Digital Solutions for the Energy Sector

A Digital Catapult white paper
May 2024

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Introduction

The energy industry is experiencing a significant transition towards decentralisation, decarbonisation, and digitisation. This transition will provide new opportunities and challenges for investment and growth for both domestic and international players.

Energy stakeholders have recognised that access to live, usable data has become essential to managing energy systems today and in the future, and that digital technologies are a crucial tool in the journey to net zero.

In the 2023 update to Tracking Clean Energy Progress (TCEP), the International Energy Agency (IEA) reports that worldwide grid-related investment in digital technologies has grown by over 50% since 2015, with total grid investment expected to have grown by 19% in 2023. During this period, investment in digital-related grid efficiency continued to grow, reaching a new high of US $63 billion globally in 2022.

The IEA also estimates that overall investment in electricity grids ‘needs to average around US $600 billion annually through to 2030 to get on the NZE Scenario trajectory. This is almost double the current investment levels, at around US $300 billion per year’.

This report looks at challenges shared across the UK energy sector, as well as digital interventions that will enable the UK energy ecosystem to deliver low carbon energy faster and more reliably.

We also look at the impact that the growth of digital technologies and infrastructure is having on the energy sector, and how responsible technology leadership is required to enable a green digital transition.

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UK digital sector and key technologies

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The UK ranks first in Europe and third in the world for the development and uptake of advanced digital technologies.

Digital Catapult Future Index, 2022

The past few years have seen unprecedented and significant change across UK society and our economy. The pandemic, leaving the European Union, and the recognition of (and responses to) the climate emergency have all played a major part in these changes.

We have seen an acceleration in the pace at which businesses are embracing digitalisation, in order to cope with challenges and opportunities arising from remote working; health, safety and social distancing; changing consumer habits; and shocks to supply chains.

Advanced digital technologies

- Immersive Technology & Spatial Compute
- Artificial Intelligence & Data Science
- Distributed Systems & Data Privacy
- Internet of Things & Cyber Physical Systems
- Future Networks: 5G/6G Telecoms & Testing
- Quantum Technologies

At Digital Catapult we see advanced digital technologies as the fundamental building blocks for the future, essential to realising economic growth and building competitiveness across the UK. Such technologies include artificial intelligence, extended reality technologies (such as virtual, mixed, augmented reality and haptics, known collectively as XR) and spatial computing; distributed ledger technologies (DLT), and related privacy-preserving and secure data sharing technologies; 5G/6G and future networks, the internet of things (IoT), cyberphysical systems (CPS) and quantum computing.

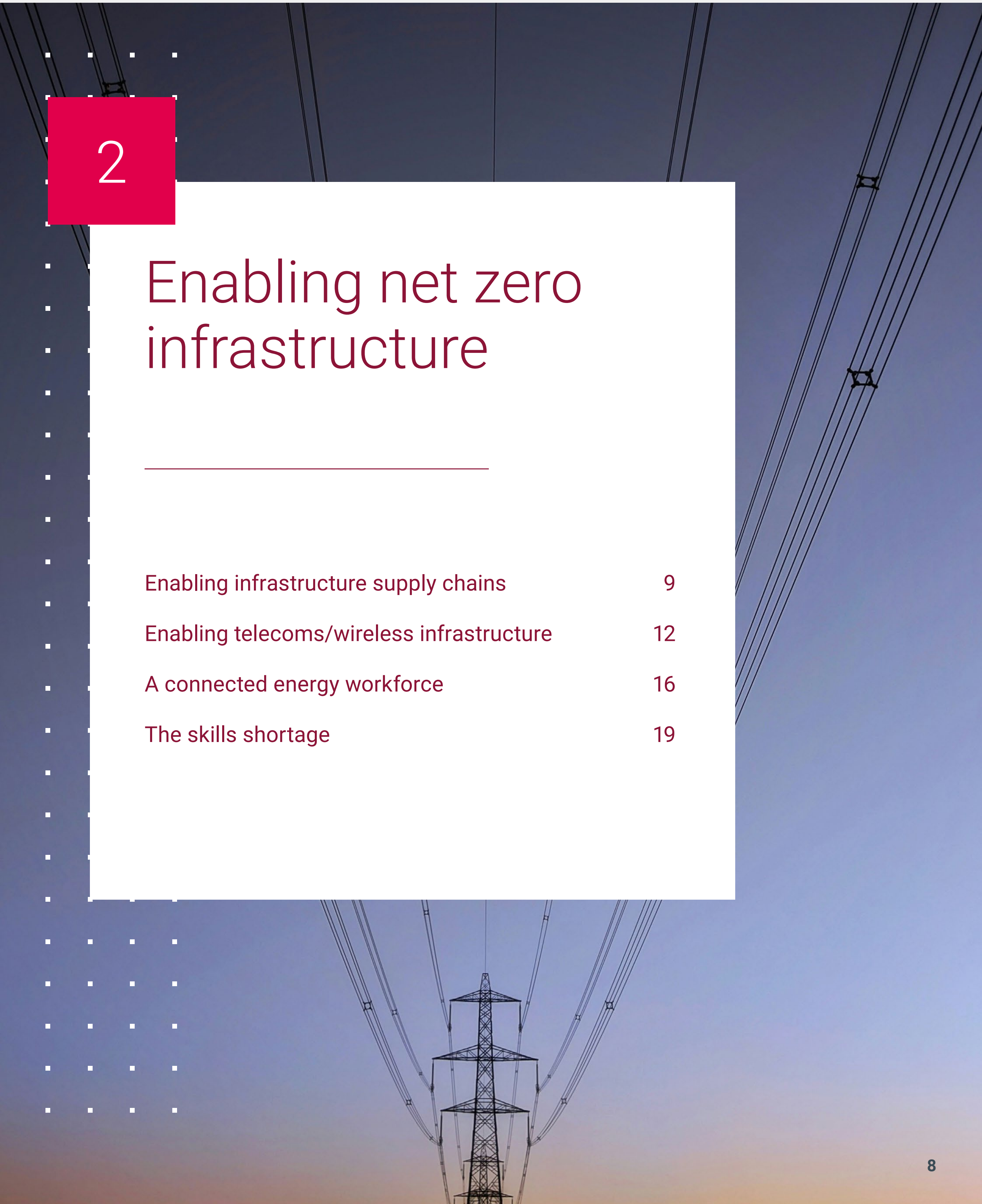
In 2021/22 Digital Catapult's Digital Future Index identified key and emerging trends in advanced digital technologies, and highlighted the strengths and challenges facing the UK in their adoption and innovation. Our research found that the UK is ranked third in the world (behind only the US and China) and first in Europe for the development and uptake of advanced digital technologies. This ranking was based on assessment of talent, investment, research, innovation and infrastructure across these technologies for each country.

The green digital transition

The UK has over 4,000 advanced digital technology companies in operation, putting us in an excellent position to leverage these capabilities for the future of the energy sector, even as the world competes to develop and adopt sophisticated new capabilities in spatial computing, digital twins and process transformation through complex robotic and autonomous systems.

This makes the UK energy sector well-placed to take advantage of existing digital expertise and accelerate to net zero through a **green digital transition**. This requires joined-up approaches to shared challenges and opportunities across our digitalisation and decarbonisation journey, focused on building capabilities, skills and best practices across both advanced digital technology companies and energy sector adopters.

While the energy system has multiple elements — electricity, natural gas, hydrogen, and a whole host of different renewables — there are shared challenges across the sector that digital can solve. This paper focuses on the two main areas where digital technology can play a key role in the short term: **enabling net zero infrastructure** and **delivering flexibility**.



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Enabling net zero infrastructure

Enabling net zero infrastructure

Electrification of heating and transportation combined with the increase in renewables means that we need significant expansion of our electricity networks, as well as ways to manage network constraints.

Delivering at the required scale — and pace — is a real challenge, especially as there is much renewable generation being held up due to delays or uncertainty in network connections.

Enabling infrastructure supply chains

The demand for new energy infrastructure is huge. For example, to meet 2030 targets, the offshore wind industry needs to deliver four times more transmission infrastructure in the next seven years than it has in the last thirty years.

While a huge amount of renewable energy infrastructure has already been procured and built, connecting renewables at distribution level involves a wait of up to 15 years. This queue represents around 400GW of unconnected renewable assets: so-called ‘zombie assets’.

While there are a number of reasons for this wait, one of the problems to be overcome is the need to increase investment confidence by being able to consistently secure the on-time supply of high-quality, cost-effective key components (such as cables, transformers, and inverters) for energy transmission.

Unfortunately, over the past two years, multiple disruptions have affected transmission supply chains, especially the key components supply chain. The supply chain is grappling with numerous challenges, compounded by the effects of the pandemic and the Russian invasion of Ukraine. These disruptions — logistics bottlenecks, shortages of raw materials, key component requirements (such as HVDC cable), labour and skills shortages — have resulted in rising costs, longer lead times, scarcity of essential components, and lower investment confidence. The gap has widened between demand and supply of equipment and key components, slowing offshore wind's potential to accelerate power system decarbonisation.

> At the current pace of change, the UK will fail to hit its 2035 target, and low-carbon projects now face 15-year delays to connect to the electricity network.
>
> Decarbonisation of the Power Sector
> (House of Commons inquiry, April, 2023)

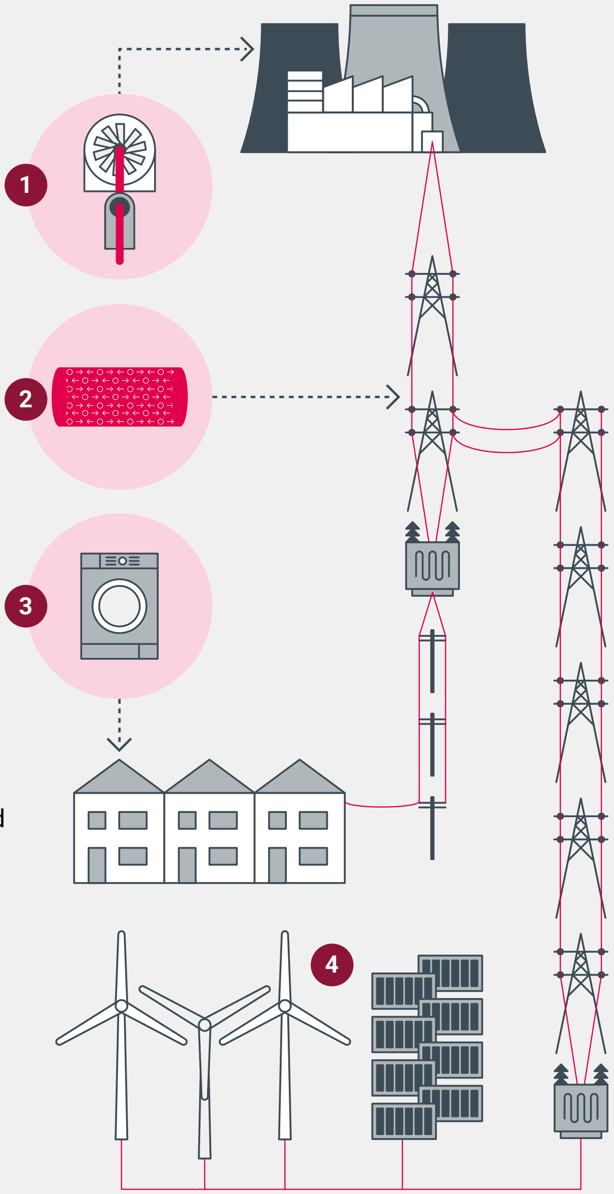
How a connected energy infrastructure operates

1. The steam turbine in the power plant spins at 50Hz. It connects to a generator which converts the spin to alternating current.

2. The generator does this by setting electromagnetic fields oscillating in the wires of the grid: a sea of electrons sloshing to and fro 50 times a second, synced to the turbine's spin.

3. That same sea of electrons runs into the wiring of your home, and into your washing machine. Then, an electric motor inverts the generator's work, converting the sloshing motion of electrons back into a physical movement i.e. the mechanical action that spins the washing machine.

4. The electricty generated from wind turbines and solar panels is not provided at the steady frequency of 50Hz that the grid requires. In order to join the grid, the electricity from the wind turbines and solar pannels must be harmonised to 50Hz at a substation. Only then can electricty join the wires of the grid and be distributed to your home.



HVDC (high voltage direct current) cable is a good example of the disruption of a supply chain that's fundamental to delivering the UK's renewable energy targets. Global manufacturing is largely at capacity, and international demand is growing rapidly, leading to inflated prices, delivery delays, and uncertainty around the capacity to meet demand for the next ten years. The HVDC supply chain has become stressed, with little depth, over-reliance on a regional supplier, and limited skilled resources available to design, construct, deliver, install, commission, and maintain its associated infrastructure.

In situations when demand outstrips supply, such as in the case of components essential for linking renewables to the wider energy network, supply chain visualisation, transparency, and prioritisation are crucial to determining how to ensure efficient procurement, and where components should be directed.

Enabling telecoms/wireless infrastructure

Advanced communications are an essential part of the digital infrastructure needed for digitalisation. Considerable effort is made to address energy system digitalisation, but the requirement for essential digital infrastructure and communications is not attracting commensurate attention - there is often an assumption that they are already in place, or will otherwise be available when needed.

Current development efforts in advanced communications are being made to address economic and social outcomes. But these focus on general consumers, not on the provision of services that could support mission-critical applications or national infrastructure such as the energy system. End-to-end integration of energy and digital infrastructure is still relatively unexplored in the depth necessary to assure outcomes — much is being taken for granted.

As a result, there is some degree of uncertainty over what the future wireless communication infrastructure will look like for the UK network. There are numerous decisions that need to be made, a range of options to be considered, and many stakeholders who should be engaged in the process.

At a high level, there are four main options for delivering advanced communication:

- Public and private fibre networks
- Commercial radio frequency networks
- Private radio frequency networks
- Blended approach using different technologies

Public and private fibre networks

Fibre networks are a tried-and-tested method of connecting energy infrastructure to communications networks. They have a proven track record in delivering the reliability, resiliency, latency, and security needed for network operation. However, this technology comes with the challenge of requiring physical access, and a reliance on costly civil works requiring significant capital investment.

In isolation, fibre networks present an option that is theoretically strong, particularly for network operations and use cases where balancing resilience, reliability, and security is critical. However, applications requiring the connection of millions of assets would be costly, and potentially rely on public networks and the Universal Service Obligation to facilitate connection to homes across the country.

Commercial radio frequency networks

Commercial radio frequency networks present the opportunity to use infrastructure and markets that are already established.

In paying commercial network operators for usage and data transfer, energy networks could benefit from the technology refresh cycles that are already integrated within business models, and there will be no further requirement for spectrum allocation.

However, the use of commercial networks presents concerns around the security, reliability, bandwidth, and availability needed to guarantee security of supply for energy. The commercial mobile networks are optimised to be efficient and low-cost. Consequently, they are focused on high-population density areas and, while reliable, do not meet the resiliency and reliability standards of energy networks. Furthermore, this option would involve exposure to the business models of the UK's communications network operators.

Using commercial radio frequency could present some cost efficiency, particularly when serving applications where large bandwidth and coverage are important but resilience and reliability are less critical, such as connections to private EV chargers or small remote assets.

Private radio frequency networks

Using private radio frequency networks would leverage the benefits of radio frequency technology while retaining control over the security, resilience, and reliability of the network. This type of network would require capital investment in communication infrastructure to establish private spectrum communications, with operating costs for bandwidth usage and data transfer, as well as eventually having to cover a technology refresh. Importantly, allocation of spectrum access would be needed for this solution.

Private radio frequency networks would give the energy networks control over reliability, latency, security, and bandwidth, allowing them to efficiently deliver network balancing, operability, and locational pricing.

A blended approach

Fibre and radio frequency networks are both valuable solutions to different challenges. A blended approach introduces the possibility of optimising the communications infrastructure, enabling networks to draw on the most appropriate solution for each situation. However, this requires additional resources to conduct a case-by-case assessment, and would introduce additional delivery and operations complexity.

Taking a blended approach requires infrastructure to be designed, built, implemented, and integrated with the existing energy and communications networks. This approach also provides the flexibility to support many different applications: it could provide security, reliability, and resilience for network operability and balancing, while offering enough scale to connect with and collect data from millions of devices.

Each of these technologies has a role to play. As they are today, the future energy networks could be supported by different technologies, depending on the market, and the regulatory and technological environments that they operate within.

> Whichever route is taken, there is an urgent need for cross-sector collaboration — within and beyond the energy sector — to orchestrate a coherent communication infrastructure that efficiently operates the energy networks.

A connected energy workforce

Digital technology presents great opportunities to support engineers in the field. They are often lone workers responsible for maintaining vital infrastructure in energy generation, transmission, or distribution, ensuring that homes and businesses have reliable power. We have identified three areas where we see digital technologies supporting engineers working on maintaining UK energy infrastructure. Maximising the speed and efficiency with which each task is scheduled and completed (whether an emergency or planned maintenance) is of huge value to a connected workforce, helping them to complete jobs safely, accurately, and quickly.

Augmented reality (AR) support

When working at height, carrying documents and schematics while also using tools can be difficult. Here, augmented reality can be a valuable companion. Using a smartphone or a headset, AR can overlay digital information such as reference images or text onto the user's view of the real-world environment.

This is a practical and hands-on way to enhance field engineers' efficiency and accuracy in diagnosing and addressing maintenance issues. By using AR technology to provide real-time guidance and instructions, engineers can swiftly identify and resolve issues, which helps to minimise downtime and enhance service reliability.

In the near future, spatial computing platforms similar to Apple's new extended reality headset will also allow the energy sector to use more complex mixed reality environments. As new enterprise services and applications are developed for spatial computing, these platforms may become an end-to-end geospatial solution that can be used to integrate physical environment data and enable scalable simulations and modelling for engineering environments.

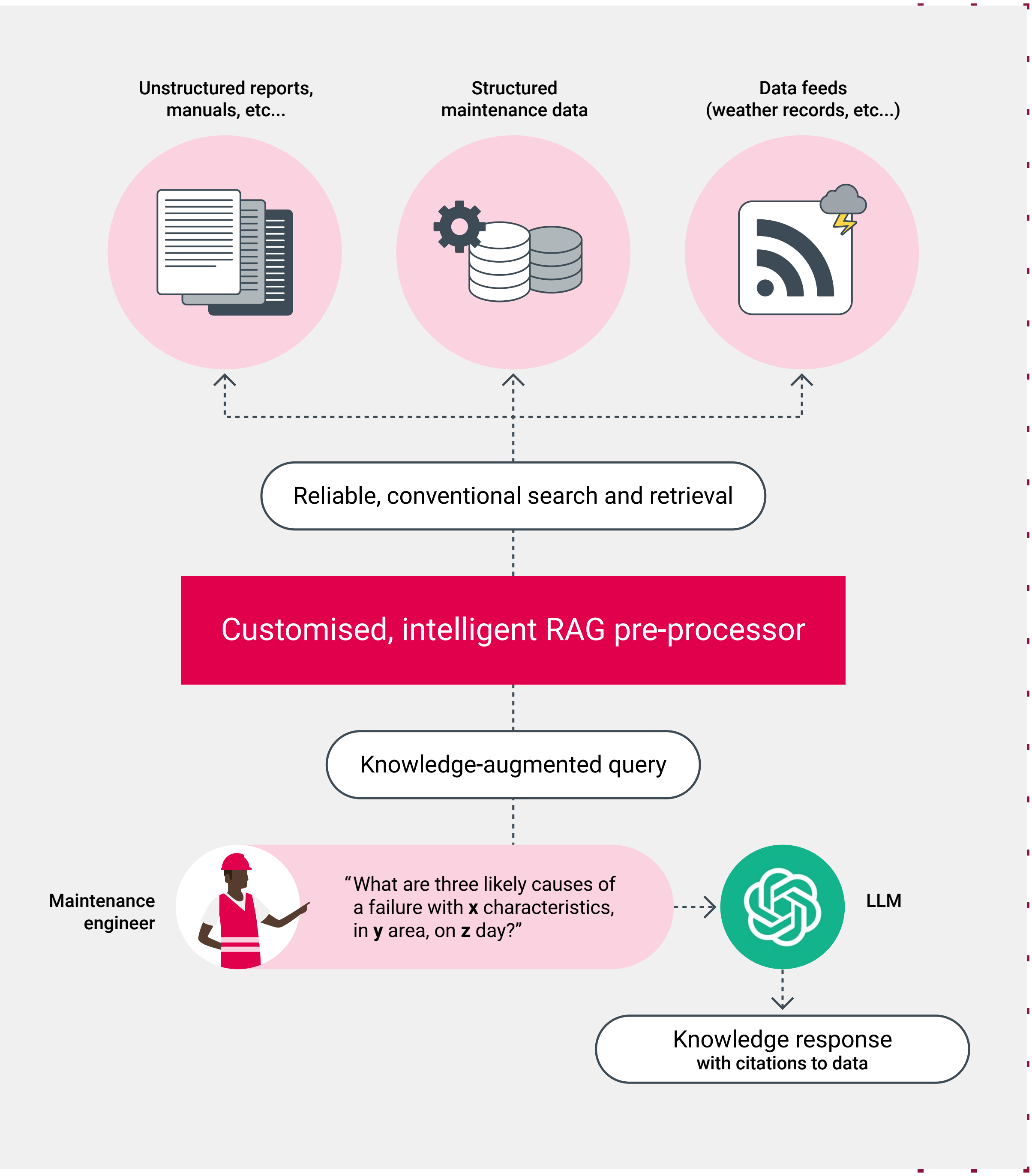
Expediting fault repairs using large language models (LLM)

When engineers are working on a fault, a significant amount of time is often spent on understanding what the source of the problem is, and why the fault may have occurred. Through a generative AI technique known as retrievable augmented generation (RAG), engineers in the field could provide information on the problem and ask for possible causes.

The AI would then look at external data feeds (such as weather conditions), structured maintenance data (such as report logs from across the sector), as well as unstructured data (such as instruction manuals, product specifications) to analyse what the problems could be. The system then replies with potential causes for the error, troubleshooting information, and citations for the sources that have been used to make that decision, allowing the engineer to immediately begin addressing the problem.

This reduces disruption for customers by minimising outages and improving service reliability, ultimately leading to fewer customer minutes lost and increased customer satisfaction.

Digital Catapult's basic PoV for retrieval augmented generation LLMs for maintenance



Connected mobile stores

Engineers working in remote locations have a large number of tools in their vans, with the aim of having everything they need on-hand. However, keeping an inventory of every vehicle's stores while out in the field can be difficult. Reaching a site without a particular tool can result in a significant delay to maintenance, while tools being left behind on-site can be costly to the network or system operator.

A distributed and automated store can be used to create a digitally auditable inventory and track where parts and tools are across the network, enabling van-to-van exchange when an engineer does not have a required piece of equipment.

This technology provides field workers with real-time visibility of inventory levels, and creates a distributed asset storage model that can decrease warehousing expenses and streamlined resource management. Additional features could be included, such as a safety alarm if the van has not sensed the worker after a set time period.

The skills shortage

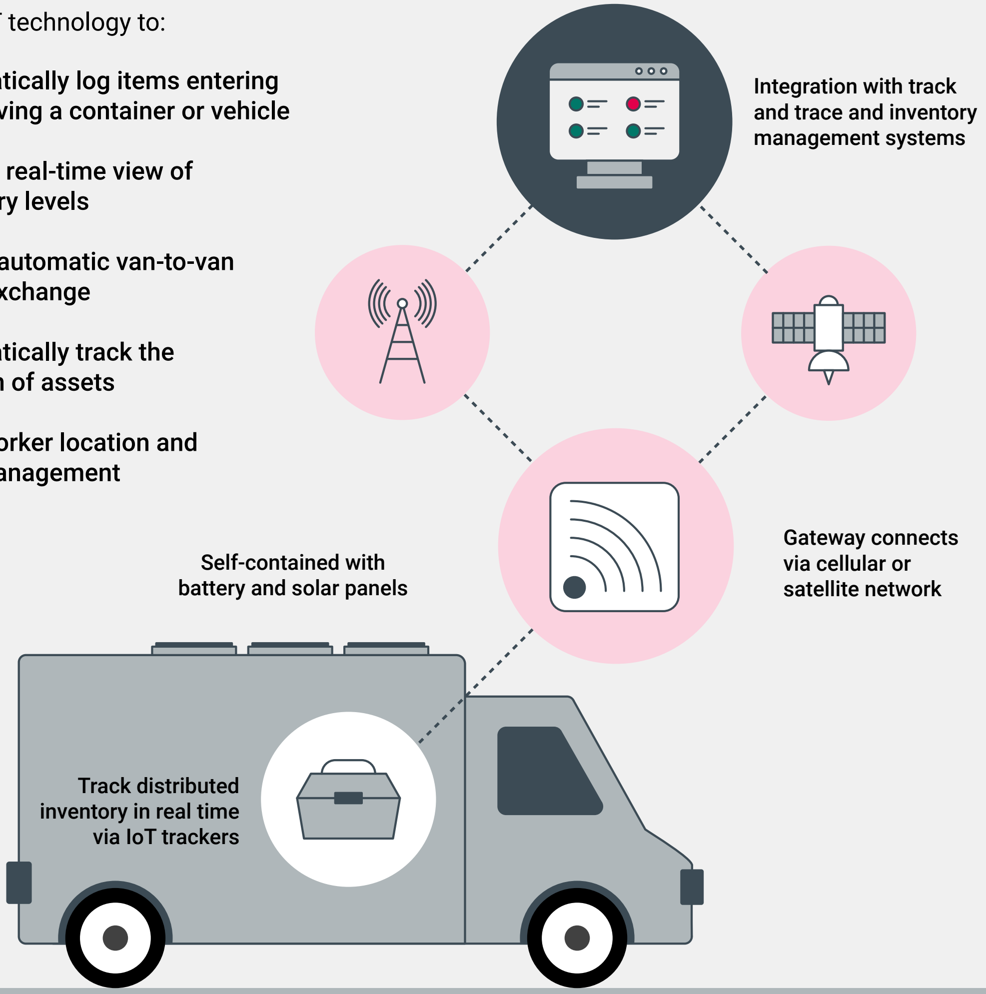
The scarcity of digital and AI skilled resources working towards decarbonisation of the energy system is an industry-wide concern. A growing number of organisations in the UK are looking to address this, including the AI for Decarbonisation Virtual Centre of Excellence (ADViCE). ADViCE is co-delivered by Digital Catapult, Energy Systems Catapult, and The Alan Turing Institute, and connects AI resources with wider industry adopters, solves challenges, and creates space for collaboration.

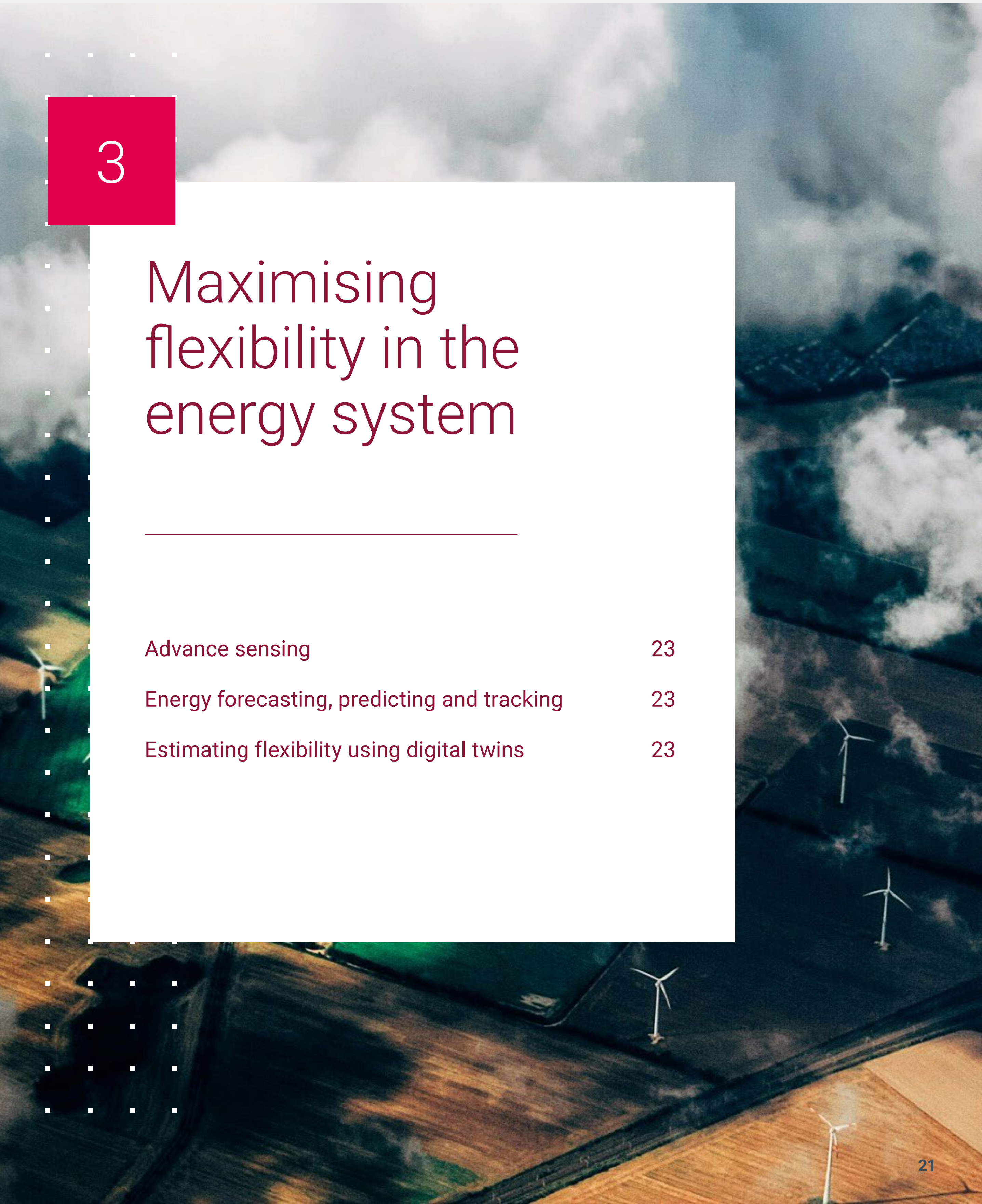
Managing logistics complexity for workers in the field

Digital Catapult's distributed asset storage solution delivers improvements in efficiency, effectiveness and situational awareness when managing inventory in remote and last mile locations.

It uses IoT technology to:

- **Automatically log items entering and leaving a container or vehicle**
- **Provide real-time view of inventory levels**
- **Enable automatic van-to-van stock exchange**
- **Automatically track the location of assets**
- **Lone worker location and alert management**





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Maximising flexibility in the energy system

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Renewable generation can be volatile and uncertain. Similarly, at low voltage and building level, energy use can be irregular and therefore difficult to predict accurately.

A low-carbon future requires energy demand to flex, so that we consume and store energy when the wind is blowing and the sun is shining. This is a radical change in approach for network and market operations, and requires an underlying introduction of new technologies. This presents a host of new challenges. In addition to improving consumer energy efficiency, energy demand and generation will need to be managed to meet net zero.

Renewable generation tends towards decentralised and specific locations, and is often weather-dependent. To make the most of these resources and ensure balance requires shifting demand to match generation, and storing energy for future use.

Devices such as heat pumps and electric vehicles that have integrated communications and controllable technology also could be used to help support the network. However, controlling these devices would be a considerable task, especially since there is a need to optimise for multiple factors: consumer needs, local and national network constraints, and local and national generation.

Advance sensing

The challenges report published by the AI for Decarbonisation Virtual Centre of Excellence (ADViCE), highlights three of the key requirements for digital solutions delivering energy flexibility:

- **Time series data:** time series data for demand, generation, and weather to produce forecasts that can be used for storage scheduling and other applications
- **Demand optimisation:** according to network constraints, demand, generation, costs, and external variables such as weather and network topology
- **Geospatial data:** understanding network topology, what is connected, the potential effect of the weather or climate, and what other assets there are nearby that could be used

Energy forecasting, predicting and tracking

As we move towards net zero, we want to be able to verify that the energy we use is green. This is particularly true for hydrogen, where the varying production methods affect its level of sustainability, which is why hydrogen is described using different colours (only green hydrogen is 100% carbon-neutral). However these different forms are not visibly different once they enter the gas network.

Estimating flexibility using digital twins

A digital twin is a virtual representation of a physical object, system, or process that mirrors its real-world counterpart in a digital environment. This twin is created through the integration of various technologies, including sensors, internet of things (IoT) devices, data analytics, and simulation models.

Digital twins provide a comprehensive and dynamic emulation of the physical entity, capturing its geometry, behaviour, and interactions.

The key characteristic of a digital twin is its ability to continuously synchronise with its physical counterpart, offering insights into its current state and performance. This synchronisation enables monitoring, analysis and optimisation of the physical entity throughout its lifecycle, from design and manufacturing to operation and maintenance.

> By leveraging data generated by the physical object, digital twins facilitate informed decision-making, predictive maintenance, and performance optimisation.

In energy networks, digital twins can enhance resilience by modelling and simulating various failure scenarios, such as extreme weather events, cyber-attacks, and equipment failures. By identifying vulnerabilities and assessing contingency plans, operators can proactively mitigate risks, minimise downtime, and ensure continuity of service.

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Future challenges

Future challenges

Energy requirements of digital infrastructure

While there is no doubt that advanced digital technologies will play a key role in delivering net zero power, the impact of digital technology infrastructure on energy demand is large - and growing - as global internet traffic doubles every 24 months.

The proliferation of digital technology infrastructure, including data centres, cloud computing and high-speed internet, has led to increased energy consumption. Data centres in particular require significant amounts of electricity and water to power and cool their servers, creating a huge amount of wasted heat.

This means that although advancements in digital technology have led to improvements in energy efficiency, the increasing use of technology generally counteracts any efficiency gains. For example, increased data centre efficiency can lead to more data-intensive activities (such as streaming higher-quality videos) which negate the value of any emission reductions being achieved. This is known as the rebound effect.

Solving the rebound effect

One particular solution to this challenge is to improve digital infrastructure integration with renewable power availability. This includes renewable energy integration and using advanced forecasting algorithms and grid management systems to help utilities better predict and manage the variability of renewable energy generation, which means that digital infrastructure has a lower reliance on the grid.

The other key requirement is exporting excess heat produced by servers into community heating networks. The Department for Energy Security and Net Zero (DESNZ) intends to introduce a regulatory framework for heat networks to enable heat network zoning in towns and cities across England. Heat network zones will identify and designate areas where heat networks provide the lowest-cost, low-carbon heating option.

In November 2023, it was announced that the government is planning for data centres to be the next industry to feed into new heat networks. While there will be no ‘one size fits all’ solution for heat export, trials are taking place in various parts of the UK to establish the best opportunities for making use of the excess heat within data centres. These trials include using digital infrastructure to warm swimming pools, community centres and residential buildings.

While digital adoption can lead to increased energy consumption, especially in data-intensive applications, it also offers opportunities for energy efficiency improvements, smarter energy management, and the integration of renewable energy sources. Balancing these factors is essential for maximising the benefits of digital technology while minimising its environmental footprint.

For more information on digital opportunities for the energy sector, visit:

AI for Decarbonisation's Virtual Centre of Excellence (ADViCE)

Hydrogen Innovation Initiative

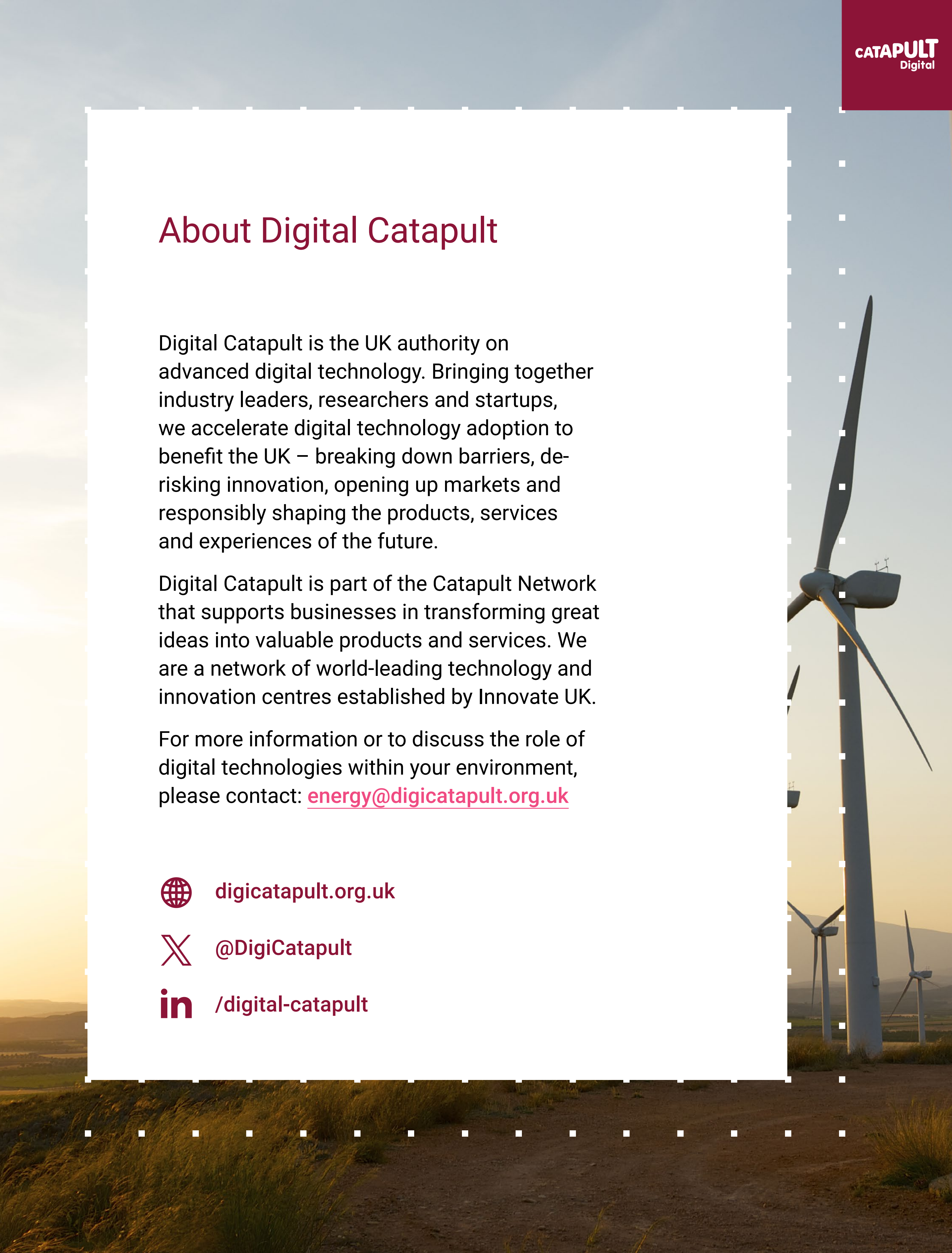
Energy Networks Association

Hydrogen
Innovation
Initiative

The Hydrogen Innovation Initiative (HII) is a trusted group of organisations working with industry, government, and academia to create an investible, globally competitive hydrogen technology and services sector in the UK. Our vision is for UK technology to power the global hydrogen economy, transforming UK industry into a net zero powerhouse.

That is why the HII is bringing together the resources of key stakeholders to coordinate efforts. The businesses and organisations represented include world-leading sector technology centres (Aerospace Technology Institute, the Net Zero Technology Centre, the Advanced Propulsion Centre UK), seven Catapult centres, and the National Physical Laboratory - all working alongside government and industry. Our combined expertise is being used to work out the size and scale of the opportunity for the UK to become truly world-leading in hydrogen technology and services.

hydrogeninnovation.co.uk



About Digital Catapult

Digital Catapult is the UK authority on advanced digital technology. Bringing together industry leaders, researchers and startups, we accelerate digital technology adoption to benefit the UK – breaking down barriers, de-risking innovation, opening up markets and responsibly shaping the products, services and experiences of the future.

Digital Catapult is part of the Catapult Network that supports businesses in transforming great ideas into valuable products and services. We are a network of world-leading technology and innovation centres established by Innovate UK.

For more information or to discuss the role of digital technologies within your environment, please contact: energy@digicatapult.org.uk

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