Energy Transition Report 2023

NatWest

in association with

BCG BOSTON CONSULTING GROUP

TOMORROW BEGINS TODAY

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Foreword

From the price volatility millions of households and businesses have faced in energy bills to the increasing frequency of extreme weather events, the past 18 months have shown the immense challenge we face in transforming our energy system.

This is no longer just a challenge for tomorrow: we are already seeing the impact of climate change on our planet. Failing to act will have profound consequences for people, businesses and communities as climate change disrupts global economies, supply chains and our natural world.

This is a significant challenge, and collaboration is critical to make it happen. The UK Government has made long-term commitments to reducing carbon emissions and signed into law targets of net-zero emissions by 2050. It's clear that supporting our energy system to decarbonise requires investment and innovation by the public and private sectors. To reduce the country's reliance on fossil fuels and achieve a net-zero energy supply by 2050, the UK needs to scale its technology and infrastructure – all of which requires finance. This must be done in a way that provides the maximum benefit for businesses and consumers while embedding energy security at its heart.

This report, commissioned through Boston Consulting Group (BCG), explores how the UK could support a net-zero energy system by 2050 while ensuring stable and affordable energy supplies, providing universal access and enabling robust economic growth. It is a huge challenge and one we estimate will require extraordinary levels of finance. Our analysis estimates that more than £900bn of capital expenditure could be needed in the next three decades to support the UK's energy supply and power generation to transition to net zero. Mobilising that magnitude of finance cannot be accomplished in isolation – it will require huge levels of public and private capital, delivered in ways that respond to the needs of people and businesses.

Over the years, we have seen how investing in solar or wind has moved from being perceived as a highly risky new technology to being no riskier than investing in any other energy source. However, it's clear we cannot stand still. Emerging technologies such as hydrogen and carbon capture and storage could enable the reduction of greenhouse gas emissions at significant scale, but investment has been constrained by several risks and challenges. We must work collaboratively to overcome these challenges to support the next generation of green technologies to play their role in the UK's transition.

I look forward to working with stakeholders across the value chain as the energy sector's journey to net zero begins to take shape.

Andy Gray,
Managing Director, Commercial Mid-Market,
NatWest Group

"We must work collaboratively to support the next generation of green technologies to play their role in the UK's energy transition."

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Foreword

To reach net zero by 2050, the energy system must undergo a tectonic shift. Society has gone through energy transitions in the past – but nothing like this one. The adoption of coal occurred over roughly five decades and the shift from coal to oil took more than three decades. To limit global warming to 1.5C above pre-industrial levels, we must ramp up renewables and other low-carbon solutions at warp speed.

Changes are already under way with energy sources such as renewables, the accelerated expansion of electricity networks and the scale up of new energy technologies or carriers such as carbon capture and storage, energy storage systems and hydrogen. But we are just at the beginning of the journey.

As the clock keeps ticking, one of the key challenges we face is plugging a substantial investment gap to support the quick roll-out of solutions and innovation we desperately need. Financial institutions are in an excellent position to leverage the learnings and experience from backing technologies such as wind and solar over the last decade.

In conditions of increasing complexity, defined by economic and political uncertainty as well as societal pressures, it has become clear that no single source of private or public finance can solve for this – we believe the answer is targeted and coordinated action. The objective of this report is to provide clarity on the dependencies around key technologies needed for the transition in the UK.

Eriola Beetz
Managing Director and Partner,
Boston Consulting Group

"To limit global warming we must ramp up low-carbon solutions at warp speed."

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Executive summary

To reach net zero by 2050, the world must undergo a fundamental global energy transition.

In this report, with insight from Boston Consulting Group in the UK, we dive into what the transition of energy supply could look like. The information presented here is a combination of analysis from organisations including the UK's Climate Change Committee, the International Energy Agency and the Intergovernmental Panel on Climate Change. The report also explores how investing in low-carbon industries could help deliver lasting economic benefits to the UK and businesses within the energy system and value chain.

The UK is embarking on a major shift from fossil fuels to low-carbon energy sources, including increased demand for electricity and development of new fuels. This new era could transform the energy system and open even bigger opportunities for businesses.

Offered coordinated support and investment, businesses could accelerate and deliver meaningful change by working together to test low-carbon solutions, to help build even more security and resilience into the system and to unlock revenue in the UK.

See capex methodology on page 39.

This shift is likely to involve significant investment in renewable generation, network infrastructure and new technologies such as energy storage systems, carbon capture and storage, and hydrogen.

Business models are evolving in response to technical innovation and new policy and regulation, with a significant role for private capital to play in this transition.

As part of our analysis with BCG, we have identified a potential investment need for the supply side of the UK energy system of more than £900bn* to 2050. This calculation is based on data from the Climate Change Committee, the Department for Business, Energy and Industrial Strategy and other publicly available industry data. We recognise that route maps or scenarios for achieving a fully decarbonised economy by 2050 could evolve or be modified over time, dependent on governmental policy. The Climate Change Committee also highlights, for example, the increasingly important role of behavioural changes in getting to net zero. But there is inherent uncertainty in predicting levels of behaviour change over the long-term.

*To derive a more nuanced estimate for the capital expenditure[1] need per technology, we also combined insight from internal models and relevant teams at BCG and NatWest, and all prices have been rebased to 2023 levels. Capex defined as costs at the time of financing in a given year and excludes cost of borrowing.

"The UK is embarking on a major shift from fossil fuels to low-carbon energy sources."

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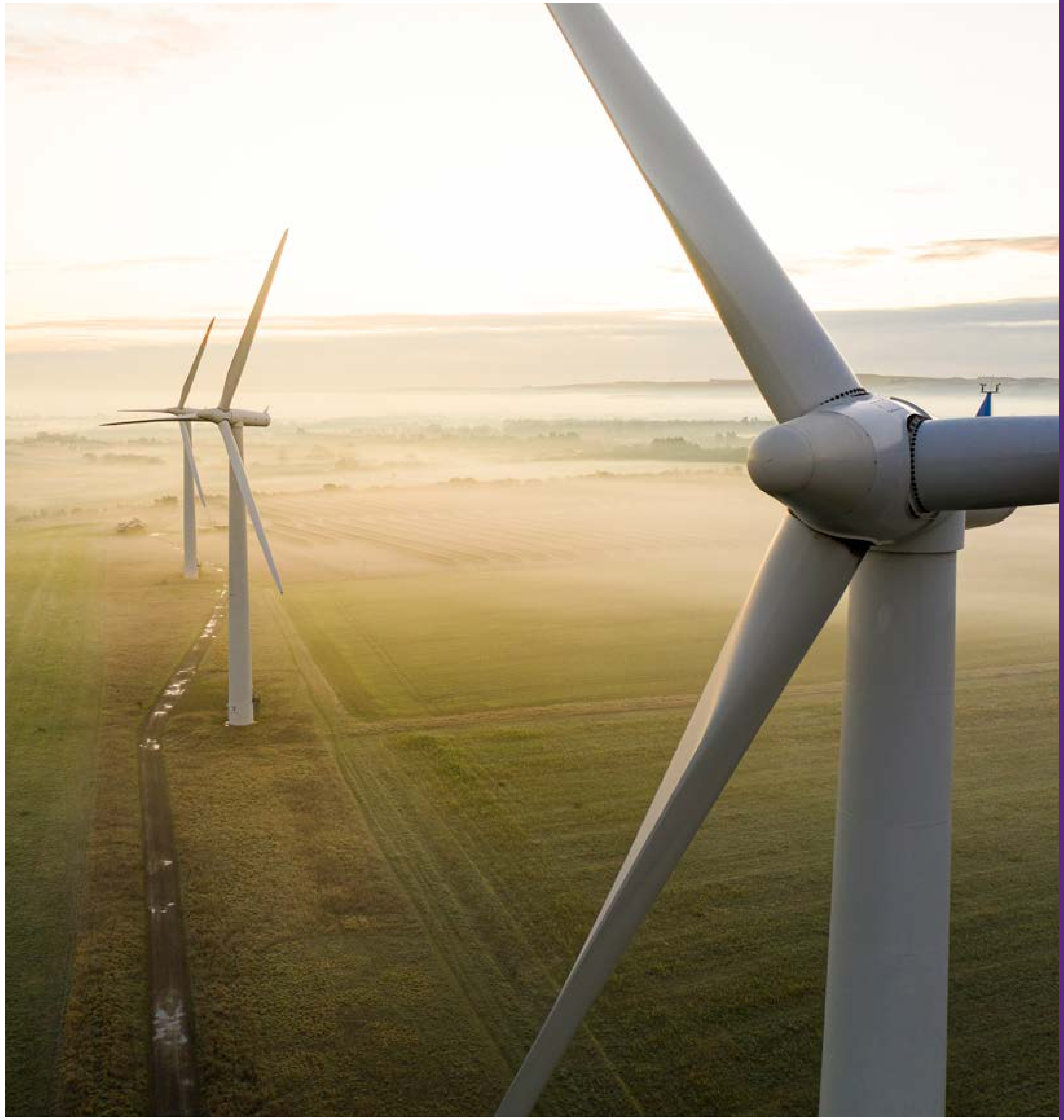
The Climate Change Committee is an independent, statutory body established under the Climate Change Act 2008. Its purpose is to advise the UK and devolved governments on emissions targets and to report to parliament on progress made in reducing greenhouse gas emissions and preparing for and adapting to the impacts of climate change.

The Climate Change Committee published the Sixth Carbon Budget, the UK's path to net zero, in December 2020. As a largely UK-focused bank, we selected the UK Climate Change Committee's balanced net-zero pathway to determine emission reductions required by 2030, where possible. In developing the initial iteration of our climate transition plan, we used the UK Climate Change Committee's Progress in Reducing Emissions: 2022 Report to Parliament as the basis of assessing current status of government policies. For consistency, we are also utilising the balanced net-zero scenario in this report.

Alongside the balanced net-zero pathway, the Climate Change Committee also explored other routes to net zero that could be achieved with greater or lesser levels of innovation and behaviour change. Its tailwinds scenario shows that with extremely high levels of behaviour change and rapid innovation, the UK could achieve net zero by the early 2040s. Its headwinds scenario shows that pessimistic assumptions about engagement and innovation result in a slower path to net zero.



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What could a successful transition depend on?

The 2022 Net Zero Strategy: Build Back Greener policy paper identified a range of practical ways in which UK net zero could feasibly be delivered with technology and resources known today. It's anticipated that a suite of technologies, including renewables, networks, hydrogen, batteries and carbon capture and storage, together with nuclear, may have a key role to play in future energy systems.

A successful transition depends on all industries dramatically changing their energy consumption, ways of working and producing. Sector partnerships could play an important role in scaling up and developing efficient and reliable solutions and new markets.

However, the transition to net zero requires a collaborative effort and action by investors, regulators, policymakers, energy companies and businesses in the supply chain to navigate the complexities.

The Climate Change Committee's 2023 progress report to parliament in June cautioned that "the UK has lost its clear global leadership position on climate action". The committee stated that "policy development continues to be too slow and our confidence in the UK meeting its medium-term targets has decreased in the past year".

There is a great deal of uncertainty inherent in any modelling as far into the future as 2050, which is highly sensitive to economic, societal and technological developments. But the path to net zero will respond to the innovation and adoption of new technologies over time.

This report makes it clear that significant investment in the UK's energy supply is needed to support its transition to net zero, and this will not be possible without collaboration.

"Significant investment in the UK's energy supply is needed to support its transition to net zero."

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At a glance

The Paris Agreement, which was signed in 2015, saw delegates from 196 countries meet to agree to cap global warming at "well below 2C", with a view to limiting this figure to 1.5C above pre-industrial levels. However, a 2021 Intergovernmental Panel on Climate Change (IPCC) Report found that unless there are immediate, rapid and large-scale reductions in greenhouse gas emissions, limiting warming to close to 1.5C or even 2C will be beyond reach.

There are a range of ways in which net zero in the UK could be achieved. Renewable energy could be deployed at massive scales, networks multiplied in size and sophistication, and fossil fuels – which have been embedded in our global energy system for centuries – could be phased out or decarbonised with new technologies such as carbon capture and storage.

Expect the current landscape of traditional energy players to be disrupted. Value chains may dramatically shift – for example, fertiliser producers may also become energy carrier (hydrogen) producers.

The International Energy Agency World Energy Outlook 2022 has identified the 2030s as a "critical decade" for the global energy system transition, but material risks remain – including the impact of the war in Ukraine.

After a change in policy position by the UK Government on, for example, banning the sale of new cars with combustible engines, there has been some commentary around whether the UK's progress towards net zero could be hindered.

The US Inflation Reduction Act and the EU's proposed Green Deal Industrial Plan could act as a strong pull for green investment away from the UK while turbocharging their growth in renewables.

The UK energy transition must be deeply transformative. Be prepared for this seismic shift – but also be galvanised to accelerate the transition.

Key features of the net-zero transition

- The Intergovernmental Panel on Climate Change (IPCC) has found greenhouse gas (GHG) emissions must fall by 43% by 2030 (compared with 2019 levels) to limit global warming to 1.5C above the long-term pre-industrial average.

What this could mean for you

This decade is essential to mobilise action and increase the chances of stabilising temperatures in line with the Paris Agreement objectives.

- The UK has signed into law targets of net-zero emissions by 2050 and a 78% reduction by 2035 from 1990 levels.

What this could mean for you

Each sector of the economy can play a crucial role in the future net-zero system and, because these are highly connected, changes in one area may directly or indirectly have an impact on others. Each sector is likely to need to undergo a dramatic transformation to achieve these goals.

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A coordinated approach to decarbonisation

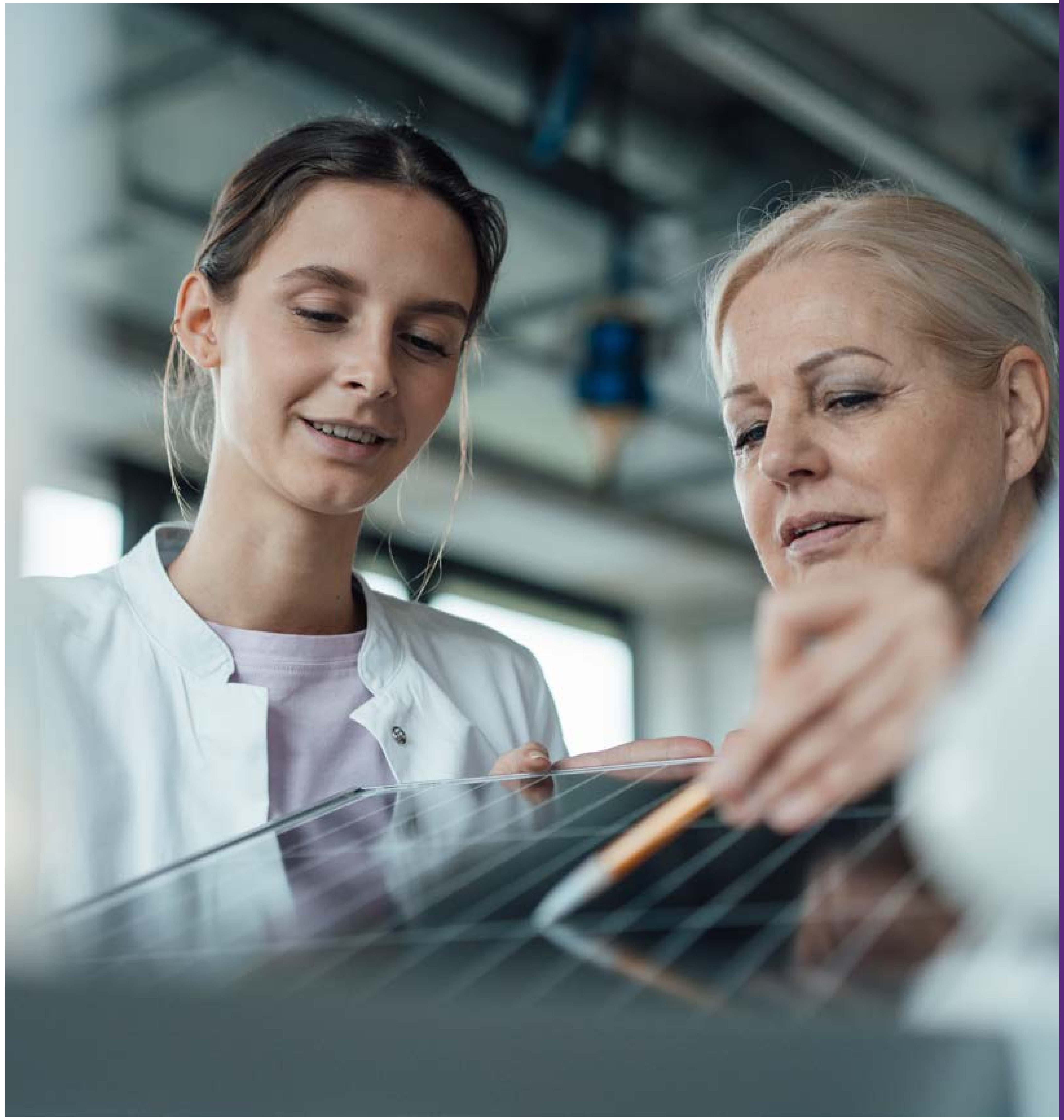
Because carbon flows between various sectors of the economy, coordination across systems could be key to energy transformation and decarbonisation.

In NatWest's Climate Related Disclosures Report 2022, we have focused on five systems: mobility, food, property, materials and energy.

This report examines the supply of energy in line with the boundaries set by the Climate Change Committee for this part of the system.

These include the primary supply of energy, conversion and transportation, as well as technologies to facilitate the transition from fossil fuels and those that are typically developed by clients within the energy sector (for example, carbon capture and storage, and hydrogen).

Nevertheless, it is important to note that reducing demand and energy efficiency measures would be the priorities to mitigate greenhouse gas emissions (before energy source substitution or carbon removals).



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The International Energy Agency road map

The energy system continues to drive most global emissions – electricity and heat production directly emitted 15 gigatonnes (Gt) globally in 2022, out of total energy-related CO_2 emissions of 37Gt, according to the International Energy Agency.

The IEA World Energy Outlook 2023 Net Zero Emissions by 2050 Scenario[1] (NZE) examines global emissions and charts a path to net zero.

The outlook is a comprehensive study of how to transition to a net-zero energy system by 2050 while ensuring stable and affordable energy supplies, providing universal energy access and enabling robust economic growth. It sets out a potentially cost-effective and economically productive pathway, resulting in a clean, dynamic and resilient energy economy dominated by renewables like solar and wind instead of fossil fuels. It also examines key uncertainties, such as the roles of bioenergy, carbon capture and behavioural changes in reaching net zero.

According to the IEA, the global energy mix is already changing, driven by target setting and investment in electrification and low-carbon technologies in both the public and private sectors (Figure 1).

For the first time, wind and solar generated more than 10% of electricity globally in 2021, according to the Global Electricity Review 2022. Alternative energy sources or carriers such as bioenergy and hydrogen are growing in importance, albeit from a lower base. NZE sees renewables climbing to 89% of global electricity generation in 2050.

While overall fossil fuel consumption declines, oil and gas continue to play a role in the energy mix, especially within this decade.

The IEA scenario sees fossil fuel use only drop from its current level of 80% of the energy mix to 70% by 2030, falling to 37% by 2050[2].

Energy efficiency measures can be highly impactful – for example, the IEA says energy efficiency in buildings could lead to a 26% reduction in commercial energy consumption in 2030 relative to 2018.

"NZE sees renewables climbing to 89% of global electricity generation in 2050."

[1]The scenario sets out a global pathway for net-zero emissions by 2050. Pathways are modelled routes illustrating different scenarios that could be followed to achieve a certain outcome, in this instance net zero by 2050. It is important to note that these are not predictions. This includes a reduction in overall energy consumption and a substantial shift from fossil fuels to renewables. It is global in scope and does not provide country-specific pathways. For details, see iea.org/reports/world-energy-outlook-2023#overview

[2]These global averages for the energy mix over time are not a direct comparison for the UK due to reasons such as developmental context and available resources to decarbonise.

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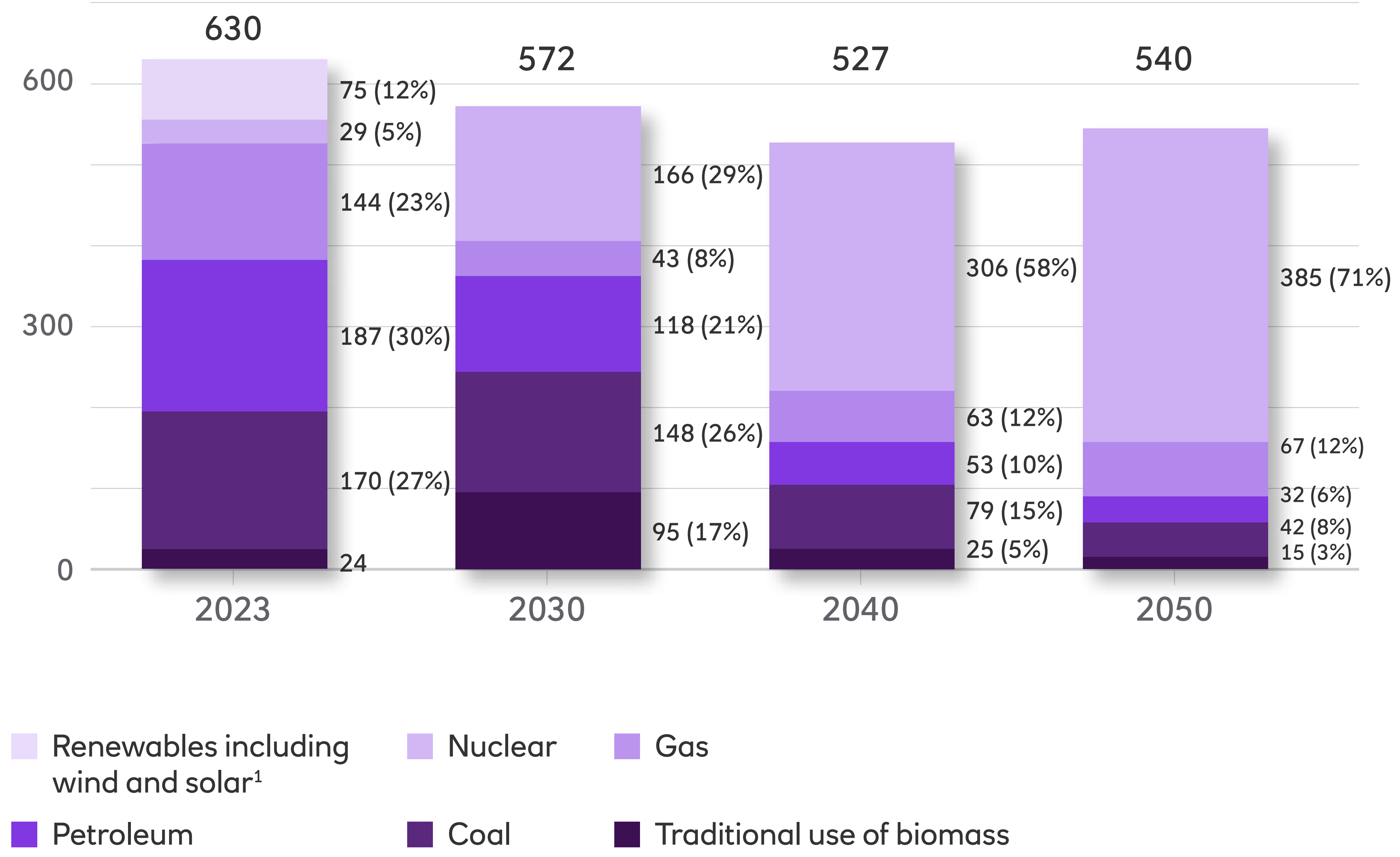
(Figure 1) Global energy supply to reach net zero | IEA net zero emissions scenario

Decarbonisation is driven by increased supply of renewables and reduced reliance on fossil fuels.



[1]Includes other variable renewables.
Source: IEA Net Zero Report (October 2023).

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> **"The IEA Energy Outlook 2023 sets out a potentially cost-effective pathway, resulting in a clean, dynamic and resilient energy economy."**

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The UK Climate Change Committee and levers for decarbonisation

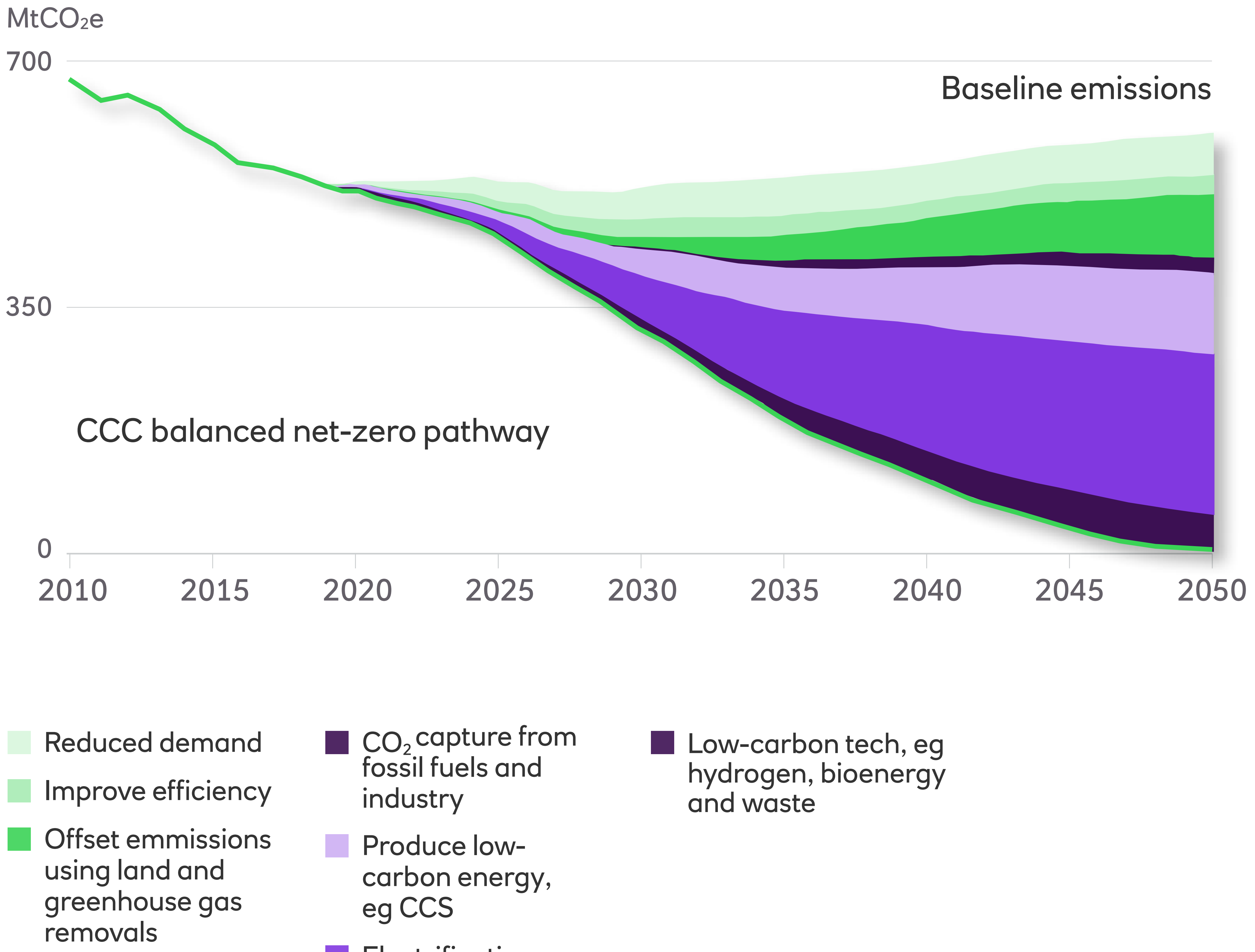
Similar to the IEA, the UK Climate Change Committee says economy-wide decarbonisation levers such as demand reduction and efficiency improvements play a key role. For example, demand timing innovations in sectors such as auto (EV charging) and property (smart meters, smart appliances) can help smooth demand and enable use of variable renewable energy.

Beyond demand reduction and energy efficiency, the Climate Change Committee has identified these three levers for carbon reduction in the energy system (Figure 2).

- Electrification (treated in this report through increased supply of low-carbon electricity and transmission/distribution only – electrification of end-use sectors is treated separately).
- Increased use of existing technologies such as renewables (mainly solar PV, onshore and offshore wind), nuclear and bioenergy.
- Development of emergent technologies and infrastructure (eg hydrogen and carbon capture and storage).

(Figure 2) Abatement pathway to reach net zero by 2050 | CCC balanced net-zero scenario

Low-carbon energy and electrification will play a central role, while techs such as hydrogen are key for hard-to-abate sectors.



Source: UK CCC Sixth Carbon Budget.

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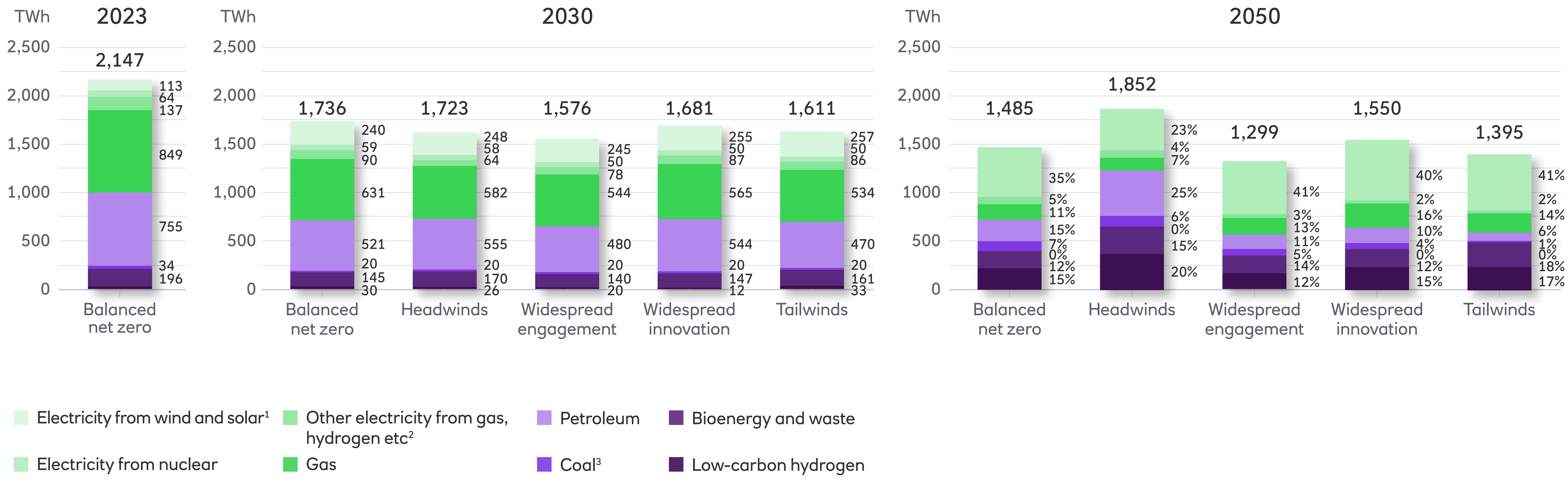
(Figure 3) Changes in the end-use energy demand mix to reach net zero | Five CCC scenarios

Scenarios largely consistent until post-2030; largest divergences in the role of renewables, hydrogen, gas.



[1] Includes other variable renewables. [2] Includes electricity from coal, CCS and storage. [3] Includes other solid fuel.

Notes: headwinds assumes lower behavioural and technological improvements. Widespread engagement assumes higher levels of societal and behavioural changes. Widespread innovation assumes higher levels of technological change. Tailwinds assumes higher behavioural and technological change. Balanced net zero incorporates elements of all scenarios.

Source: UK CCC Sixth Carbon Budget.

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Deep dive on technologies and opportunities

We are aware of the scale of the challenge the energy system faces and the immediate action required to address it. We estimate more than £900bn of capital expenditure is needed in the next three decades to support the UK transition of the energy supply and power generation sectors within the energy system, with additional significant investment needs from the demand side of the economy – such as in mobility and property.

Let's explore the fuel sources and technologies that net zero is likely to depend on.

(Figure 4) Technologies at a glance

	Technology	Emissions abatement	Merchant/ offtake risk	Tech risk	Policy risk
Mature technologies	Renewables	Minimum impact	Minimum impact	Minimum impact	Minimum impact
	Networks[1]	Minimum impact	Minimum impact	Minimum impact	Minimum impact
Emerging Technologies	Battery storage[2]	Minimum impact	Moderate impact	Minimum impact	Moderate impact
	CCUS[3]	Moderate impact	Moderate impact	Moderate impact	Minimum impact
	Hydrogen	Moderate impact	High impact	Moderate impact	Minimum impact
Technologies with more uncertainty	Nuclear	Minimum impact	Minimum impact	Moderate impact	Moderate impact
	Bioenergy, waste, BECCS	Moderate impact	Moderate impact	Moderate impact	Moderate impact
	Alternative long-duration energy storage	Minimum impact	High impact	High impact	High impact

Minimum impact   Moderate impact   High impact

[1]Excludes heat networks.
[2]Excludes batteries within Mobilitv-energy storage only.
[3]Includes CCS networks; excludes CCS for industrial use.

Document classification: external.

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Oil and gas

The phase-out of unabated fossil fuels is key to ensuring the UK can meet the 2035 carbon budget and reach net zero by 2050 (Figure 5). To meet net zero, the Climate Change Committee recommends the UK Government commits to a phase-out of unabated gas by 2035 and includes a limited role for petroleum beyond 2035, largely for aviation.

However, oil and gas and its derivatives are likely to be required in the future for grid stability, for example. Oil and gas is also a key fuel source and feedstock for several sectors, such as aviation and iron/steel, which will require innovative solutions such as carbon capture and storage, and potentially hydrogen, to decarbonise. Both are dependent on UK Government policy because they require additional financial and policy support.

In its June 2023 report to parliament, the Climate Change Committee said: "Policies with immediate delivery are needed, in parallel with development of new strategic visions. In most sectors, there is a clear set of actions that can be taken now and should be pursued while the longer-term picture is clarified."

On 20th September 2023, a change in policy position was announced by the UK Government. One part of this approach is to not ban new oil and gas in the North Sea. On 27th September 2023, the North Sea Transition Authority confirmed consent had been granted for the development and production of the Rosebank field, which lies north-west of Shetland.

How could this impact future plans?

To decarbonise the use of gas for fuel supply and electricity generation, gas plants may need to be retrofitted with carbon capture and storage or converted to produce blue hydrogen. Both options are highly dependent on the successful rollout of carbon capture and storage infrastructure and equipment in the late 2020s and early 2030s.

Should the UK fail to deploy widespread renewable energy supply and electrification with strong grid capacity, there is potential for oil and gas to remain at higher levels than in the BNZ scenario. This could be possible while still maintaining net zero (headwinds scenario) with sufficient carbon capture and storage, though it is challenging. However, even the headwinds scenario sees steep cuts in demand (gas at about 50% of 2020 levels and oil at around 14%).

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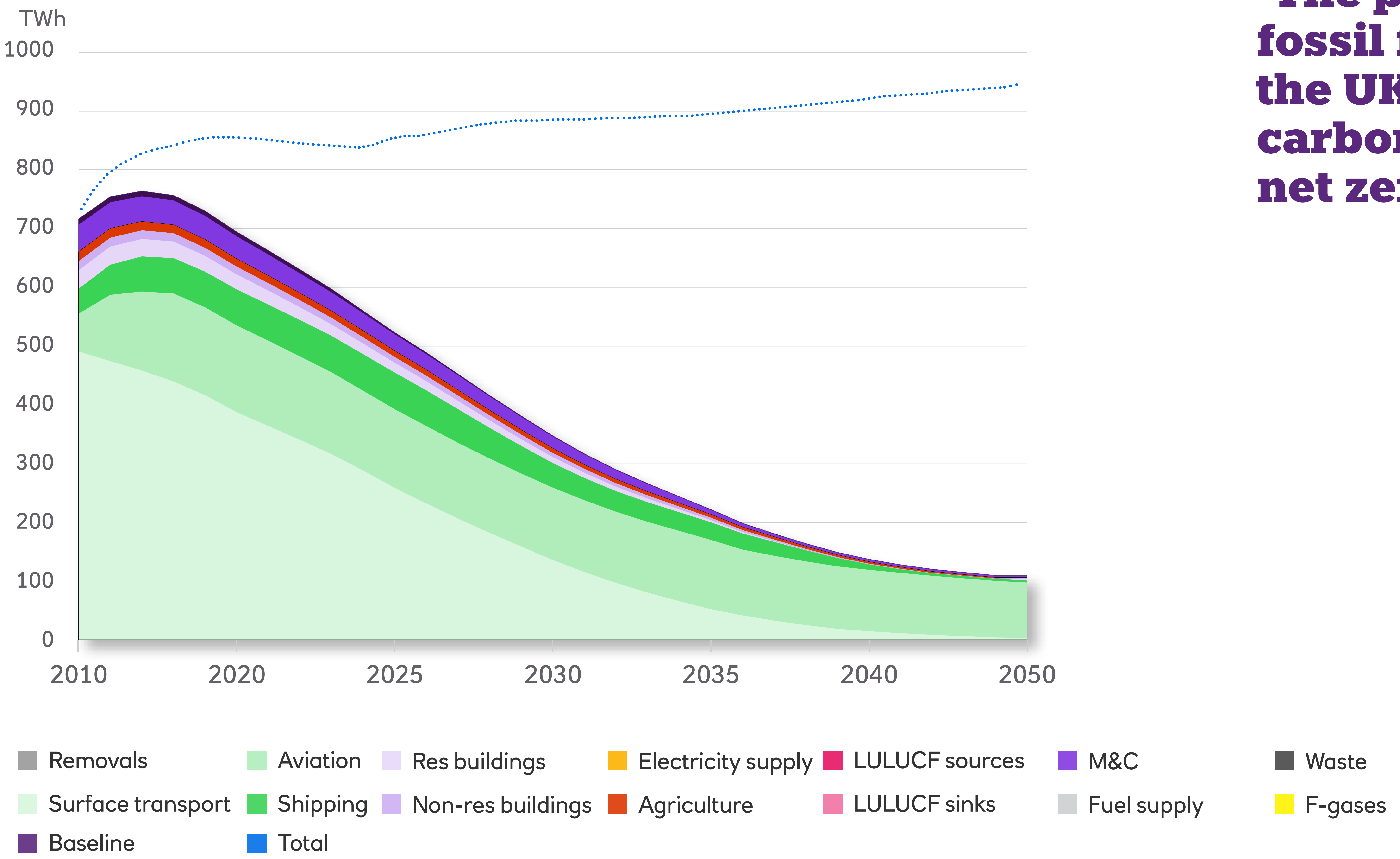
(Figure 5) Petroleum demand | CCC balanced net-zero pathway



Source: UK CCC Sixth Carbon Budget.
Document classification: external.

"The phase-out of unabated fossil fuels is key to ensuring the UK can meet the 2035 carbon budget and reach net zero by 2050."

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Renewables

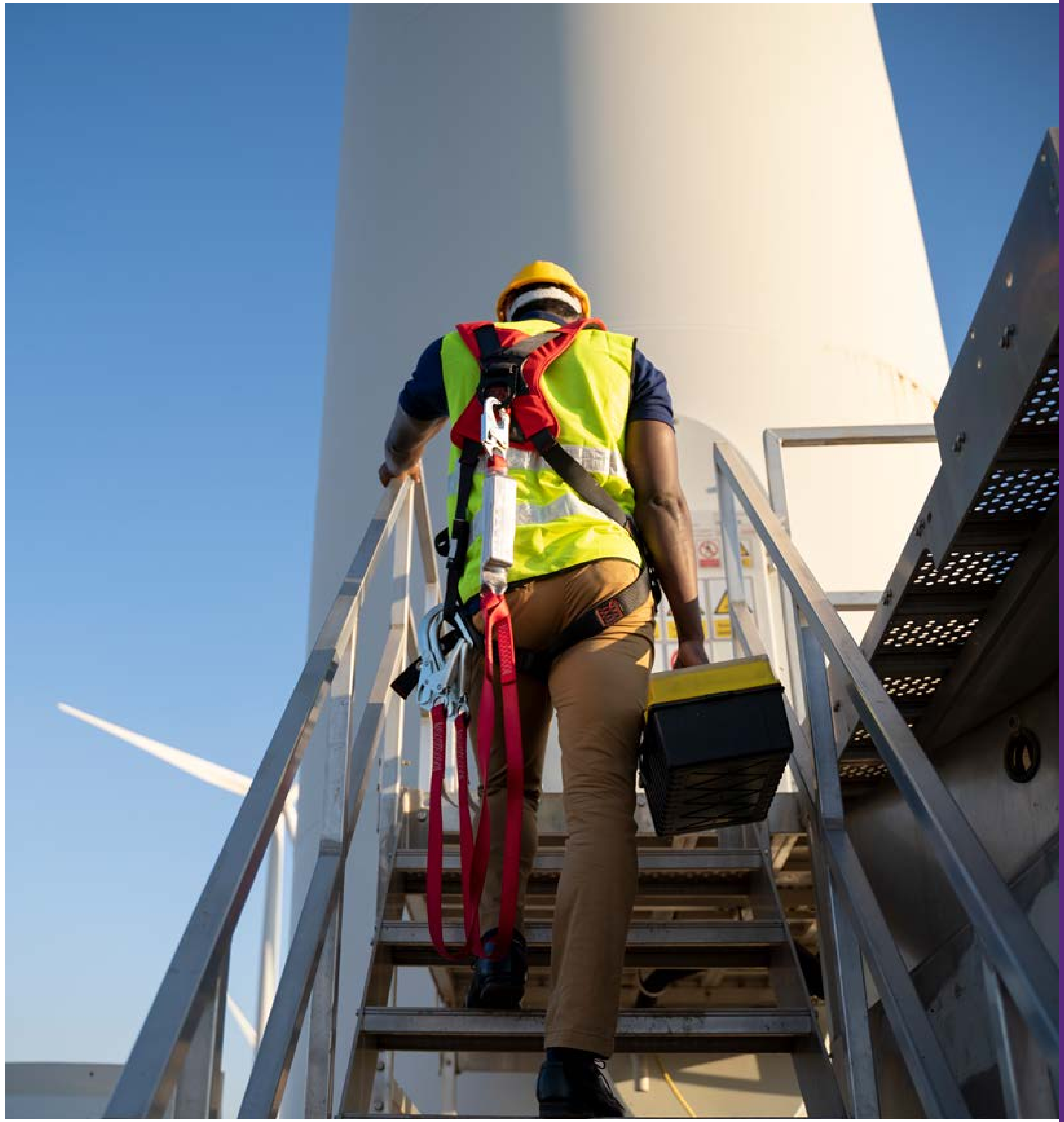
For the purposes of this report, we have only considered onshore wind, offshore wind and solar as renewables. We understand there are a wide array of other emerging technologies (eg deep geothermal) and will continue to monitor their development and policy support to explore opportunities.

What are the potential opportunities?

Renewables has a pivotal role to play in the UK's energy mix.

The UK Government has committed to decarbonising electricity supply by 2035, subject to ensuring security of supply, together with ambitious targets for building new renewables and nuclear. Demand for renewables is likely to grow as the pathway to net zero relies on renewables as the main source of power generation.

Renewable generation also presents an opportunity to co-locate green hydrogen production, which uses curtailed renewables. Sufficient delivery of renewables may also allow for widespread electrification to replace reliance on fossil fuels within other systems, such as mobility and property.



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What are the challenges?

These technologies have matured at a highly accelerated pace. The UK has been a world leader in offshore wind – capacity has expanded rapidly from 1.3 gigawatts (GW) in 2010 to 14GW today – and onshore wind and solar make up a smaller, though important, role in the energy mix.

But in September 2023, the UK Government's latest auction for renewable power – an annual scheme to incentivise private-sector investment in a range of power sources – failed to bring forward any new offshore wind projects (see page 31 for more on this).

Renewables investment faces other headwinds. Building sufficient infrastructure to connect renewables to the grid is a major challenge to increased generation. Some renewable energy projects are taking up to 15 years to connect to the UK grid, making the process among the slowest in Europe[3].

Partly in response to connection challenges, renewables generation could become much more decentralised, with a rise in distributed energy resources as a disrupter to the current landscape.

For example, commercial buildings could generate their own power from solar rooftop PVs. This distributed energy generation is likely to be a substitute for, and not in addition to, centralised energy supply as seen today.

[3]Oral evidence session, Business, Energy and Industrial Strategy Committee, 19th June 2023.

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Network infrastructure

What are the potential opportunities?

Alongside the rapid scale-up of electricity generation from renewable energy, nuclear, dispatchable generation (gas carbon capture and storage, bioenergy with carbon capture and storage and hydrogen) and electrified heat networks, the UK requires an extensive expansion and upgrade of network infrastructure to connect new energy with offtakers and consumers.

Networks need to double in capacity between 2025 and 2035 to meet the BNZ scenario requirements. To reach the government's target of 50GW of offshore wind by 2030, the amount of transmission infrastructure in England and Wales in 2023-2030 will need to be about five times what was installed in the last 30 years[4].

These costs will only be higher in a scenario in which electrification is high and overall energy demand is not reduced, requiring even more electricity.

What are the challenges?

Beyond network capacity to keep up with electricity generation, additional large-scale investment is needed to support adaptation and resilience measures for the UK's energy infrastructure, much of which has been built around a narrow range of specifications for heat, moisture, etc.

Not only is investment likely to be needed to repair networks damaged by severe weather events, but operators are increasingly likely to need to invest early to reinforce and future-proof infrastructure.

[4] National Grid, March 2023.

Energy storage capacity: short-medium duration.

As the economy becomes more dependent on intermittent sources of renewable energy in the form of electricity flows, the UK is likely to expand and enhance its energy storage capacity rather than energy stocks in the form of fossil fuels.

What are the potential opportunities?

Storage solutions for the UK will likely include battery storage for short term, pumped hydro for medium term and hydrogen for medium/long term, inter-seasonal storage or to meet demand in prolonged periods of low wind resource (the BNZ assumes that hydrogen is the primary form of long-term storage, see page 26).

On the next page we explore alternative long-duration energy storage technologies.

Pumped hydro has been a mature technology for decades. Batteries are also mature from both a technology and commercial standpoint, but constantly improving.

Their importance is likely to grow as batteries fall in cost. Most battery energy storage in the UK is around one hour versus other storage technologies but it could reach two to four hours by 2035, increasing the use cases for batteries (eg in capacity markets).

Given the scope limitations of this report, batteries are not discussed in detail.

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What are the challenges?

The successful deployment of storage, namely batteries, depends not only on storage technology but also on the supporting infrastructure.

The rapid scale-up of renewables requires transmission-connected stand-alone storage, which is only possible if networks are upgraded.

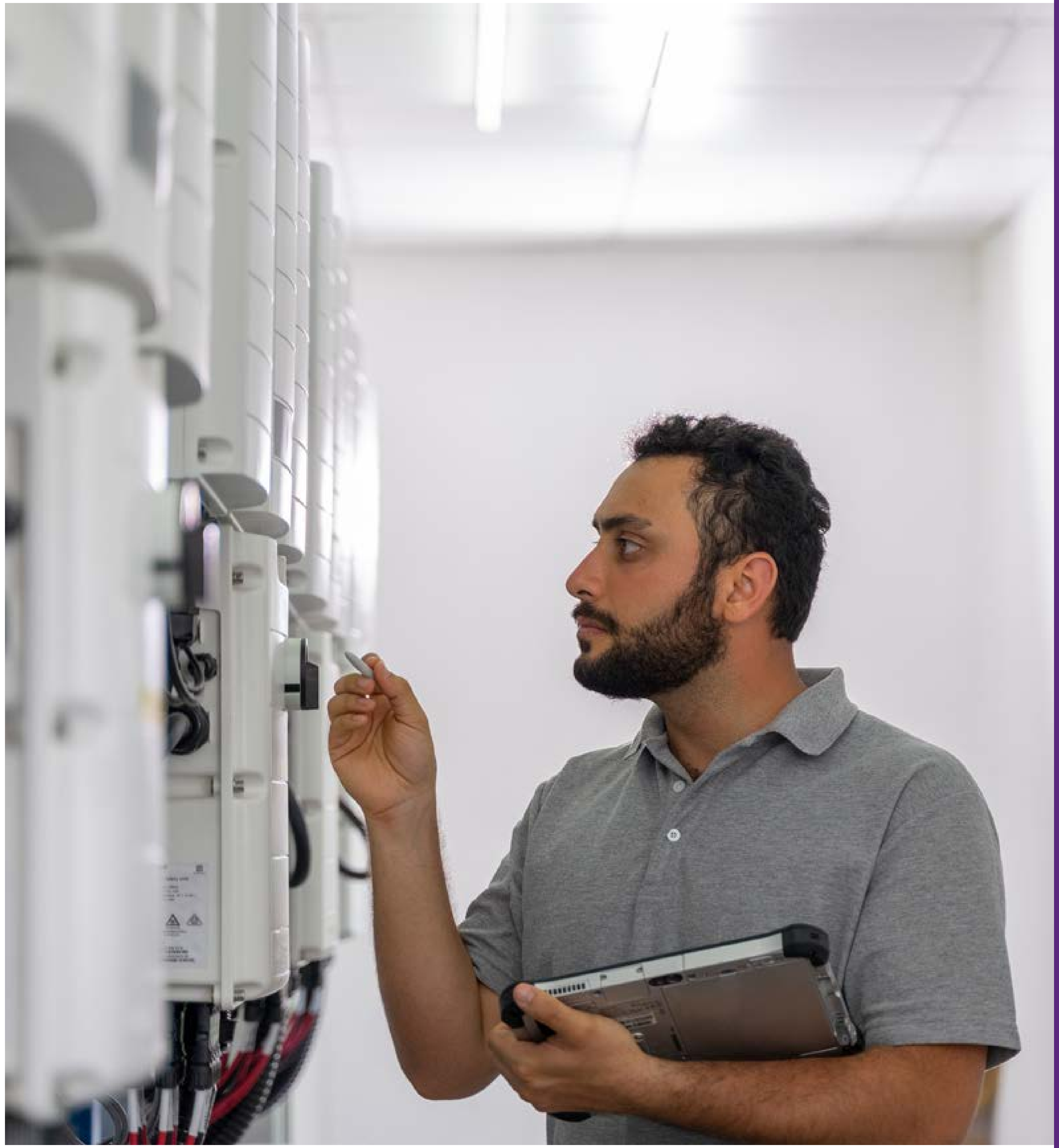
It also depends on the availability of critical minerals such as lithium, which increases the reliance of the UK on foreign supply.

Energy storage capacity: alternative long duration.

Beyond hydrogen, there are several alternative long-duration energy storage technologies that show promise to provide intraday (eight to 24 hours), multi-day and seasonal storage from when supply exceeds demand (eg excess wind) to when demand exceeds supply.

They can also be used to provide off-grid resiliency, capacity provision and grid stability services, as well as transmission and distribution line optimisation.

These technologies include mechanical (eg compressed air, liquid air and gravitational), thermal (eg resistance heaters) and electrochemical (eg aqueous electrolyte flow batteries) forms of energy storage.



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Nuclear

According to a UK parliament research briefing in 2022, nuclear has provided approximately 15-20% of the UK's electricity generation. End-use energy demand from nuclear is largely electricity.

However, nuclear-generated electricity can also be used for hydrogen production via electrolysis, especially if demand is low so nuclear production leads to excess generation.

The Climate Change Committee has identified five ways in which nuclear might contribute to emission reduction targets:

1. It has a low land footprint. This is considered a large advantage over wind and solar, which require significant area for deployment and naturally are often situated in remote areas.
2. Nuclear can be deployed across the UK, such as near high centres of energy use in the south, making distribution easier (wind power is concentrated in the north) and reducing costs of network upgrade.
3. It can generate on a 24/7 basis at predictable cost and does not suffer from market volatility of input fuels such as gas.
4. It has a low carbon footprint, relative to both fossil fuels and renewables.
5. It is reliably available year-round, complementing intermittent renewables.

What are the next steps?

Nuclear has been controversial for several reasons – safety concerns considering historical meltdowns, delays and cost overruns, as well as environmental impacts and long-term waste storage issues.

Alongside large-scale nuclear reactor plants, a range of technologies for small modular reactors (SMRs) are in the early stages of development as an energy source.

The UK Government's policy and regulatory announcements in the coming few years will substantially shape the trajectory. In 2023, the government set up Great British Nuclear to promote and manage the development of the nuclear industry in the UK, including the investment in SMR technologies.

"The UK Government's policy and regulatory announcements will substantially shape the trajectory of nuclear."

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Hydrogen

Hydrogen has a role to play in the BNZ pathway, across a variety of applications. They are presented below in order of what is likely to be most feasible.

1. Replace grey hydrogen with cleaner forms of hydrogen already in use in refineries or steel production, for example, or as a feedstock for fertiliser production as ammonia. This is considered a clear win for decarbonising existing hydrogen use.

2. Storage of electricity for long durations: back-up power on-demand to meet peaks in demand and to smooth supply across periods of higher or lower wind power generation. This requires large storage facilities such as salt caverns, which are a significant investment.

3. Fuel supply: applications where electrification is less feasible, such as for high temperature heat – for example, within the glass industry.

4. Additional potential end-use in a hydrogen economy:

   (a) mobility – hydrogen could be used as an energy carrier for transport, either as ammonia, coupled with captured carbon dioxide as synthetic fuels (eg e-methane, e-methanol, e-kerosene), or with hydrogen fuel cells. Shipping is likely to be decarbonised with ammonia or methanol. Hydrogen buses are already in use. For most road transport, however, electrification is considered a more likely outcome given its cost competitiveness and overall efficiency.

   (b) heating – the UK has a history of using hydrogen for heating. Until the 1960s, most of the UK's gas supply included a high proportion of hydrogen ("town gas"). The UK Government is planning to conduct trials that use hydrogen for heating and will decide in 2026 on its strategy for this use case.

What are the potential opportunities?

Hydrogen's potential as a source of energy to address intermittency issues with electricity derived from renewables (eg retrofitting of gas peaking stations) is considered high. This is particularly so where electrolysis can use renewable power that would not otherwise be used (curtailed). An example is at off-peak times when more wind power can be generated than is needed.

What are the challenges?

There is still significant policy uncertainty around the potential of hydrogen as a fuel in mobility or as a replacement for natural gas in applications such as heating.

This is because green hydrogen loses considerable amounts of energy throughout the production and supply chain, such as through the electrolysis process, which requires significant power, liquefaction, conversion to other carriers such as ammonia or transportation. These inefficiencies make direct electrification a far more efficient solution where feasible.

If hydrogen is to achieve its full potential, it must become less expensive and more efficient to produce, distribute and use.

There are also technological and economic reasons why certain applications may or may not prove feasible for hydrogen. In some cases, an alternative technology may prove more attractive. We recognise the Climate Change Committee's scenario is something that is likely to evolve.

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Carbon capture and storage

Carbon capture and storage is also a necessary technology for the Climate Change Committee BNZ scenario to meet its net-zero carbon budget. Without carbon capture and storage paired with high-carbon energy elements like gas or energy-from-waste, the committee observes that the UK will struggle to maintain its carbon budget during the transition to a low-carbon energy supply.

What are the potential opportunities?

Carbon capture and storage, and other carbon removals, are seen as a "backstop" in a typical carbon mitigation hierarchy, taking lower priority than reduction in energy use or replacement of high-carbon power sources with renewables. However, the Climate Change Committee recognises the urgency and severity of the climate crisis requires all possible decarbonisation solutions to be explored and developed.

There may also be a use for captured CO_2 in making synthetic e-fuels, such as e-methane, e-methanol or sustainable aircraft fuels. Here, captured CO_2 is combined with green hydrogen to create hydrocarbons that can replace fossil fuels.

If the CO_2 is captured from biogenic rather than fossil-based sources, the fuels are seen as a sustainable replacement for existing fossil fuels. This carbon could be captured from processing biomass or other natural resources, or potentially captured directly from the air (direct air capture, or DAC), although the technology is still nascent and expensive.

Carbon capture and storage has an important use case to capture and store CO_2 from large-scale, hard-to-abate industrial sources (eg cement, chemicals), and is a key lever for decarbonisation of the manufacturing sector. Carbon capture use and storage (CCUS) is also important for using CO_2 in industrial applications such as the production of e-fuels, although this is dependent on UK Government policy.

The UK is well-positioned to lead in carbon capture and storage, given its large storage potential in the North Sea (an estimated 78 billion tonnes of CO_2) and expertise from the oil and gas sector.

Development of these clusters is a key dependency for the BNZ scenario's

"The UK is well-positioned to lead in carbon capture and storage, given its large storage potential in the North Sea."

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deployment of carbon capture and storage.

Bioenergy and waste

In the BNZ scenario, bioenergy is used only where most carbon-efficient, and 85% of bioenergy in 2050 is paired with carbon capture and storage for use as bioenergy with carbon capture and storage (BECCS). The UK Government published its updated Biomass Strategy in August.

What are the challenges?

Several challenges to deployment may be anticipated.

- It is reliant on imported biomass (around 25% of bioenergy supply in 2050), the cost of which is set by the global market and is likely to increase over time as demand increases, potentially driven by investment in new fuels supported by the Inflation Reduction Act in the US.
- The sustainability credentials of biomass are often challenged, and it will be important that there is robust and transparent regulation to ensure that all sources of biomass meet sustainability criteria.
- It is unclear how domestic production could be achieved sustainably at scale given the land area needed and competition with food production. The UK climate is not best suited for energy crops, which also tend to be challenging chemically to convert into the most efficient form of fuel.
- Clear carbon accounting is still in development for land sector removals, and many stakeholders across industry and non-governmental organisations (NGOs) are uncertain how to measure and account for the use of bioenergy.
- As stated above, carbon capture and storage is required at scale by 2030 to support the deployment of BECCS. The timing of adoption is dependent on when such technology will be deployed.

“It will be important that there is robust and transparent regulatiion to ensure allsources of biomass meet sustainability criteria”

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(Figure 6) BNZ energy mix in 2035 v projected state of play (I/II)

Technology/ infrastructure	BNZ energy mix in 2035[1]	Current forecast base on policy and marketing developments in 2020–2023	Status for reaching target mix
Oil and gas	• Phase-out of unbated gas by 2035, but gas CCS continues to be used	Russia's war in Ukraine increased gas prices reducing UK gas consumption UK Government's energy security strategy focuses on transition away from O&G NSTA forecast production of oil to decrease by c.75% and gas by c.95% by 2050 UK will follow guidance on climate tests for new licensing rounds Uncertain whether hydrocarbon demand will fall in line with BNZ	Impact of geopolitical tension is unclear
Networks	• Electrification and investment in T&D significant share of CAPEX throughout transition	National Grid's Pathway to 2030 Holistic Network Design, announced in 2022, aims to deliver up to £548bn of investment and connection of 23GW wind Ofgem removed competition for £20B of projects (ASTI) Planning delays and supply chain constraints will slow grid build out	Depends on faster approvals process
Renewables	• Scaling up is key to the transition • Wind is the backbone of the transition, providing 265TWh of generation by 2035	In 2022, government updated target from 40GW to 50GW of offshore wind capacity by 2030 Government initiated yearly CfD auctions between now and 2030 But inadequate networks infrastructure is causing unnecessary curtailment (£1.5bn of wind congestion costs 2021-2023) and delays in grid connection	Grid connection delays are slowing deployment
Storage	• 18GW of batteries by 2035, from 2.1GW today • Pumped hydro capacity remains at 3GW	30GW government target of low-carbon flexible assets including energy storage by 2030 National Grid forecasts that 29GW of storage will be needed by 2030 and up to 51GW by 2050, a substantial increase relative to the BNZ's 18GW Many alternative long-duration energy storage solutions are being experimented with in the UK	High storage investment in past three years than BNZ
Nuclear	• 10GW of nuclear capacity, maintained at current levels by replacing retiring capacity with new plants	Great British Nuclear set up by government to deliver new reactors Delays and cost overruns in Hinkley Point C construction cast possible doubt on the new plants Concerns of insufficient private investor buy-in for £20bn needed for Sizewell C	More uncertainty than BNZ

All depend on networks

No clear gap with BNZ | Slightly behind BNZ | Moderately behind BNZ | Significantly behind BNZ

[1]Based on CCC Balanced Net Zero scenario, published in 2020.

Source: UK CCC Sixth Carbon Budget.
Document classification: external.

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(Figure 7) BNZ energy mix in 2035 v projected state of play (II/II)

Technology/ infrastructure	BNZ energy mix in 2035[1]	Current forecast base on policy and marketing developments in 2020–2023	Status for reaching target mix
Hydrogen	• A lynchpin in the BNZ with increased demand from 2025, through integration with gas networks; use in industry • The primary technology for long-term storage	⌃ Supportive government stance outlined in 2023 UK Hydrogen Strategy, doubled target to 10GW by 2030, and £240m Net Zero Hydrogen Fund set up in 2020 ? Policy framework being developed through CfD model but regulatory clarity expected to be delayed, eg hydrogen levy cancelled ⌄ UK Government has committed to much less funding compared to Germany and others ⌄ Carbon pricing, at about £83/ton CO_2e, is currently much lower than necessary for green and blue hydrogen to be cost-effective without subsidies	Insufficient government funding relative to what is needed on BNZ pathway
CCS	• Wide-scale infrastructure across the UK by 2030, including four CCS clusters • CCS widely rolled out in the 2030s for use in gas, hydrogen, biomass and waste	⌃ Government committed £20bn to early CCS deployment and £1bn on the CCUS Infrastructure Fund, 2023 ⌃ Consortium of energy companies formed the Northern Endurance Partnership (NEP) in 2020 to develop offshore CCUS infrastructure in the North Sea (although Shell and NGV pulled out in 2023) ⌄ CCS clusters already delayed and BNZ roll-out looks unfeasible given (i) three to five-year time-to-build of carbon capture plants and (ii) carbon storage is essential infrastructure for the clusters but its assessment and development process can take much longer	Infrastructure roll-out is delayed relative to BNZ assumptions
Bioenergy and waste	• Bioenergy use declines 2025-2030 before picking up, but CAPEX limited • BECCS provides 3% of electricity generation by 2035	⌃ Government's Net Zero Strategy committed to 5 $MtCO_2$/year of carbon removals by 2030 and 80 $MtCO_2$/year by 2050, which implies c.50% more by 2050 than in BNZ ⌄ No decision to date from government on importing biomass, creating uncertainty ⌄ DRAX paused £28bn BECCS plans of policy uncertainty	Policy uncertainty hampers progress relative to BNZ

No clear gap with BNZ | Slightly behind BNZ | Moderately behind BNZ | Significantly behind BNZ

[1]Based on CCC Balanced Net Zero scenario, published in 2020.

Source: UK CCC Sixth Carbon Budget.
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How energy projects could evolve to transform the system

The seismic changes in the energy system, in terms of scale, mix and technological innovation, are likely to also transform the cast of organisations building and operating the energy system of the future (Figure 8).

Current large players, such as oil and gas producers and network operators, may in time transform their businesses to transition from fossil fuels to low-carbon energy sources.

New entrants or players with experience in other industries could play a much larger role in energy.

The transformation of the energy system is likely to require the activation of much larger supply chains, with opportunities for growth and development of key UK industries.

The fourth round of the Contracts for Difference (CfD) scheme was described as the most successful ever, securing almost 11GW across a range of clean technologies including offshore wind, solar, onshore wind and – for the first time ever – floating offshore wind and tidal stream, helping to boost British energy security and independence with cleaner, more affordable and diverse energy created in the UK.

The latest round of auction for offshore wind was unsuccessful in September 2023, though, because the "strike" price was deemed too low. The impact of inflation will need to be considered in the next round.

What are Contracts for Difference?

The Contracts for Difference (CfD) scheme is the government's main mechanism for supporting low-carbon electricity generation. CfDs are designed to give certainty to project developers to invest in new renewable energy infrastructure by protecting them from volatile wholesale prices.

They are a private law contract between a low-carbon electricity generator and the Low Carbon Contracts Company (LCCC), a government-owned company. The government holds annual auctions for CfDs in which developers planning to build renewable energy bid to provide energy at a price guaranteed (or "strike") by the government.

There have been five auctions, or allocation rounds, to date, which have seen a range of different renewable technologies competing directly against each other for a contract.

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(Figure 8) Key players and investing opportunities increase when emerging business models and entire supply chain are considered (I/II)

Energy elements and technologies.

	Oil and gas extraction	Nuclear	Onshore/ offshore wind	Solar	Other renewables eg tidal, hydro
Players	• IOCs • North Sea intependents	• Power utilities, private operators • Engineering/ manufacturing players	• Power utilities, private operators • Traditional O&G • Independent developers	• Power utilities, private operators • Traditional O&G • Independent developers	• Power utilities • Traditional O&G • Independent developers
Direct investments	• Some E&P investments; maintenance • Decarbonisation of operations (eg methane flaring, electrification of platforms)	• Development of large plants • Small modular reactors (SMRs) • Maintenance/replacement	• Leasing of sites • Development of wind farms (fixed and floating for offshore) – foundations, platforms, etc • Maintenance/replacement	• Leasing of sites • Development of PV panels • PV components • Maintenance and replacement	• Research and develpment for scale-up • Leasing of sites • Development of plants/sites
	+	+	+	+	+
Supply chain opportunities (non-exhaustive)	• Platform electrification developers	• Construction and technical services • Scaffolding and insulation • Waste management	• Ports/vessels • Engineering • Production, eg turbines • Construction and technical services	• Production of components • Polysilicon • Ingots • Wafers • Cells	• Ports/vessels • Engineering • Production, eg turbines • Construction and technical services

Document classification: external.

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(Figure 9) Key players and investing opportunities increase when emerging business models and entire supply chain are considered (II/II)

Energy elements and technologies.

	Hydrogen	Bioenergy and waste	CCS	Networks (electricity, gas, H2)	Storage (batteries, pumped hydro, alternative long-duration
Players	• Power utilities • Traditional O&G • Independent developers • Industrial gas players	• Power utilities • Traditional O&G • Pulp and paper • Financial sponsors	• Power utilities • Traditional O&G • New tech players	• Utilities • iDNOs • OEMS • Others	• Power utilities • Pumped hydro • Independent developers • Financial sponsors
Direct investments	• Electrolysers • Retrofitting gas plants for methane reformation and CCS • Storage facilities (caverns, saline aquifers, tanks)	• Biojet, biodiesel, bioliquids, biomethane and biohydrogen conversion facilities • Biomass feedstock costs (opex)	• CCS fitting to eg gas plants, biofuel • Capture facilities • Pipeline/ships (transport) • Drilling wells (storage)	• Substantial/overhead lines cables/pipes • Smart grids/distributed systems/grid modernisation equipment (eg sensors, circuit breakers)	• Large-scale battery/pumped hydro build • Cathodes/anodes • R&D on alternative technologies
	+	+	+	+	+
Supply chain opportunities (non-exhaustive)	• Storage civil works – labour, equipment, training • Manufacture of, for example, packages, compressors	• UK biomass production (limited opportunities given land area available)	• Pipeline/drilling parts manufacturing • Capture technology production (equipment, chemicals, training)	• Civil works – labour and equipment • Manufacturing of cables, tranformers • Training centres	• Critical minerals • Manufacturing of, for example, cathodes, anodes • Civil engineering

Document classification: external.

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The decarbonisation of sectors: systems thinking.

We recognise that the decarbonisation of certain sectors could have a large impact on decarbonisation within other sectors, the most prominent being energy. It is appropriate and expected that there will be synergies across systems.

Mobility

The phase-out of fossil fuels demands innovation in fuels for surface transport.
- Electrification.
- Biofuels.
- Hydrogen.

According to the BNZ scenario, aviation will continue to be fuelled largely by kerosene, though there is also a role for synthetic jet fuel.

Materials

The three biggest abatement levers in materials (Climate Change Committee's manufacturing and construction sector) are electrification, hydrogen and carbon capture and storage. Materials are critical to facilitating the energy system transformation.

- Electrification could support the decarbonisation of processes currently powered by fossil fuels. Connecting manufacturing sites to the grid instead of relying on on-site power generation, or using electric boilers for heat, relies on strong network infrastructure and a steady supply of clean energy.
- Hydrogen is already used as a feedstock for processes such as ammonia production, but currently from carbon-intensive grey hydrogen. Blue and green hydrogen could support decarbonisation, while also being used for power and heat.
- Carbon capture and storage is key for hard-to-abate sectors, where energy source switching is not sufficient for emissions from the chemical process (eg limestone calcination in cement manufacturing). Widespread availability of carbon capture and storage equipment, infrastructure and storage are as important for enabling this system as they are for the energy system.

"Mobility, materials and property are critical to facilitating the energy system transformation."

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Property

Predictions in the Climate Change Committee's Sixth Carbon Budget report tell us 34% of abatement comes from energy efficiency measures. And the deepest source of emissions abatement for property is in residential heating abatement.

- The BNZ adopts a phase-out of gas boilers from 2033.
- Boilers must be hydrogen-ready by 2025 – 11% of homes use hydrogen for heat.
- Heat pumps make up 75% of low-carbon heat installations, including hydrogen hybrids, with 19% heat networks.
- All heat networks are electrified.

We recognise these scenarios may shift and evolve. For example, in June 2023 the Climate Change Committee reported on hydrogen: "The government does not expect to make a strategic decision on the role of hydrogen in heating until 2026. It must overcome this uncertainty by accelerating deployment of electric heating and pressing ahead with low-regret energy infrastructure decisions."

In September 2023, the UK Government announced people will have more time to make the necessary transition to heat pumps.

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Delivering on the aspiration: what actions could we all take now to support future energy systems?

The UK financial sector, government, energy players and wider society must work collaboratively to accelerate large-scale energy transformation. Several key market developments are necessary to unlock further action.

1. Clear and decisive government policy to set direction for the market.
2. Leading support from public institutions such as the UK Infrastructure Bank and British Business Bank (BBB). These institutions could be helpful to step in with additional capital or risk mitigation support.
3. Cooperation between banks and investors to overcome challenges to scaling investment. For example, financial institutions partnering together to provide debt and equity needed to develop an ecosystem pairing renewables, storage, hydrogen and carbon capture and storage could be transformative.
4. Strong commitments from energy players to put new technologies on the market, procure components and materials from UK supply chains, and work with financing partners on developing innovative business models.
5. Action from society, SMEs and consumers to support the energy transition, such as implementing energy efficiency measures and asking energy providers for low-carbon electricity, heat and fuels. Demand signals from civil society can be strong catalysts for change.

Get the information you need to make considered decisions around reducing your organisation's emissions and achieving sustainability goals.

Check out our climate support hub for more information or chat to our energy transition team.

Discover BCG's latest thinking on energy on its website.

> **"The UK financial sector, government, energy players and wider society must work collaboratively to accelerate largescale energy transformation."**

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We believe sharing information is a great way to make progress. We also believe transparency is important.

Climate is an evolving topic and so we have set out below some of the challenges and uncertainties with climate-related metrics and data to provide you with further context to this report. We have also set out below the terms on which We make this report available to You.

CAUTIONS ABOUT CLIMATE-RELATED METRICS, DATA AND METHODOLOGY CHALLENGES.

Caution about climate metrics challenges

Climate metrics, including aims, ambitions, estimates, forecasts, plans, projections, targets and other climate metrics included or referred to in this report, especially if they are forward-looking, merit special caution as they are more uncertain than metrics based solely on factual historical financial information.

The evolution of climate change and its impacts is highly uncertain, as are the metrics and methodologies used to measure, estimate and report those impacts and emissions. Accordingly, both historical and forward-looking climate metrics are more inherently uncertain and, therefore, less reliable than metrics based on historical financial statements.

There are many significant uncertainties, assumptions and judgements underlying climate metrics that limit the extent to which climate metrics are reliable.

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The preparation of certain information in this report requires the application of a number of key judgments, assumptions and estimates. The reported measures in this report reflect good faith estimates, assumptions and judgments at the given point in time. There is a risk that these judgments, estimates or assumptions may subsequently prove to be incorrect and/or may need to be restated or changed.

There is currently no single globally recognised or accepted, consistent and comparable set of definitions or standards (legal, regulatory or otherwise) of, nor widespread cross-market consensus as to:

- what constitutes, a 'green', 'social' or 'sustainable' or having equivalent-labelled activity, product or asset
- what precise attributes are required for a particular activity, product or asset to be defined as 'green, 'social' or 'sustainable', or such other equivalent label
- climate and sustainable funding and financing activities and their classification and reporting.

Therefore, there is little certainty, and no assurance or representation is given, that such activities and/or reporting of those activities will meet any present or future expectations or requirements for describing or classifying funding and financing activities as 'green', 'social' or 'sustainable', or attributing similar labels. We expect policies, regulatory requirements, standards, and definitions to be developed and continuously evolve over time.

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Certain sections in this report contain climate-related and other forward-looking statements and metrics, such as aims, ambitions, forecasts, plans, projections, targets and other climate metrics.

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Uncertainties and factors include, without limitation:

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- uncertainty around future climate-related policy, including the timely implementation and integration of adequate government policies
- the effectiveness of actions of governments, legislators, regulators, businesses, investors, customers and other stakeholders to mitigate the impact of climate and sustainability-related risks
- changes in customer behaviour and demand, changes in the available technology for mitigation
- the roll-out of low-carbon infrastructure
- the availability of accurate, verifiable, reliable, consistent and comparable climate-related data
- lack of transparency and comparability of climate-related forward-looking methodologies
- variation in approaches and outcomes – variations in methodologies may lead to under or overestimates, and consequently present exaggerated indication of climate-related risk
- reliance on assumptions and future uncertainty (calculations of forward-looking metrics are complex and require many methodological choices and assumptions).

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Capex methodology

The overall approach taken to calculate the capex opportunity in the UK for the supply side of the energy system is to closely align the CCC BNZ as a central pathway that reaches net zero by 2050. The scenario was designed by the CCC to drive progress through the 2020s, while also creating options in a way that gives flexibility to respond to changing circumstances. This is the pathway on which the recommendations for the UK's NDC and the legislated Sixth Carbon Budget were based.

The BNZ is accompanied by assumptions for generation, as well as capex estimates across technologies over time. In some instances, BCG and NatWest have supplemented our own assumptions to get a bottom up per technology view on capex for the purposes of this report. For example, the CCC BNZ scenario provides a capex number for fuel supply (oil and gas, decarbonisation, hydrogen, bioenergy and waste, CCS) but it doesn't break down capex for wind and solar, instead offering an overall capex number for electricity supply. To address this, BCG and NatWest have taken the approach to calculate capex as per the formula below, leveraging generation and utilisation rates from the CCC but supplementing those with NatWest and BCG view on levelised costs.

Methodology for capex per technology, per year.

$$\text{Total capex} = [\text{Levelised cost (capex component only)}] \times [\text{GW of gross additional capacity}]$$

$$\text{Capacity} = \frac{[\text{TWh of generation}]}{[\text{8,760h in a year}] \times [\text{utilisation rate}]}$$

$$\text{Gross additional capacity in year } t = [\text{capacity in year } t] - [\text{capacity in year } t-1] + [\text{decomissioned capacity in year } t]$$

It is important to note the CCC BNZ scenario will be updated by the CCC, reflecting changes in policies, socioeconomic trends and other factors that might impact uptake and evolution of technologies. Please refer to the 'Deep dive on technologies and opportunities' sections of the report (starting on page 17) to review some of the currently identified dependencies that may impact future updates of the scenario.

The presented views in this report on the development of each technology fundamentally reflect the BNZ and are therefore consistent with the key assumptions behind the capex estimates.

Types of investment captured:

- Offshore wind, onshore wind, solar and nuclear, including pre-development and construction costs.
- Gas CCS and BECCS, including retrofitting existing plants and new builds.
- Networks, including electricity transmission and distribution infrastructure.
- Battery storage, including battery module, balance of system, installation, etc.
- Oil and gas decarbonisation, including:
  - platform electrification
  - energy-efficiency measures
  - technologies to reduce methane flaring, vents and leakage.
- Hydrogen, including:
  - storage and network infrastructure
  - facilities for electrolysis and fossil gas with CCS capacity (across all end-sectors including power/for use as energy storage)
  - production facilities for ammonia and synthetic jet fuel.
- Bioenergy and waste, including:
  - biojet, biodiesel, heating bioliquids, biomethane and biohydrogen conversion facilities
  - waste conversion facilities
  - bioenergy component of BECCS.
- CCS, including:
  - CCS component of gas CCS
  - CCS component of BECCS
  - waste-from-energy CCS
  - CCS used in the fuel supply
  - CCS and transportation for economy-wide emissions
  - DACCS.

  This doesn't include CCS on-site for industrial emitters.

Costs are in 2023 values and reflect costs at the time of financing, without splitting out supply chain investments or development spending. This isn't a comprehensive estimate of the capital costs for the energy system – it doesn't offset savings as operational cost. Investments in energy technologies financed by other sectors (eg manufacturing, auto) are excluded from the analysis.

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