments tend to erode along with their multiple values, including, for example, those associated with culture, agriculture and the life cycles of fish and other organisms. Common outcomes of simplified hydrology in tropical regions also include proliferation of waterborne diseases such as bilharzia, West Nile and Zika viruses and leptospirosis, as their vectors proliferate in moderated flows.

Dam schemes also have significant implications for the life cycles of fish and other migratory riverine organisms of diverse inherent, subsistence, functional, recreational and spiritual value. Inundation of irreplaceable cultural assets also occurs, such as sacred Hindu temples, many over 1,000 years old, behind dams unwisely conceived as 'temples of modern India' – a term coined in 1954 by India's first prime minister, Jawaharlal Nehru.[6] Dams and reservoirs can be massive in scale.

Three Gorges Dam on the Yangtze River in China, with a total capacity of 39.3 km^3 (a theoretical mass of 3.93 billion tonnes), is the world's largest dam scheme that in 2012 also became the world's largest hydropower generation plant with an installed capacity of 22,500 MW. However, filling of the Three Gorges Dam measurably shifted the Earth's tilt and also increased seismic activity in the region by seven to eight times, including triggering a 5.1-magnitude earthquake near the dam site in 2013.[7] Displacement of hundreds of people was driven by rockfalls and landslides around the dam, adding to the displacement of at least 1.3 million people along the river during construction and filling.[8] Many large dams constructed or conceived in the Indian Himalayas are in highly geologically active zones, with potential dam failure posing considerable implications for deluges of released water. Many nations also ban the photographing of dams to prevent them from becoming terrorist targets.

Likely but overlooked implications for all systemically interconnected ecosystem services were assessed in a study of the proposed Pancheshwar Dam, potentially the world's second tallest, intended to harness hydroelectric power and water and planned to impound the Mahakali River that divides India and Nepal in the Middle Himalayas.[9] Dam proposals reached an advanced state in 2010 but have not progressed since, in part informed by wider dissemination of the distributional outcomes of that ecosystem services assessment, but also due to other factors such a political change in Nepal. The assessment concluded that ecosystem services would be affected across substantial areas both upstream and downstream with significant impacts and some complete losses of ecological, cultural, spiritual and tourism importance, and that these would have ramifications over substantial distances lower in the catchment. Most people directly or indirectly dependent on the river's ecosystem services were not considered or engaged in the planning process. Consideration of environmental and social consequences only came later, seemingly too late to influence scheme design and decisions locked in by sunk costs. The net value of the proposed Pancheshwar Dam to Nepal, India and beyond was considered at best highly questionable, with potential positive outcomes overstated and negative consequences substantially overlooked.[9] No consideration was given to how people use water and energy, or to other potentially more sustainable and less disruptive options to the catchment ecosystem.

These discussions bring into question not only the winners and losers from the impoundment of flowing water for energy and water harvesting but also the net value of these interventions once the costs of compromised or lost ecosystem services are weighed against the intended benefits. Undoubtedly, the winners include politically and economically influential and often remote beneficiaries of piped water and wired power. But what about the potentially millions of graziers and other rural farmers whose livelihoods depend upon depleted catchments, potentially for hundreds of kilometres downstream of dams, those afflicted across this range by the possible proliferation of waterborne diseases, and the diverse people dependent upon natural ecosystems and cultural resources, many of which are irreplaceable?

Dam building for hydroelectric power and large-scale water transfers often primarily serves already economically and politically advantaged and frequently remote beneficiaries, but with inevitable negative outcomes for people local to dam sites and those dependent upon multi-beneficial flows at catchment scale. This form of technological appropriation of water and energy is analogous to the enclosure of terrestrial commons, formerly supporting countless livelihoods but annexed as private or municipal property and often converted for short-term profit.

THE UGLY

Annexation of power and water from transboundary rivers by a country that deprives its downstream neighbours can be a source of conflict and civil unrest. It can even be so between states within large nations, such as Tamil Nadu and Karnataka in southern India that share the Kaveri River. While sharing transboundary rivers has been found to be more of a lever for collaboration than a source of conflict,[10] there remain many global instances of inter-state tensions, such as the sharing of Indus River resources between India and Pakistan. Looking beyond utilitarian access to resources, wider distributional implications become apparent when all ecosystem services are considered.

ANALYSIS


© Lee Van Put | Adobe Stock

These systemic implications are still largely overlooked yet have geographical and inter-generational ramifications.

There are also many instances of large dams featuring more as a facet of empire building than a population benefit. One such example was the Aswan High Dam, one of the world's largest embankment dams built across the Nile between 1960 and 1970, with the promise of year-round irrigation and the lifting of the Egyptian people out of poverty. Yet this scheme, creating the vast Lake Nasser, bearing the then-President's name, overlooked numerous consequences and hardships resulting from the impoundment of the River Nile. The once-productive floodplains of the Nile Valley – formerly naturally replenished by high seasonal flows of sediment-laden water – have been progressively eroded, starved of nutrients and deprived of crucial salt-flushing processes, leading to widespread salinisation from evaporation during year-round irrigation. Additionally, the reservoir experiences substantial rates of evaporation from its 5,250 km^2 surface area under a tropical sun as well as rapid infilling from trapped sediment. A further downstream consequence is the systematic degradation of the structure and associated cultural, agricultural and ecological resources of the Nile delta.

Even where international aid flows into developing nations for dam construction, ostensibly to benefit the people, key beneficiaries often include consultants from the developed world with vested interests in narrowly framed technical solutions of more immediate payback than ecosystem-informed alternatives. And that is before we get into any implications of corruption and the distributional outcomes of dam operation.

POWER TO THE PEOPLE

Yet we need energy for development. We need renewable energy too, helping us make a transition away from dependence on fossil fuels and nuclear resources. However, it would be foolhardy to conflate renewable with sustainable energy if all ecosystem service ramifications are overlooked.

The World Commission on Dams (WCD) report recognises that 'dams have made an important and significant contribution to human development'.[4] However, the report recognises the need to think, plan and operate on a far more systemic basis taking account of the implications and distributional benefits of dam design and operation, including prior consideration of alternative approaches to resource security and enhancement. The WCD proposed seven strategic priorities: public acceptance; comprehensive options assessment; addressing existing dams; sustaining rivers and livelihoods; recognising entitlements and sharing benefits; ensuring compliance; and sharing rivers for peace, development and security. These priorities are backed up by 26 guidelines for good practice to shape more sustainable and equitable water resource development.

The extent to which the WCD's priorities and guidelines have been applied is, at best, moot.[5] However, practical, rapid and, above all, fully systemic approaches to ecosystem service assessment have since been developed to analyse the likely outcomes of different development options. This includes the Rapid Assessment of Wetland Ecosystem Services, adopted at intergovernmental level at the 2018 Ramsar Convention on Wetlands, which provides a pragmatic approach suitable for testing and comparing alternative solutions and revising designs and operations for benefit optimisation.[11]

TIME FOR FORESIGHT

Consideration of energy in terms of the ecosystem services from which it can be harvested leads to an interesting observation about three different timescales:

1. The first and longest relates to fossil fuel energy captured from solar input during the Carboniferous (or coal-bearing) period between 358.9 and 298.9 million years ago. However, releasing energy from the molecular bonds of fossilised organic matter also remobilises sequestered carbon with damaging implications.

2. Next in terms of time lag from input to exploitation is harvesting from flows of water, extracted from the response of the water cycle to solar energy (and in some cases lunar gravity) but with wider impacts across a broad spectrum of water-vectored ecosystem services. (Biomass-based generation shares similar features.)

3. Finally, the near-instantaneous harvesting of direct solar and wind energy has far more localised and fewer systemic complications.

Energy generation from solar and wind sources now exceeds price parity with fossil fuels; along with novel energy carriers such as hydrogen and together with battery technology they are important renewable sources forming the backbone of an energy transition towards net-zero carbon.[12] There is therefore no reason to hold back from rethinking energy development along this energy-source hierarchy: closer to the arrival of solar input, with fewer wider damaging repercussions for the atmosphere and water cycle, and with fewer and more localised impacts to mitigate.

Hydropower has a role to play as an inherently renewable energy source, although it should always be contextualised by wider thinking about the right solution, right place and optimising systemic benefits. The energy-source hierarchy can be integrated into national strategies and priorities for development aid as a framework against which to consider all energy-harvesting options in the context of their distributional outcomes, and to prioritise unlocking restrictive patents to accelerate progress towards sustainability. **ES**

Professor Mark Everard is an ecosystems consultant, Visiting Professor at Bournemouth University and Associate Professor of Ecosystem Services at the University of the West of England (UWE Bristol). He has championed development and application of ecosystems thinking for over 40 years in academic, policy-development, NGO and business environments, and in both the developing and developed world. Mark is Vice-President of the IES, and a prolific author and broadcaster.

mark.everard@uwe.ac.uk

REFERENCES

1. Forest de Bélidor, B. (1737) *Architecture Hydraulique:* Volume 1. Paris: Chez Charles-Antoine Jombert.
2. United Nations Department of Economic and Social Affairs Sustainable Development (2022) *The 17 goals.* https://sdgs.un.org/goals (Accessed: 4 December 2022).
3. United States Office of Energy Efficiency & Renewable Energy (2022) *Benefits of hydropower.* https://www.energy.gov/eere/water/benefits-hydropower (Accessed 4 December 2022).
4. World Commission on Dams (2000) *Dams and Development: A New Framework for Decision-making.* Oxfordshire: Earthscan.
5. Everard, M. (2013) *The Hydropolitics of Dams: Engineering or Ecosystems?* London: Zed Books.
6. DNA INDIA (2013) PSUs: Modern industrial temples of India, *DNA INDIA*, 19 November. https://www.dnaindia.com/special-features/report-psus-modern-industrial-temples-of-india-1296571 (Accessed: 18 February 2023).
7. Huang, R., Zhu, L., Encarnacion, J., Xu, Y., Tang, C-C., Luo, S. and Jiang, X. (2018) Seismic and geologic evidence of water-induced earthquakes in the Three Gorges Reservoir Region of China. *Geophysical Research Letters*, 45 (12), pp. 5929–5936. https://doi.org/10.1029/2018GL077639 (Accessed: 18 February 2023).
8. Britannica (2022) *Three Gorges Dam.* https://www.britannica.com/topic/Three-Gorges-Dam (Accessed: 8 December 2022).
9. Everard, M. and Kataria, G. (2010) *The Proposed Pancheshwar Dam, India/Nepal: A Preliminary Ecosystem Services Assessment of Likely Outcomes.* An IES research report. https://www.the-ies.org/resources/proposed-pancheshwar-dam (Accessed: 4 December 2022).
10. United Nations (2006) *Ten stories the world should hear more about: from water wars to bridges of cooperation – exploring the peace-building potential of a shared resource.* https://www.infoplease.com/world/conflicts/uns-list-stories-world-should-hear-more-about-2006 (Access: 15 February 2023).
11. Ramsar Regional Center for Asia (2020) *RAWES Practitioner's Guide.* http://rrcea.org/rawes-practitioners-guide/?ckattempt=1 (Accessed: 8 December 2022).
12. International Energy Agency (2021) *Renewables 2021: Analysis and Forecast to 2026.* https://iea.blob.core.windows.net/assets/5ae32253-7409-4f9a-a91d-1493ffb9777a/Renewables2021-Analysisandforecastto2026.pdf (Accessed: 15 February 2023).

OPINION

The transition to net zero needs to focus on reducing energy demand

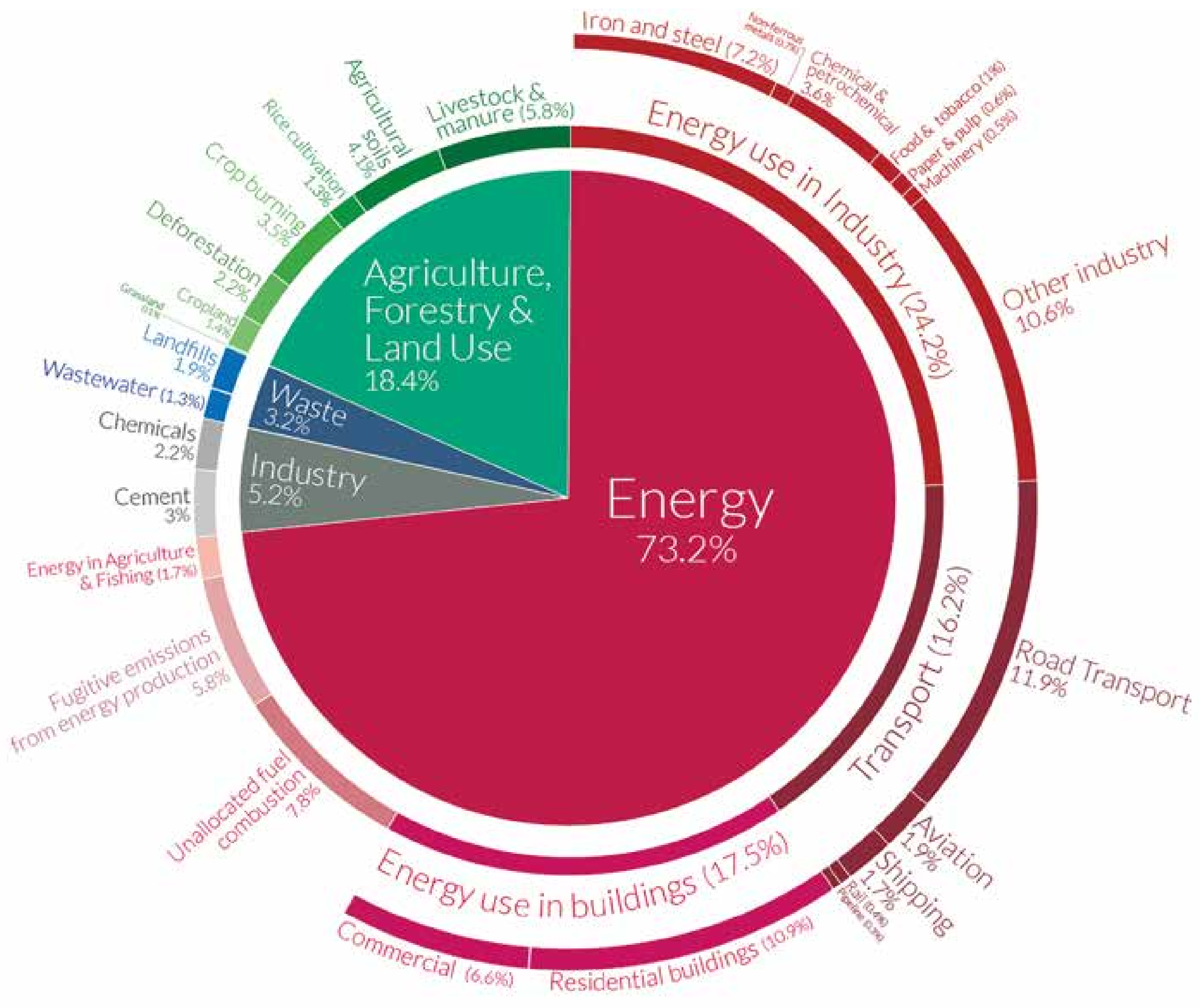
Ian Byrne sets out why demand reduction should lead the way in the energy transition.

Energy and carbon are intertwined. The transition to a net-zero carbon economy cannot happen without a parallel transformation in how we generate, distribute and use energy – activities that are responsible for around three-quarters of global carbon emissions (see **Figure 1**). Yet in the wider discourse, *how* we use energy is often overlooked,[1] with analysis focusing more on zero-carbon energy sources and rebound effects such as the Jevons paradox (the economic effect of energy savings leaking back into the cycle, with increased consumption as incomes rise). However, the consensus is that while there is a rebound effect, its magnitude is significantly lower, leading to a net reduction in energy consumption.[2]

Importantly, we cannot reduce carbon emissions without reducing the amount of fossil fuel-generated energy we consume. This transition requires both switching to renewable energy sources (and potentially some nuclear energy) and reducing demand if we are to have even a remote chance of keeping to a 1.5C temperature increase – and this must be done quickly. Demand reduction also helps solve the energy trilemma – environment, reliability and affordability – since reducing consumption usually improves the resilience of the energy system. It frequently costs less in the long term as well, although there are often upfront costs associated with improving systems.

An effective energy transition can start today. Most of what we need to do involves tried-and-tested technology, despite governments appearing to be fixated on throwing money towards research and development in the hope of finding a magic bullet rather than on refining and disseminating existing solutions. By aggressively reducing demand, we can rely on existing technologies to meet it: mainly wind and solar, perhaps backed up by some nuclear and with significant amounts of energy storage. Biofuels and hydrogen may have limited use, possibly in shipping and aviation.

OPINION



▲ **Figure 1. Global greenhouse gas emissions by sector based on 2016 data of a total of 49.4 billion tonnes of carbon dioxide equivalent. (© Our World in Data)**[3]

ENERGY IN BUILDINGS

Globally, around one-third of energy is used to heat, light and power buildings, mainly in the domestic sector. This proportion is higher in the UK, due to our cool climate and economy focusing on services not manufacturing, making our homes some of the most expensive to heat in Europe. The UK has the continent's oldest housing stock, and likely the world's,[4] with an estimated 37.8 per cent of homes built before 1946. These were constructed with minimal insulation and often without cavity walls. On a positive note, although more likely than not to be in disrepair, many older properties are sturdily built and capable of being upgraded. As a rule of thumb, demolishing a property and replacing it with a new one is generally unwise from a carbon viewpoint. Commercial property – notably offices and retail – tends to be newer, but increasingly energy intensive through the use of air conditioning and excessive areas of glazing.

To reduce energy demand, the industry mantra is: fabric first – insulation, insulation, insulation. There is little point in spending money to upgrade a heating system if heat is lost through the building fabric – walls, windows, roof and floor. In most buildings (with the possible exception of bungalows and warehouses) heat is lost through the walls rather than the roof – a common misconception. While cavity walls can be safely filled, solid walls are more troublesome, but internal insulation is often cost-effective and can lead to carbon savings. One thing is certain: upgrading insulation will always reduce running costs and help alleviate the recent rise in energy prices.

UK homes are also notoriously leaky and prone to draughts; airflows also make them feel colder in winter, leading to a desire to raise internal temperatures above the recommended 19–21C. However, simply wrapping a house in insulation and blocking all vents can adversely affect air quality: carbon dioxide levels rise and longer-term issues with condensation are created. Controlled ventilation should be the solution, but the UK has a poor record of using mechanical ventilation with heat recovery due to a combination of inappropriate design and poor installation. There is a real skills gap here – as in many other areas of retrofitting – as well as a reluctance to monitor (and adjust) installed systems. For most UK homes, windows have been less problematic since the adoption of double glazing. However, quality can be a problem. Low-emissivity coatings are not universally applied, but the main problem lies in thermal bridging or, quite simply, poor installation, which allows air infiltration round the window units.

With the recent shift to working from home, heating has risen in importance; the jury is out on whether closing offices saves energy. UK policy, quite rightly, sees the electrification of heating as a prerequisite for a low-carbon energy system, with a focus on heat pumps. Here, again, the problem is not technological, but of reducing capital costs, simplifying planning restrictions and improving skills. Properly fitted, heat pumps do work, although may require upgrades to internal heat distribution (i.e. large radiators) to be effective in older properties. In contrast, heating systems that are fuelled by wood are now discredited due to high levels of particulates adversely affecting air quality. Whichever form of heating is used, digital controls, with better time and zone management, are an essential part of the transition.

One major difference today compared to when I first started working in the sector 30 years ago is that lighting has largely been solved by a technological revolution. Light-emitting diode (LED) lighting is now low-cost and gives a quality of light at least as good as filament bulbs and using only one-tenth of the energy. Of course, architects and designers still need to avoid unnecessary lighting, users should still switch lights off when not in use, and stores often maintain too high a lighting level.

ENERGY IN INDUSTRY AND COMMERCE

Just as in dwellings, buildings (and lighting) are important in these sectors. But it is in industry that good energy management comes to the fore – with a relentless focus on metering, monitoring consumption against output, and targeting, underpinned by training staff and using energy management systems such as ISO 50001: 2018 Energy Systems.[5] Each sector needs to have its own transition plan without stifling innovation through restrictive patents or competition law. Supply chains may also need to be rethought: does it make sense to ship wood or seafood from Europe to China for processing by cheap labour, only to sell the finished products back in Europe,[6] or is it necessary to airfreight components just to minimise locally held stocks?

Large energy users can also benefit from flexibility, modulating demand to take advantage of periods of low grid-carbon intensity (and low energy prices), while curtailing demand when price or carbon signals require, often receiving additional payments from distribution system operators for doing so.

ENERGY IN TRANSPORT

Transport is responsible for the final third of emissions, principally from the use of petrol and diesel in road vehicles. The current transition focus has thus fallen onto encouraging a switch to battery electric vehicles (BEV). In my view, this is misguided: mass uptake of BEVs is not a sustainable solution. Instead, we need to completely rethink our approach to personal mobility (as well as to supply chains).

BEVs require huge amounts of natural resources, including rare earth metals, and, while some can be recycled as the first generation of vehicles come to the end of their life, electrification of the global vehicle fleet will place a huge strain on countries such as the Democratic Republic of the Congo, where much of the necessary cobalt is produced with little regard to the environment or fair employment practices.[7] BEVs also fail to address issues such as noise or congestion. Although electric motors are quieter than internal combustion engines (ICE), a simple (if unscientific test) of standing by the roadside and listening to passing cars shows that Teslas can be noisier than smaller, lighter cars simply due to tyre noise. (This applies to both high and low speeds and is due to the greater weight of BEVs carrying large, long-range batteries.) This reveals a second problem: particulates resulting from larger (and heavier) BEVs can be higher than for petrol cars due to tyre wear. This is not to argue for continuing use of ICE cars, but to suggest that long-range BEVs with large batteries are not the answer.

If there are doubts about BEVs, autonomous vehicles are definitely not the solution. Although it is sometimes claimed they reduce emissions due to a more efficient driving style, there are significant parasitic emissions from centralised and onboard data processing and sensors, such as lidar, and they still cause particulate emissions and congestion.[8]

Battery swapping, where cars can simply exchange a depleted battery for a fully charged one at a specialist service station, is a promising technology that has faltered, partly due to a lack of standardisation, but also because the Israeli–Belgian company that pioneered the technology a decade ago was poorly managed. A car manufacturer called NIO has attempted to revive the concept, but unless there is agreement on standardising the batteries, uptake may be limited to its home market of China.


© Ingo Bartussek | Adobe Stock

Instead, the transition needs to focus on active and public transport so they become the default options for short- and long-distance travel for reasonably able-bodied people. Much can be achieved with existing technology, such as more comprehensive real-time information on trains and buses or the location of rental bicycles. Interoperability between apps would help to allow users registered in one bikeshare scheme to access others. More needs to be done on combining docked/dockless rentals, with a small premium charged if rented bikes are left away from a docking station or geofenced area (as happens in Berlin, Germany). Better ticketing across transport modes is also required – initiatives combining train and bus transport are good but could be extended to include active travel, such as bikeshare schemes – and all main rail stations should be required to have rental bikes or e-scooters available.

Cycling infrastructure needs consistent funding, and it begs the question: why are cycle routes not incorporated as a default option on road-improvement schemes? More secure cycle racks are required, with the basic Sheffield stand often being the best solution. It also needs to be easier to take cycles on trains (especially Eurostar), ending constraints such as having to pre-book a small number of spaces on intercity trains or the prohibition of cycles on many commuter trains.

Buses, in particular, have a lot of room for improvement. Surprisingly, we could learn from the USA, where it is relatively common to be able to carry up to three cycles strapped to the front of buses. Electrification of urban transport is also necessary, but the best solution is probably trolleybuses (abandoned in the UK in 1972) with small batteries to allow navigation away from the wires for roadworks and on some low-traffic sections.[9] Trams are great in dense urban areas, but still too costly for most municipalities to implement.

And finally, for the occasions when a private vehicle is essential, car-sharing schemes – possibly integrated with traditional car hire – allow for the shared use of assets (and lower embodied emissions) and complement active travel.

CONCLUSION

The transition to a zero-carbon economy can be expedited with a clear focus on reducing energy demand by using existing technologies. This sometimes requires better integration of data or customer information as well as improved skills and training for installers and operators. To misquote an Energy Saving Trust 1998 marketing campaign: Energy efficiency – it's not clever stuff. But it is largely about applying best practice. ES

Ian Byrne lives in a 1970s home that was featured as exemplary for its low energy use on TV in 1993; today it is merely average. He cycles to work in an office that wastes masses of energy (which he cannot control) and sometimes drives a car that simultaneously pays no road tax due to its low emissions, but cannot enter the London ULEZ due to its high emissions.

REFERENCES

1. Herring, H. and Roy, R. (2007) Technological innovation, energy efficient design and the rebound effect. *Technovation*, 27 (4), pp. 194–203. https://doi.org/10.1016/j.technovation.2006.11.004 (Accessed: 18 February 2023).
2. González, J.F. (2010) Empirical evidence of direct rebound effect in Catalonia. *Energy Policy*, 38 (5), pp. 2309–2314. https://doi.org/10.1016/j.enpol.2009.12.018 (Accessed: 19 February 2023).
3. Ritchie, H., Roser, M. and Rosado P. (2020) *CO2 and greenhouse gas emissions*. https://ourworldindata.org/co2-and-greenhouse-gas-emissions (Accessed: 23 March 2023).
4. Piddington, J., Nicol, S., Garrett, H. and Custard, M. (2020) *The Housing Stock of the United Kingdom*. Watford: BRE Trust. https://files.bregroup.com/bretrust/The-Housing-Stock-of-the-United-Kingdom_Report_BRE-Trust.pdf (Accessed: 19 February 2023).
5. International Organization for Standardization (2018) *Energy Management Systems – Requirements with Guidance for Use (ISO 50001:2018)*. Geneva: ISO.
6. Winther, U., Hognes, E.S., Jafarzadeh, S. and Ziegler, F. (2019) *Greenhouse Gas Emissions of Norwegian Seafood Products in 2017*. SINTEF Ocean. https://www.sintef.no/contentassets/25338e561f1a4270a59ce25bcbc926a2/report-carbon-footprint-norwegian-seafood-products-2017_final_040620.pdf/ (Accessed: 19 February 2023).
7. NS Energy (2021) *Profiling the six largest cobalt reserves in the world by country*. https://www.nsenergybusiness.com/features/largest-cobalt-reserves-country/ (Accessed: 25 February 2023).
8. Sudhakar, S., Sze, V. and Karaman, S. (2023) Data centers on wheels: emissions from computing onboard autonomous vehicles. *IEEE Micro*, 43 (1), pp. 29–39. doi: 10.1109/MM.2022.3219803.
9. Połom, M. and Wiśniewski, P. (2021) Assessment of the emission of pollutants from public transport based on the example of diesel buses and trolleybuses in Gdynia and Sopot. *International Journal of Environmental Research and Public Health*, 18 (16), 8379. https://doi.org/10.3390/ijerph18168379 (Accessed: 19 February 2023).

ies

Editors	Bea Gilbert and Rosie Bowyer
Guest editor	Ian Byrne
Subeditor	Christina Petrides www.lastglance.net
Designer	Kate Saker katesaker.com
Printer	Lavenham Press Ltd
Published by	Institution of Environmental Sciences 1st Floor 6–8 Great Eastern Street London EC2A 3NT
Tel	+44 (0)20 3862 7484
Email	info@the-ies.org
Web	www.the-ies.org
Twitter	@IES_UK

There are many reasons why we're one of the UK's fastest growing professional bodies. Find out why you should join us.

Professionalism

Sound science

Quality assurance
Responsibility

Equality
Equity

Integrity

www.the-ies.org

The Institution of Environmental Sciences

ies