Core Document
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Clean Power 2030

Advice on achieving clean power for Great Britain by 2030

NESO
National Energy
System Operator

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Foreword

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I am proud to present the National Energy System Operator's (NESO) advice on how to achieve clean power by 2030. This report is NESO's first since its establishment, in its capacity as a strategic advisor to the Government and Ofgem.

As NESO passes this advice to the Government for it to consider, I am reminded of how far Great Britain has come on its journey to decarbonisation. Earlier this year, the electricity system was run at 95% zero carbon for a short period of time, demonstrating the power of world-leading engineering and innovation. In September 2024, coal was phased out from our power system completely.

These proof points demonstrate that monumental shifts can be made by doing things differently. However, our advice to the Government indicates that to achieve clean power by 2030, a once in a generation shift in approach and in the pace of delivery is required. Without that shift, we risk failing to help consumers, society and the economy navigate a transition to clean energy that is secure, reliable, affordable and fair for all.

There's no doubt that the challenges ahead on the journey to delivering clean power are great. But if the scale of those challenges is matched with the bold, sustained actions that are outlined in this report, the benefits delivered could be even greater. A secure, clean power system - a backbone of home-grown energy that breaks the link between volatile international gas prices; that affordably powers our homes and buildings; that decarbonises the transport that we take to school and work; that drives the businesses of today and catalyses the innovations of the future.

Overall, what this process has demonstrated to me is the enthusiasm to collaborate across the energy sector, government, Ofgem and wider society, to deliver a clean power system that benefits everyone across Great Britain.

Finally, on behalf of NESO, I would like to extend my sincere thanks to all the stakeholders that took the time to engage with our analysis process. It is only with your insight and the challenging questions that you have asked of our approach and assumptions that we have been able to deliver this report with confidence and assurance.

Key messages

1

Clean power is a huge challenge but is achievable for Great Britain by 2030.

- It is possible to build, connect and operate a clean power system for Great Britain by 2030, while maintaining security of supply.
- Several elements must deliver at the limit of what is feasible: a key challenge will be making sure all deliver simultaneously, in full and at maximum pace, in a way that does not overheat supply chains, is sustainable and sets Great Britain on the right path beyond 2030.

2

Clean power will require doing things differently. It will only be achieved with bold action and sustained momentum, across every area and every step of the way between now and 2030.

- Harness the value of flexibility for households, businesses, suppliers and aggregators by unlocking markets, promoting engagement and removing wider barriers.
- Contract as much offshore wind capacity in the coming one to two years as in the last six combined.
- Deliver first-of-a-kind clean dispatchable technologies, such as carbon capture and storage and hydrogen to power.
- Build all planned transmission network on time, which involves twice as much in the next five years as was built in total over the last decade.
- Reform connection processes in 2025 to align with the clean power goal and future strategic plans.
- Reform planning and consenting processes and improve community engagement. Key decisions on funding, awarding contracts, consenting and policy are needed within the next year to ensure construction on key projects starts as soon as possible.
- Reform electricity markets while ensuring a stable and attractive investment environment, to secure over £40 billion of investment annually to 2030.
- Consolidate isolated and siloed digitalisation initiatives into a unified sector-wide prioritised plan, with expedited data sharing and enhanced decision-making driven through rapid adoption of artificial intelligence.

3

Achieving clean power by 2030 will put Great Britain in a strong position.

- Cut the link between electricity bills and volatile international gas prices, without increasing costs to consumers. Other factors will also impact electricity bills to 2030, including a reduction in legacy policy costs (as contracts expire) and energy efficiency improvements.
- Help meet the UK's carbon targets and ramp up supply chains and delivery momentum ready to meet the annual growth in demand from electrification beyond 2030.
- Opportunities for local growth and good jobs in the clean power investment programme and its supporting supply chain.
- Opportunities for positive impacts on nature, the environment and public health.

Executive summary

The Government's clean power mission must be about delivery. Clean power by 2030 is a huge challenge that will only be met by doing things differently, by prioritising pace over perfection and by working together across the industry towards a shared vision.

Our analysis, and what we have heard from stakeholders, give us confidence that the step up can be made. The pipeline of projects exists, the necessary network expansion has begun, the system would be secure and operable, and the technologies are available at reasonable cost. It will not be easy, but the foundations are in place.

Reaching clean power by 2030 would restore Great Britain's access to homegrown resources for electricity generation and support the wider push towards net zero by 2050. It will involve an investment programme averaging £40 billion or more annually, which, with the right policy mix, can be delivered without increasing costs for consumers, without compromising security of supply, and while bringing local economic and job opportunities.

Clean power also enables a compelling offer to consumers to 'plug in and go green' and positions Great Britain for the required surge in electric vehicles, heat pumps, electrification of industry and hydrogen production through the 2030s.

Flexibility from both demand and supply will be vital to managing the system and keeping costs down, while offering an opportunity for consumers to engage with the energy system and unlock lower costs for their energy. Data and digital will be key enablers across the whole energy system, but particularly for more efficient use of greater levels of flexibility, to the benefit of consumers.

In this report, we lay out pathways for how Great Britain can reach a clean power system by 2030. Offshore wind must be the bedrock of that system, providing over half of Great Britain's generation, with onshore wind and solar providing another 29%. New dispatchable low carbon technologies, such as using carbon capture and storage (CCS) or hydrogen, add significant value to the system, with even relatively small levels of operational capacity materially reducing the overall challenge for the rest of the programme.

A major network expansion is needed, in line with published plans for the transmission network and with further strengthening at distribution level. Important projects face multiple barriers, and some are already expected to deliver after 2030. However, they must now be accelerated to deliver by 2030 if the clean power goal is to be achieved. Failure in any single area – generation, flexibility, networks – will lead to failure overall; all parts need to deliver to achieve clean power.

Our pathways imply some choices for the Government and markets to make. Given the scale of the challenge, it may be appropriate to aim high and unblock barriers across all areas, driving through delivery at maximum pace while staying responsive to changing circumstances and new information. Inevitably, some areas will underdeliver, but most investments are low regret, and the risk of over-building is low, given the need to meet growing electricity demand through the 2030s.

A clear plan for clean power, along the lines of the pathways we lay out in this report, can enable a new phase of focused and fast delivery. It should guide decisions on planning, community and public engagement, contracting, grid connections, markets and system operations. With a short and shrinking window of time, pace must be the primary goal. However, this cannot come at the expense of public consent or excessive cost as that would mean the clean power objective would be self-defeating.

An effective plan should give as much visibility as possible to industry, including looking through 2030 to the 2030s and beyond. Clean power is not just a build challenge. The plan should look beyond the infrastructure programme to the supply chain, to operations, including digitalisation, to distribution networks and to the consumer, and beyond power to the rest of the economy.

Our advice reflects a significant programme of analysis and stakeholder engagement, building on previous work such as the Future Energy Scenarios and Pathway to 2030. The next step will be for the Government, reflecting on the advice in this report, to set out its own plan for clean power and then use it to drive delivery. We will use the Government's plan as the starting point for our Strategic Spatial Energy Plan (SSEP), for the reformed connections queue, and as a guide to the changes we will make as NESO to enable a secure, flexible and efficiently operated clean power system by 2030.

A clean power plan for Great Britain by 2030

A clean power system is one where demand is met by clean sources (mainly renewables), with gas-fired generation used only rarely to ensure security of supply, primarily during sustained periods of low wind. For the analysis in this report , we have described this as: by 2030, clean sources produce at least as much power as Great Britain consumes in total and unabated gas should provide less than 5% of Great Britain's generation in a typical weather year.*

Our analysis points to the following priorities for successful pathways to clean power:

- **Unlock flexibility of demand and supply.** Flexibility is vital in a system with more variable renewables. There are large opportunities to increase flexibility in both demand and supply, across residential and commercial applications, and in industry. However, flexibility is not currently valued in full and faces multiple barriers. Markets and processes must be redesigned, and data and digital approaches embraced, enabling infrastructure must be delivered and barriers unblocked.
- **Backing offshore wind and renewables.** There is no path to clean power without mass deployment of offshore wind, together with onshore wind and solar. Sustained rollout of offshore wind is needed at over double the highest rate ever achieved in Great Britain. Increased rollout will need to continue through the 2030s. Transparent and comprehensive investment signals, contracting arrangements and delivery environment for these projects will be key to the costs and success of the clean power programme as a whole.
- **Recognising the value of dispatchable low carbon plants.** These play a vital role that is different to weather-dependent and firm low carbon plants in being able to match to demand regardless of conditions. Biomass can shift into this role as can new CCS and hydrogen projects if they can come online by 2030. CCS and hydrogen are also important and currently under-developed technologies for the global transition, implying progress in this area can help lead the global effort. Contracting arrangements should be developed with the expectation that these plants operate flexibly, rather than operating continuously. More will be needed beyond 2030 and will be advantageous if delivered earlier, potentially enabling a lower cost 2030 system that takes pressure off other delivery challenges.
- **Delivering network plans in full and faster.** Current plans for network expansion are sufficient, but must overcome many barriers to deliver on time, and some vital projects need to be accelerated to deliver by 2030. More than twice as much transmission network needs to be built in the coming five years than the previous ten, along with accompanying enabling works, connections and distribution network strengthening.
- **Keeping options open.** Our pathways recognise various uncertainties, including on demand and deliverability of certain options. In the face of these uncertainties, and the need to manage delivery risk, there is high value in pursuing multiple options where they exist and encouraging competition between, not just within, different technologies.

The rest of this summary outlines the findings from our analysis and engagement: our pathways, their feasibility, critical enablers of clean power and the benefits and costs.

* This is the description of Clean Power used in this report. Government will set out how it is defining Clean Power 2030 in due course.

Clean power pathways

As Great Britain has improved efficiency and rolled out renewables, the share of electricity generation from unabated gas (from gas-fired plants not using carbon capture and storage) has fallen to around a third. A further 12% of demand was met by imported power in 2023.

Our clean power pathways see Great Britain become a net exporter of power and reduce the share of unabated gas generation to below 5%. All our pathways involve early electrification of heat, transport and industry. A reductionist approach that slows down electrification to lessen the challenge of clean power would undermine the core objectives of cutting energy costs and supporting net zero.

Our clean power pathways see a four-to-fivefold increase in demand flexibility (excluding storage heaters), an increase in grid connected battery storage from 5 GW to over 22 GW, more pumped storage and major expansions in onshore wind (from 14 GW to 27 GW) and solar (from 15 GW to 47 GW) along with nuclear plant life extensions.

Our work identifies two primary clean power pathways. In addition to the elements outlined above, one pathway successfully builds 50 GW of offshore wind by 2030, but no new dispatchable power from hydrogen or gas with CCS. The other pathway delivers new dispatchable plants (totalling 2.7 GW) and 43 GW offshore wind. Either of these requires a dramatic acceleration in progress compared to anything achieved historically and can only be achieved with a determined focus on pace and a huge collective effort across the industry.

The pathways involve different risks and challenges, both at the portfolio and project levels. Delivering new dispatchable power would reduce supply chain pressures for renewables and bring lower system costs in our analysis. However, new technologies may need more government support initially and would leave some exposure to volatile international gas prices, albeit significantly reduced from today. The higher levels of both offshore wind and dispatchable power will be needed soon after 2030 and progressing both could in parallel bring industrial benefits and new jobs to Great Britain.

Our clean power pathways push the limits of what is feasibly deliverable, but there are some flexibilities at the margin. For example, onshore wind and solar could substitute for offshore wind, more demand side response could substitute for batteries and more hydrogen or CCS could substitute for most other supply options.

A major expansion of the electricity networks is needed alongside to connect and transmit these new power supplies. Operation of the system will need to evolve too, which can be done and will be reflected through our developing plans, which will be updated in our March 2025 Operability Strategy Report to align to the clean power goal.

Feasibility of clean power

Delivering a clean power system by 2030 will be hard, but our analysis and engagement indicates the foundations exist to make it possible. Success will need a combination of efforts across the household, community, regional and national levels.

Historically, customer engagement with energy has been low. However, energy efficiency has improved as lights and appliances become more efficient. Trials of demand flexibility, by us and market participants, demonstrate the untapped potential that can grow with the rollout of new technologies like electric cars alongside smart capabilities and digitalisation. We are already seeing demand side flexibility playing a role in the balancing mechanism, frequency services and distribution network markets.

Key supply-side technologies (e.g. offshore wind, onshore wind, solar, batteries) will all need to deploy more on average each year to 2030 than they have ever done in a single year before. This will inevitably stretch supply chains and require accelerated decision making in planning, permitting and awarding of contracts. But there are enough projects in the pipelines to sustain the required rollout if they can progress to delivery.

CCS and hydrogen are first-of-a-kind projects for Great Britain and previous attempts have not progressed to delivery. The Government has begun awarding funding, which provides a platform for a material contribution by 2030 or soon after. There are developers with specific projects ready to deliver for 2030 under the right conditions.

Our clean power pathways require up to £60 billion of network investment cumulatively to 2030, to build nearly 1,000 km of onshore and over 4,500 km of offshore network and accompanying enabling works. That is more than double over five years what has been built in total in the last ten. The industry has begun to mobilise for this challenge, with most projects set out in the ESO Pathway to 2030 network plan underway and aiming for delivery by 2030. A handful of key projects will need to be brought earlier from their current delivery dates of after 2030.

The clean power system must also be a secure system. Our analysis shows that the mix of demand, storage and supply in our clean power pathways can manage the risks associated with balancing supply and demand at the same or better than current levels. This will require that even as use of gas generation drops to very low levels, most of today's gas plants remain on the system out to 2030 and beyond. Appropriate arrangements will need to be in place to ensure these plants remain open but do not run excessively (such as to provide power for export).

Perhaps the hardest challenge will be delivering across all areas together. Many elements of the supply chain are shared and there are overlaps in the required workforce and skills. Failures in any one area can cascade to failures elsewhere. At the same time, doing things differently, the shift to a mission-led approach, the opportunity for a positive national conversation, the chance to provide greater visibility and confidence and the possibility of resolving challenges at programme rather than project level can bring benefits for all parts of the challenge.

Enablers for clean power

Government has taken initial steps to support their clean power ambition, including lifting planning restrictions for onshore wind in England, increasing the low carbon auction budget, establishing the Clean Power 2030 Unit and funding a range of CCS enabled projects, including power CCS and low carbon hydrogen production that can support hydrogen to power. Continuing this progress to enable clean power by 2030 will require that things are done differently across the delivery chains:

- **Markets and investment.** Various market arrangements and investment support schemes are in the process of, or will need, reform to reach clean power and operate the system efficiently. Decisions must provide stability and confidence to underpin the large amount of investment required, while supporting innovation and efficient operation of the system. An element of competition will help to keep costs down.
- **Planning and consenting.** Significant volumes of projects need to pass through the planning system to start construction on rapid timescales, while maintaining community consent which is vital to the mission. Given that construction for many of the required projects needs to begin in the next 6-24 months to be in place by 2030, upcoming planning reforms will need to significantly streamline and speed up processes.
- **Connections.** The connections queue must be formed of ready-to-connect projects that align with the Government's plan for clean power by 2030 and once developed, the Strategic Spatial Energy Plan (SSEP) and future iterations. We have begun the process of connections reform and will develop the SSEP based on government's plan for clean power by 2030.
- **Supply chain and workforce.** Acute supply chain and workforce challenges must be overcome across nearly all generation, storage and network projects. Policy certainty, visibility of the future market and swift funding decisions are needed to ensure developers can mobilise the supply chains and workforce needed. Over the medium term, greater strategic coordination can enable delivery while supporting the growth of domestic supply chains and a skilled workforce to meet the growing pipeline of projects.
- **Digitalisation and innovation.** Prioritised and coordinated action is needed across the sector to drive digitalisation and common governance is required for orchestration of a sector-wide digital and data plan. Work has started on a common data sharing infrastructure for the sector, but this needs to be accelerated through policy and incentivising adoption. Accelerated AI adoption and transformative innovation need to be prioritised to align with the government's plan for clean power by 2030.
- **NESO as a partner in delivering clean power.** NESO will play a central role in delivering clean power. Putting the government's plan for clean power by 2030 into operation will require coordinated action across the energy industry and its institutions, with NESO working as a partner with Government, Ofgem and key decision makers. This includes supporting Energy Code Reform, developing our implementation and engagement plans and reviewing our operations to ensure alignment with the plan.

These actions are needed for 2030 and must be implemented alongside actions needed to maintain momentum for the period beyond 2030. Many projects are already in development that will only come to fruition in the 2030s and must collectively deliver continued progress through that decade.

Reaching clean power will have impacts on consumers, communities and businesses across Great Britain. While energy policy is generally a reserved matter, planning and consenting are devolved. Consenting of some projects will require a mix of reserved and devolved competency, requiring coordinated partnership between the UK, Scottish and Welsh governments. Furthermore, devolved policies such as the Scottish Government's Energy Strategy and Just Transition Plan will have implications for reaching clean power and beyond. This report does not go into details of the planning and consenting changes required, but it is clear that close collaboration between the UK and devolved governments will be needed.

Benefits and costs of a clean power system for Great Britain

A clean power system will help meet Britain's climate targets. It will reduce gross power sector emissions in 2030 to below the level in the Climate Change Committee's net zero pathways. It will set the system on track for the higher demand growth expected through the 2030s as electrification accelerates and supports that electrification by offering consumers clean power. Being one of the first major economies to decarbonise from a historically fossil fuel-based power system to clean power can form a strong part of the UK's wider climate leadership.

Clean power can also support wider economic objectives. An investment programme averaging over £40 billion annually can support economic opportunities and new jobs across the UK, and our analysis suggests it can be paid for without increasing costs to consumers, provided the increased pace does not overheat supply chains or otherwise drive up project costs. New networks and an abundant supply of clean power can enable growth in other sectors, including the growing digital and data economy.

This major investment programme should be largely delivered by the private sector and will bring material savings in annual running costs as less gas needs to be bought to provide power. Our analysis in this report suggests that, together, these will lead to overall costs for clean power – the costs that are passed on to consumers – in 2030, that are no higher than they would have been without the shift to clean power.

Great Britain would be much less reliant on energy imports for power and far less exposed to fluctuations in international gas prices. Without accelerated action a repeat of the gas price spike of 2022 would add around £10 billion to electricity system costs in 2030, but would add only £5 billion in a clean power system. Avoided price spikes could be far more significant, noting the very high rises in electricity prices during the recent gas price crisis.

A crucial determinant of overall costs will be the impact of the Government's new approach to clean power. If it can provide greater visibility and greater confidence, while unblocking barriers and easing delivery, there may be opportunities for costs to fall. Conversely, if supply chains become excessively stretched, costs could escalate.

How costs translate to customers' electricity bills will depend on policy design and market dynamics that we do not attempt to predict in this report. Additional opportunities exist for bills to fall with energy efficiency (expected to reduce typical household electricity consumption by 5 - 10% to 2030) and as legacy policy costs for early renewable contracts expire.

Policy design should target not just the average electricity user, but the distribution of customers. The benefits of shifting to clean power and electrifying heat and transport should be available to all households and businesses, ensuring a just and affordable transition.

In conclusion, the success of the Government's clean power mission will be as much about how it is delivered as what it is delivering. Urgency and momentum are critical. A good approach begins with a good plan. There is an opportunity to create a virtuous circle of reduced barriers, increased visibility, easier delivery and lower costs alongside increased pace. As the newly established National Energy System Operator, we look forward to supporting the Government in this challenge.

Navigating this report

The report is structured in the following chapters:

Supporting analysis referred to throughout is published on our NESO website.

Chapter 1. Foundations for clean power

Progress to date: Power sector emissions have fallen by 65% since 2010.* In 2023, clean electricity sources met 62% of Great Britain's demand** setting a good foundation to build on for clean power.

Describing clean power: We describe clean power as at least as much power being generated from clean sources as Great Britain consumes across the year, and when unabated gas generation makes up less than 5% of Great Britain's generation in a typical weather year.

How our advice will be used: Our advice, built from analysis and stakeholder feedback, will feed into the development of the government's plan for clean power by 2030.

* *Latest published data from 2022*.

*** As calculated from the NESO dashboard, using total generation and net imports, excludes Combined Heat and Power, Energy from Waste and unmetered generation.*

1.1 Where we are now

Delivering a clean power system for Great Britain will be a huge challenge but important foundations are in place.

Power sector emissions have fallen by more than 65% since 2010. Clean electricity sources provided for 62% of demand last year, primarily from renewables and nuclear, and September 2024 saw Great Britain, and more widely the UK, become the first G7 country to phase-out coal power.

A strong pipeline of clean power projects is currently at various stages of development and deep cost reductions over the last decade for renewable technologies has meant that these can produce power at lower cost than running unabated gas-fired generation.

Advances in data and digitalisation, including the advent of smart chargers and appliances alongside the rapidly falling costs of batteries, pave the way for an enhanced consumer experience, for more flexibility, and for managing a clean power system effectively.

Renewables expansion has begun to reduce share of fossil generation

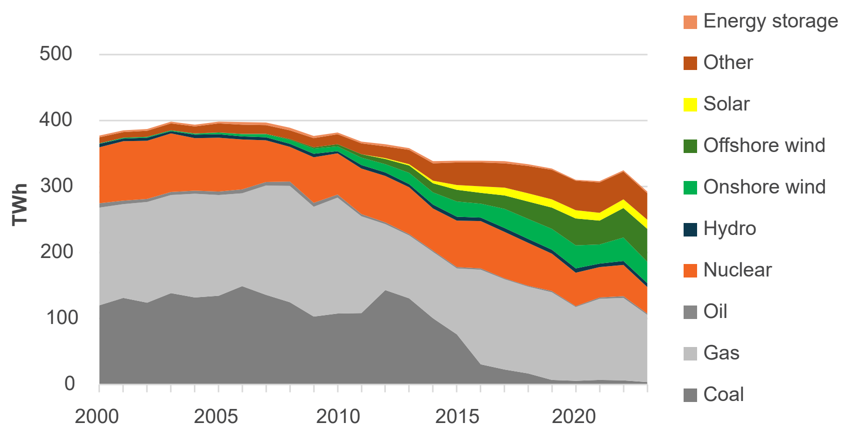


Figure 1: Clean sources are already reducing the share of fossil fuel generation

(Source: DUKES, NESO. Note: Historical data includes Northern Ireland. Excludes CHP and waste)

1.2 Describing a clean power sector

A clean power system for Great Britain in 2030 will be one where demand is met by clean sources, mainly renewables, with unabated gas-fired generation used only rarely to ensure security of supply, primarily during sustained periods of low wind. In developing our advice for this report, we describe this clean power sector as one which, by 2030, meets the following quantitative criteria:

- Clean sources produce more power than Great Britain consumes in total.
- Unabated gas (i.e. without carbon capture and storage) provides less than 5% of Great Britain's generation in a typical weather year.

Our hybrid definition of clean power reflects the variable nature of renewable sources such as wind and solar. A clean system must provide enough to cover Great Britain's demand while balancing demand and supply to limit the use of unabated gas for security of supply.*

We include as clean power sources: renewables (including biomass) and other low carbon sources (nuclear, plants using carbon capture and storage – CCS, hydrogen produced from low carbon methods such as electrolysis or with CCS).

For 2030, we net off from demand generation from existing plants that have primary roles in other sectors of the economy – those producing combined heat and power (typically meeting an industrial heat need) and energy from waste (acting as a means of waste disposal). In line with the Climate Change Committee's classification, we attribute emissions from these plants to the industry and waste sectors respectively, rather than the power sector. We note that these plants release fossil carbon emissions and will also need to decarbonise in the long run, for example by fitting CCS.

Under this description, our analysis shows grid carbon intensity drops below 20 gCO_2/kwh (excluding BECCS).

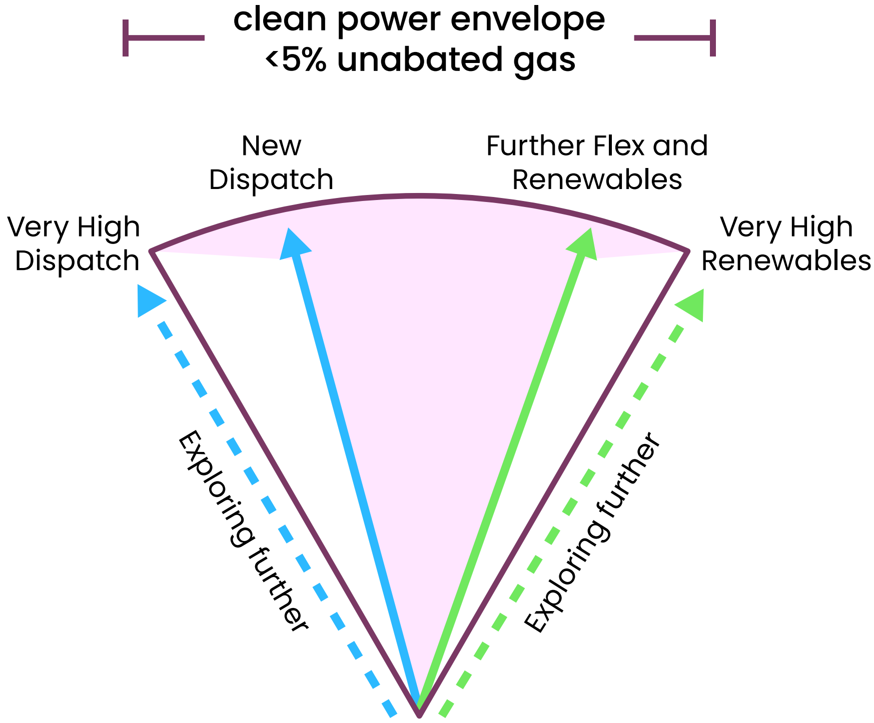
* This is the description of Clean Power used in this report. Government will set out how it is defining Clean Power 2030 in due course.

1.3 Our approach to pathways in this report

We have developed two primary pathways that meet our clean power description. These offer challenging, but realistic and cost-effective, routes based on our assessment of the project pipelines and stakeholder feedback.

We have also developed two wider sensitivities, which offer more stretching levels of deployment of key technologies – more renewables or more dispatchable power, alongside a Counterfactual which does not accelerate progress and misses the UK's legally binding carbon targets. These, along with further exploratory sensitivities, have allowed us to examine a range of possibilities and explore the relative importance of specific elements of the clean power system.

We have explored the range of options and influences through sensitivity studies presented in Chapter 3.



All pathways see increased electrification of transport, heat and industry by 2030 as needed to meet economy-wide carbon targets. Energy efficiency improvements continue across both pathways. Clean power pathways will all require increased digitalisation, open data and Innovation.

New Dispatch	Further Flex and Renewables
• Growth in renewables but at a lower level compared to Further Flex and Renewables. • Deployment of new low carbon dispatchable power (CCS and hydrogen) alongside highest nuclear capacity.	• Highest levels of societal engagement, with higher residential and industrial demand flexibility and more storage. • Fast deployment of renewables (50 GW offshore wind), but no new dispatchable power.

1.4 How our advice fits in to wider plans

This advice responds to a formal commission from the Department for Energy Security and Net Zero (DESNZ) to provide practical advice on achieving clean power by 2030 for Great Britain, including developing a range of pathways that reflect the possible routes to a decarbonised power system. As outlined in the formal commission to NESO, our analysis includes:

- Energy generation and demand mixes.
- Key requirements for the transmission network.
- Consideration of criteria that could support connections reform.
- View of actions needed to enable delivery.
- High level assessment of costs and benefits, opportunities, challenges and risks.

Our advice is intended to be an input to the development of the government's plan for clean power by 2030.

In October 2024, we were commissioned by the UK, Scottish and Welsh governments to create a Strategic Spatial Energy Plan (SSEP) for the energy system, land and sea, across Great Britain.

The SSEP will be used to help plan the future of the energy system for the whole of GB. It will sit alongside and grow with future government policy and market-led interventions; it is intended to be complementary to these, providing a more strategic approach to spatial planning, and is intended to become part of the framework of planning systems across GB.

The SSEP will take as its starting point the government's plan for clean power by 2030.

1.5 Stakeholder engagement

Previously, as the Electricity System Operator, we engaged with over 3,000 stakeholders each year to create the Future Energy Scenarios, alongside specialists from the energy industry and planning experts in developing future network plans. As the National Energy System Operator (NESO), we will build and expand on the extensive engagement in line with our new responsibilities. Our engagement also goes beyond the sector, working with end users of energy from housing associations and local authorities to energy-intensive industries.

NESO has taken a similar, whole system approach, which builds on our continuous engagement with stakeholders in developing our Clean Power 2030 advice.

We have been transparent with our analysis to test our thinking and seek input during development. All interim analysis shared externally has been published on NESO's website and we have made various changes in response, including evolving our pathways to those described above. We include key messages received in our engagement throughout this report.

A key theme raised by an overwhelming number of stakeholders was that clean power would only be deliverable if it were to be accompanied with immediate action by the Government, Ofgem and NESO to put Great Britain on a path to achieving clean power by 2030. Feedback highlighted the need to do things differently, act with a sense of urgency and quickly build momentum.

We have engaged with stakeholders in a number of ways

Bilateral & roundtables with market participants & experts

Open written feedback submissions

Policy and analysis literature review

Industry and societal stakeholder forums established

Public webinars and operational transparency sessions

We have engaged 318 stakeholders in the process of developing this advice.	Across this spectrum of stakeholders, we have sought feedback via:
124 organisations, consisting of: **81** energy industry **24** societal delivery partners (planning experts, local government representatives, land use representatives, environmental specialists,) **19** UK Government, Ofgem, devolved government	**114** bilateral meetings **5** industry and societal forums **12** engagement Events **25** Literary reports We have also had 91 formal written submissions of feedback.

Chapter 2. Core elements of a clean power system

Reaching a clean power system by 2030 will require taking a new approach, coordinating delivery at maximum pace across all areas: electricity demand, system flexibility, electricity supply, networks, connections, operability and operations.

This chapter sets out the core elements of a clean power system to be delivered by 2030. Further detail on the basis of our analysis and stakeholder feedback at a technology level can be found in Annex 1.

Electricity demand and demand flexibility: Demand could rise by around 11% by 2030, but energy efficiency and demand flexibility can reduce costs for consumers and lower investment needs.

Electricity supply and system flexibility: Significant growth in offshore wind (from 15 GW in 2023 to 43-50 GW in 2030), onshore wind (14 GW to 27 GW), solar (15 GW to 47 GW) and battery storage (5 GW to over 22 GW) is needed to displace gas, to meet growing demand and to replace retiring plants. Longer-duration storage and dispatchable clean resources, such as gas with carbon capture and storage, can have an important role alongside renewables.

Electricity networks: Current expansion plans must overcome barriers, with critical projects needing acceleration to deliver by 2030. Network expansion must proceed at more than four times the rate of the last decade, delivering twice as much in half the time.

Connections reform: Central to the proposed connections reform is the creation of a direct link between the technology and capacity needed, by location, in government's plan for clean power by 2030, and the connection offers that are made.

Operability and access: Our analysis suggests that the wider challenges for a clean power system can be met for the gas network, for managing network access and outages and for operating the electricity system. Strong coordination and collaboration across the industry will be needed, including an active role for NESO.

2.1 Electricity demand and demand flexibility

Clean power offers an opportunity to transform how residential, industrial and commercial consumers engage with their energy use. Consumer participation in actively shifting demand in line with signals from flexibility services, alongside the adoption of smart home devices and good operating practices will provide vital support to the network.

This engagement must be supported by a transformation in data and digital infrastructure and it will be an important part of the clean power transition with the potential for wide-ranging benefits for consumers. Achieving this means building on, and accelerating, the progress and innovation we have seen in the sector in recent years.

The demand flexibility opportunity

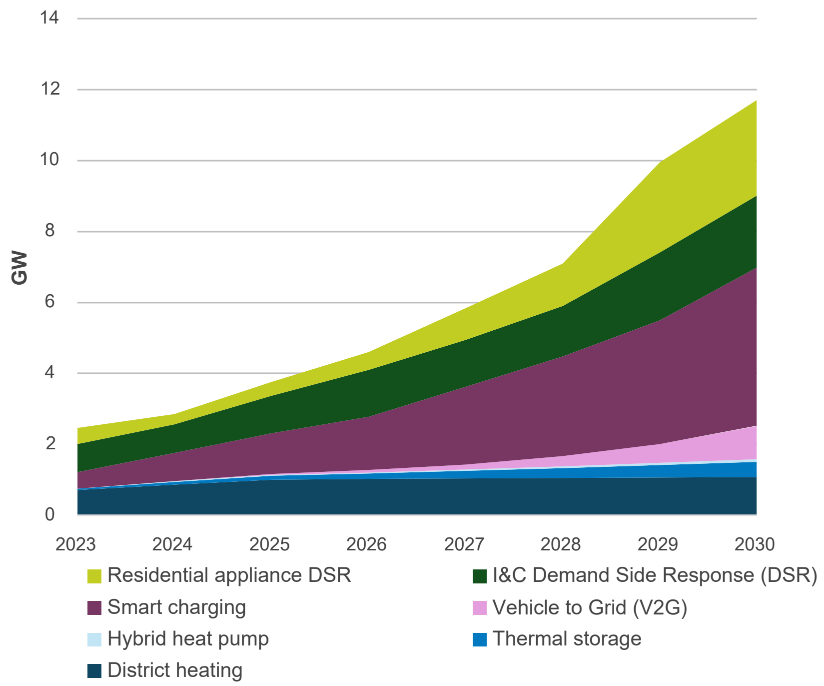


Figure 2: Demand flexibility at peak in our Further Flex and Renewables pathway

The advent of smart technology, electric vehicles (EVs) and electrified heating provides new ways for consumers to engage with the energy system and cut their costs by flexing their demand. These opportunities will differ across households, requiring well designed policy to ensure no consumers are left behind and the transition is affordable and fair for all.

Levels of demand flexibility (excluding storage heaters) can increase by four-to-five times to 2030, with significant benefits for the transition to clean power by moving energy demand away from peak periods. By 2030, demand flexibility in our pathways reaches 10-12 GW through smart charging of electric vehicles, time-shifting household demand and enabling more responsive industrial demand, with a further 4 GW from storage heating.

Unlocking the benefits of this increased flexibility for consumers will require engagement. However, effortless participation in demand flexibility through digitalisation and automation is likely to be the path to the highest and most effective levels of responsiveness. It must be affordable and accessible for all consumers to ensure a fair transition and to maintain public support.

Virtually, all of this demand side flexibility will be connected onto the distribution network, providing flexibility throughout the network.

Most of the demand flexibility will be enabled by automation and digitalisation, from a growth in smart appliances and implementation of the Energy Smart Appliances Regulations in the government's Smart Secure Energy System Programme, and the Electric Vehicles (Smart Charge Points) 2021 Regulations which require chargers installed after this date to default to off-peak charging. To increase participation in smart technologies and demand side flexibility, innovative tariffs and other retail market offerings will be needed.

A consistent coordinated approach that enables people to make more informed decisions will allow demand flexibility to be unlocked. Using data and targeted communication methods can provide consumers with the right signals at the right time, that directly impact the choices they make on a day-to-day basis, such as when to turn on their appliances.

Levels of demand flexibility are limited by factors such as a consumer's ability to participate and technology adoption. It cannot fully replace network infrastructure upgrades, which are essential for ensuring capacity, reliability, and meeting future demand growth.

There are a broad range of views from our stakeholders around the achievable levels of demand flexibility. Some feel the country can go much further and faster, while others think the levels in our pathways are overly ambitious. There is, however, agreement that some consumers will need more support than others to benefit from demand flexibility and energy efficiency. The critical importance of Government, Ofgem, NESO, Elexon as the Market Facilitator, and the wider sector was noted throughout our engagement. Demand side flexibility is not subject to the same planning, development consenting, connections or supply chain challenges associated with building energy infrastructure projects and therefore does not carry large cost burdens. Indeed, many of the interventions necessary to release the potential of demand side flexibility are administrative or regulatory. Some stakeholders highlighted the need for consumer investment in technology and the importance of appropriate marketing in enabling widespread voluntary adoption of new technology and more efficient appliances.

Demand turn-up can offer additional potential deliverability benefits and cost savings.[1]

1 Dispatch and redispatch modelling do not include demand turn-up, but it is included in operability analysis.

Energy efficiency measures help manage demand growth

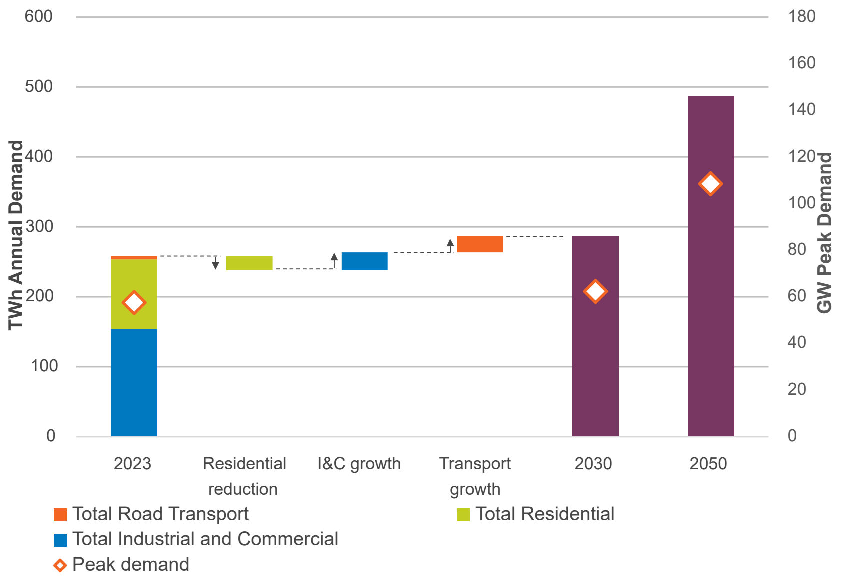


Figure 3: Changes in consumer electricity demand from 2023 to 2030

Our pathways assume high levels of societal change and digitalisation with a growing number of personal electronic devices and data service needs. We assume high levels of development in artificial intelligence and off-site computation needs for a wider economy. This means a fourfold growth in data centre electricity demand from today out to 2030. This investment will underpin the establishment of a smart energy system.

Electrification of transport, heat and industry will help enable delivery of the UK's carbon targets. Our analysis assumes that sectors electrify at sufficient pace to meet the Nationally Determined Contribution (NDC) emissions target for 2030 and the legally-binding carbon budgets recommended by the Climate Change Committee. This results in an electricity demand growth of approximately 11% to 287 TWh from today to 2030 (Figure 3).

Energy efficiency can help moderate this demand growth while saving money for consumers. While efficiency improvements to buildings such as insulation has long underperformed in Great Britain, efficiency of electricity use has steadily increased. We expect this to continue with the replacement of lighting and appliances with newer, more efficient models. Without this efficiency in place, 2030 demand could be around 7% higher - equivalent to the output of around 5 GW of offshore wind.

On top of reducing annual demand, energy efficiency also reduces peak demand. We expect efficiency improvements in light bulbs and appliances to reduce peak demand by 4.2 GW by 2030.

As part of our stakeholder engagement, we heard that there was potential for Industrial and Commercial demands to be lowered through improvements in energy efficiency. To reflect this feedback, we have adjusted our Industrial and Commercial demands downwards by 4 TWh (in 2030), compared to the level in our FES 2024 Holistic Transition pathway.[2]

2 This is a top-down adjustment to reflect feedback received, rather than a specific set of actions that we have modelled.

2.2 System/bidirectional flexibility

As the energy system becomes more reliant on weather dependent sources of generation, flexible technologies, such as storage and interconnection to other markets, will be crucial during periods of low generation and high demand (for example, wind droughts in colder winter weather). While these resources do not generate power, they do help to move power to when or where it is needed. Levels of this flexibility must grow significantly to 2030. Achieving a clean power electricity system requires replacing fossil fuel flexibility with low carbon within-day flexibility to shift supply and demand over a day. The wholesale market and retail signals will incentivise the system to self-balance, promoting flexible resource participation.

Access to the right data and the development of digital infrastructure will be vital to using these and other resources efficiently.

Our analysis implies a broad hierarchy of flexibility options for times when there is insufficient clean power to meet demand:

- Demand side flexibility, responding to innovative tariffs or other retail market offerings, would typically come first, reducing peak demand.
- Shorter duration storage from batteries or vehicle-to-grid (V2G) may then discharge, followed by longer duration storage.
- Interconnectors may import based on price differentials and additional generation, such as low carbon dispatchable power or increased demand side flexibility.
- If all other resources are exhausted, unabated gas will need to be used to maintain security of supply and meet consumer demand.

The flexibility sources discussed in this section are only the supply side sources that do not generate electricity. Low carbon dispatchable power and unabated gas-fired generation will provide flexibility but are discussed in section 2.3.

The sensitivities we explore in this report suggest that more interconnection or Long Duration Energy Storage (LDES) can help reduce curtailment, constraints[3] and costs and can improve security of supply. Despite this, the impact of additional capacity above our pathways on reducing the use of unabated gas is limited and dependent upon location.

3 Constraints in the electricity network refer to limitations that prevent the efficient flow of electricity from power plants to homes and businesses, often due to issues such as transmission line capacity or unexpected high demand.

Batteries

Our pathways see battery capacity increase from around 5 GW in 2023 to between 23 and 27 GW in 2030. This represents a major scale-up in build rates, but there are many more projects in the pipeline. Batteries currently have a one-to-two-year deployment lead time and annual levels of deployment have increased every year since 2020.

The principal role of batteries today is to provide within-day flexibility by cycling regularly to help match supply and demand. Additionally, they provide vital system services, such as frequency response, for which their role is likely to grow to 2030 as use of gas generation falls. NESO's ability to access these assets effectively has until recently been hindered by challenges with legacy systems in incorporating batteries fully into the economic dispatch process (manifesting in "skip rates"). The activities we have initiated and recently accelerated have been designed to ensure that batteries will be included on a level economic playing-field with all other technologies.

The connections queue is currently oversubscribed. Delivery relies on reforms to the connections queue, planning issues being resolved and market structures providing the right revenue opportunities. These challenges were also raised by many stakeholders.

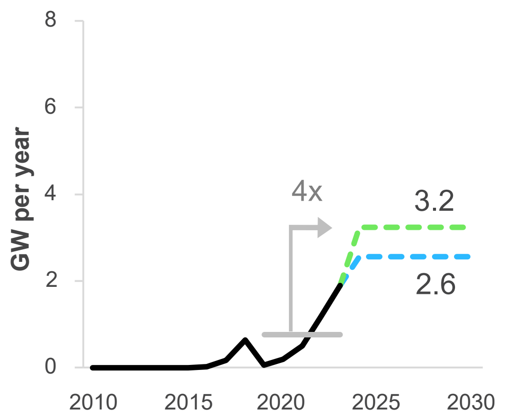


Figure 4: **Batteries scale up needed**

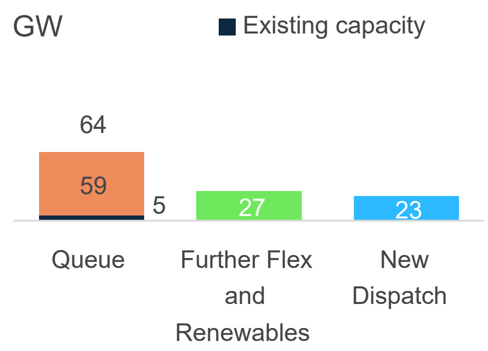


Figure 5: **Connection queue versus pathway capacity**

Long duration energy storage

Long duration energy storage (LDES), such as pumped hydro storage and liquid air, are particularly important for longer term flexibility and additional operability needs (such as during extended periods of wind drought or to spread demand between weekend and weekdays).

The pipeline for options ready to deploy by 2030 is limited and our analysis sees capacity potentially increase from 3 GW in 2023 to 5-8 GW, with storage capacity growing from 28 GWh to 50-99 GWh[4] by 2030. This would require completion of Great Britain's first pumped hydro stations in more than 40 years. Pumped hydro is a mature technology and, while work has started on some sites, the rest would need to commence urgently if they are to be operational by 2030, particularly given complex workforce requirements and the need to manage the impacts to local infrastructure and communities.

New and innovative LDES, liquid air, compressed air and longer-duration batteries (10+ hours) projects have successfully operated at a small scale. Work has started on new projects and feedback from stakeholders was that the lower range is within what they can build for 2030.

Stakeholders welcome deployment of LDES and believe there could also be potential in redeveloping former hydro power stations across the country. It was noted that decision making on funding mechanisms would need to speed up to accelerate delivery.

4 Lower LDES storage capacity value updated from 81 to 50 GWh on 10/03/2025, due to an initial typographical error in the report and data workbook.

Interconnection

Interconnectors allow Great Britain and neighbouring markets to benefit from different supply mixes, generation patterns and demand patterns.

We assume projects with regulatory approval deliver by 2030 in line with their regulatory delivery dates, increasing capacity from 8 GW in 2023 to 12 GW in 2030. Our analysis shows Great Britain becomes a net exporter of electricity across the year, switching from the current situation, where we are a large net importer.

Careful consideration is required around the arrangements for interconnector flows, especially where these could incentivise gas-fired generation in Great Britain to run for export across interconnectors. Arrangements should balance economics, achieving Great Britain's clean power metric and the impact on power sector emissions across the wider region.

2.3 Electricity Supply

The vast majority of Great Britain's generation (77-82%) will come from renewable energy for a clean power system in 2030, with the majority of this from offshore wind. This will be supplemented by firm sources of generation (such as nuclear) and low carbon dispatchable sources (such as bioenergy, gas with CCS and hydrogen).

Significant growth in generation needed

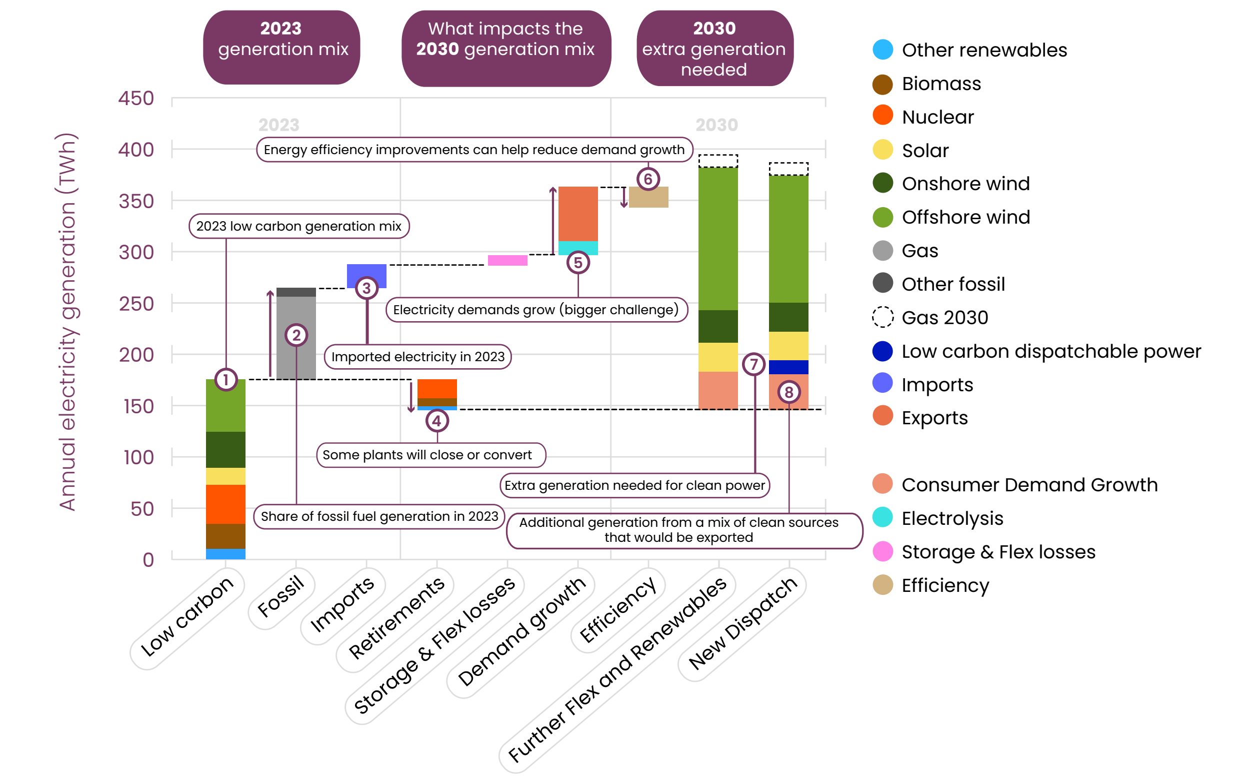


Figure 6: **Increase in electricity supply for 2030**

Weather dependent renewables

80-84% of GB's 2030 supply[5]

Wind and solar technologies already have a strong track record of delivery and have seen rapid growth in recent years. A further scale-up in delivery is needed across the key technologies for clean power by 2030.

Offshore wind

48-53% of GB's 2030 supply

Access to suitable offshore locations and favourable wind conditions provide ideal geographic and natural resources for offshore wind, making it a highly effective option for generating clean energy for Great Britain. The clean power system must be based on offshore wind. It is the only clean option available at the scale required by 2030, with a lower cost compared to burning gas in existing power plants. An additional 28-35 GW of offshore wind is required to reach a total of 43-50 GW in 2030, with average load factors (the proportion of energy generated compared to the maximum possible generation capacity) of 43% generating 167-187 TWh. Our load factors are sourced externally, are site specific for a typical weather year and change over time with the development of wind turbines. If load factors as high as 63% (as proposed by DESNZ in their Generation Cost 2023 publication) can be achieved then the same generation levels could be delivered with around 6 GW less new build of offshore wind.

While the connection queue has enough projects to expand from the current 15 GW up to 54 GW by 2030, reaching even the lowest level of 43 GW in our pathways will be challenging.

Data from the Crown Estate and Crown Estate Scotland published in September 2024, shows that 20% of the offshore wind pipeline capacity is committed, split roughly equally between projects with financial support and those already under construction. Around a third of the pipeline capacity is under development, with just over a quarter of that already having secured planning consent. Around 30% of the pipeline capacity is in the pre-planning stages and the remaining 17% of pipeline capacity is in very early development, unlikely to be delivered by 2030.

Offshore wind contracting and deployment must happen at unprecedented pace, far exceeding previous records. Our pathways require around 4-10 GW from each of allocation rounds[6] 7 (in 2025) and 8 (in 2026). To put that into context, the highest allocation round to date awarded 7 GW in 2022 and build can be cancelled or delayed after a successful auction. Once contracted, annual deployment of offshore wind will have to be at a scale multiple times higher than ever achieved before – as shown in the figure below.

The lag between awarding of contracts to commissioning of built capacity will need to fall from the historical experience if projects contracted in 2026 are to deliver by 2030. And unless newly contracted projects can deliver by 2027, buildout rates will be uneven, with even higher build needed in the following years.

5 These percentages are based on the range of our New Dispatch and Further Flex and Renewables pathways.

6 The Contracts for Difference (CfD) scheme is the government's main mechanism for supporting low carbon electricity generation. Allocation rounds are annual auctions for CfDs.

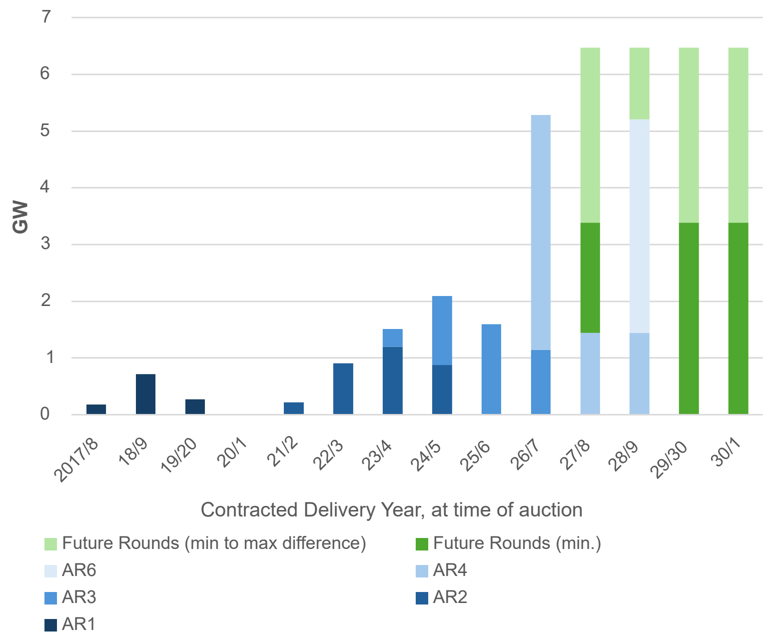


Figure 7: Historic and required CfD allocation round (AR) capacity under our pathways

The development of offshore wind relies on substantial onshore infrastructure to support the transmission and distribution of generated electricity. This infrastructure includes substations, transmission lines and grid connection points, which are essential for efficiently integrating offshore wind energy into the national electricity grid and ensuring reliable delivery to consumers.

Stakeholders believed that offshore wind and other renewable projects are vital for the 2030 clean power goals. Some believe that delivery of 55 GW (the upper limit of our sensitivities) pushes the bounds of deliverability due to capacity and timeline constraints, which reinforces the findings of our analysis of the project pipeline. We have reflected this in our analysis by reducing the upper range within our two primary pathways to 50 GW, while continuing to explore the higher capacity through a sensitivity.

Onshore wind and solar

Onshore wind and solar are the cheapest clean power options available, with largely complementary generation patterns and with potential, in some cases, to locate away from transmission constraints, often by connecting to the distribution network. These can deploy at a faster rate than offshore wind and include smaller community-scale projects.

29–30% of GB's 2030 supply

Our pathways see a doubling of onshore wind capacity from 14 GW in 2023 to 27 GW by 2030 and a trebling of solar from 15 GW to 47 GW by 2030 which means scaling up annual delivery as shown in the figures below. These projects produce less annual output per GW of capacity than the equivalent offshore project.

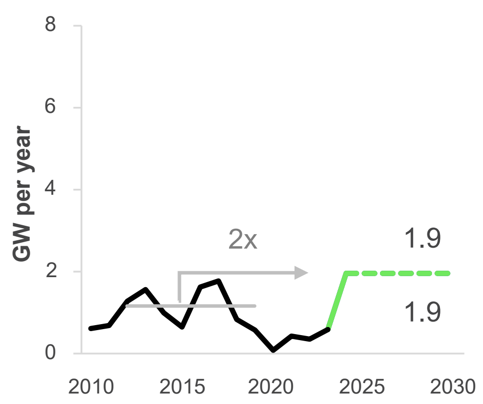


Figure 8: **Onshore wind scale-up**

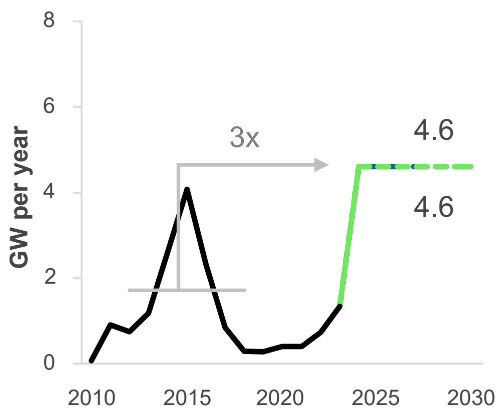


Figure 9: **Solar scale-up**

The distribution network will play an important role in the deployment of renewable generation, with 29% of onshore wind and 90% of solar capacities connected to the distribution network in our pathways. The 2030 connection queue has higher capacities of solar and onshore wind than is required. The technologies are mature and have an effective support mechanism in place, while the lifting of the planning restrictions in England in July 2024 provides further scope for growth in onshore wind.

There were stakeholder views that, while deployment is possible, this could be limited by enabling work, supply chain, planning resource and high-quality engagement that considers the needs of different projects and communities.

Firm generation

14-15% of 2030 supply

This includes plants that are not weather-dependent and have limited flexibility. These typically run at full availability.

Nuclear

Nuclear power will play an important role in achieving a clean power system by 2030 and beyond into the 2030s, when a new generation of nuclear plants can help replace retiring capacity and meet growing demand as the economy electrifies.

Most of Great Britain's existing nuclear plants are due to retire before 2030 and these are currently being considered for life extension, subject to approval from the Office for Nuclear Regulation. A new plant is also under construction at Hinkley Point.

In combination, we assume these see a reduction in Great Britain's nuclear capacity from 6.1 GW in 2023 to 3.5-4.1 GW in 2030, with scope for more new build beyond 2030. Our baseline assumption includes Sizewell B, one unit at Hinkley Point C and a lifetime extension of one AGR unit.

Some stakeholders also raised the possibility that new Small Modular Reactors (SMRs) could be built and deliver clean power by 2030. Should that be possible, it could compensate for any shortfall should plant life extensions not proceed as we have assumed and/or if Hinkley Point C does not begin generation until after 2030. If SMRs can be built in addition to our other assumptions, that could compensate for under-delivery elsewhere in the clean power programme. Beyond 2030, it is clear that SMRs and/or other large nuclear projects provide solid base generation that delivers a large contribution to clean power. There is also the opportunity for these plants to provide heat.

Combined heat and power

Unabated gas combined heat and power (CHP) plants provide energy for industrial process heat requirements or for space heating requirements in heat networks. These are typically driven by heating demand and offer greater heat output than power output. In line with the Climate Change Committee's classification, we include their emissions in the industrial sector, not the power sector. Nonetheless, these will need to be decarbonised in the long run, and we would not consider new CHP plants to contribute to meeting the clean power objective. CHP plants provide 12 TWh of electricity in our modelling in 2030.

Energy from waste

EfW plants exist primarily as a waste solution, not a power solution. As with CHP, these will need to decarbonise in the longer term. EfW plant emissions are counted in the waste sector, not the power sector in line with the Climate Change Committee's classification. Energy from waste contributes 12 TWh of electricity in our modelling in 2030. This includes waste CHPs.

Low carbon dispatchable generation

Gas CCS and Hydrogen

0-3% of 2030 supply

These plants can turn up and down to match demand needs and can fill gaps during periods of low renewable output. Although this can pose some challenges for their operation, it is an important requirement of a clean power system in 2030. Higher levels of dispatchable generation reduce the need for weather-dependent renewables significantly and the need for very long-duration energy storage.

After 2030, low carbon dispatchable power could be built up to replace the need for the remaining unabated gas generation. Hydrogen in the long run can be produced via electrolysis at times of high renewable output and stored for later use when renewable output is low, without reliance on fossil gas or residual emissions. However, large-scale hydrogen storage appears unlikely before 2030 and relative costs for hydrogen and gas with CCS are uncertain. We therefore group these technologies in our clean power pathways.

The Government has announced funding for a gas with carbon capture and storage (CCS) plant as part of its Track 1 process. There is a wider pipeline of potential projects, which if delivered by 2030, would help deliver a clean power system and could support a deeper reduction in use of unabated gas further below 5%.

Both gas with CCS and hydrogen to power are first of a kind technology for Great Britain and up to 2.7 GW through a combination of hydrogen to power and gas CCS is included in our clean power pathways.

Low carbon dispatchable power connected to the distribution network can assist under times of stress. Our analysis includes just under 0.3 GW capacity at low load factors, where they may need to operate to reduce network constraints. This could be met by a range of fuels, including biomass, biomethane or hydrogen, depending on local access.

Biomass and Bioenergy with Carbon Capture and Storage (BECCS)

Sustainable biomass provides a renewable low carbon power source. Great Britain's units are currently incentivised to run for maximum output, under contracts that are due to expire in 2027. For those that fit CCS, high load factors will remain desirable, but the role of biomass (without CCS) should shift to dispatchable to help meet demand during times of low wind and solar output. This will make the best use of the limited sustainable biomass resource. In 2030, the biomass and BECCS capacity of 3.8 - 4 GW in our pathways is a reduction from the 4.3 GW in 2023 partly as we assume some converts to use CCS, which means a reduction in how much power is produced from the same unit.

Biomass generally and BECCS (biomass with carbon capture and storage) were supported in DESNZ's 2023 Biomass Strategy,[7] which emphasised the importance of sustainability. These technologies can contribute to a resilient energy supply. To ensure biomass use delivers its role in the UK decarbonisation goals, there are already mandatory stringent sustainability criteria in the power, heat and transport sectors.

The CCC included bioenergy with CCS (BECCS) in its pathways to net zero as a means of removing carbon from the atmosphere, identifying this as a best long-term use of scarce bioenergy resources. In line with the CCC's 2020 advice on the Sixth Carbon Budget[8] and our July Future Energy Scenarios,[9] we assume conversion of at least one biomass unit to BECCS by 2030 in our pathways. We assume that this operates at high capacities to maximise carbon removal from the atmosphere.

Should there be no biomass CCS conversions by 2030, a clean power system can still be reached as the unconverted biomass plants would have slightly higher capacity and use slightly less fuel. These plants could still provide the required clean power when needed. However, there would be less removal of carbon from the atmosphere, making wider carbon targets harder to meet.

7 Biomass Strategy 2023
8 Sixth Carbon Budget
9 Future Energy Scenarios

Alternatives

Our clean power pathways push the limits of what is feasibly deliverable, but there are some flexibilities at the margin. For example, onshore wind and solar could substitute for offshore wind, more demand side response could substitute for batteries (and vice-versa); more hydrogen or CCS could substitute for all other options.

There is also a wider set of less advanced alternatives that we have not included in our pathways. These could, nonetheless, feasibly contribute in 2030 and relieve pressure in other areas.

- **Biomethane.** If further sustainable supplies can be developed, such as waste based or anaerobic digestors on farms, biomethane could provide an additional clean dispatchable option in the power sector.
- **Dedicated imports.** Projects to ringfence renewables overseas for dedicated export to Great Britain. It will be for Government to decide whether to support these projects and the terms for doing so. We have not undertaken a separate deliverability assessment for this report.
- **Tidal.** A small amount of tidal generation was awarded a contract at the recent renewable auction. It remains higher cost when compared to wind and solar and is not, therefore, expanded upon in our pathways. Although output is variable, it is predictable and follows a different pattern to wind and solar and would be feasible if costs fall.
- **Small modular reactors (SMRs).** A programme to roll out new nuclear SMRs is being developed for the mid-2030s. SMRs can be operated more flexibly than larger plants, although their economics as a capital-intensive project still favour baseload operation. Government could consider the value of bringing this rollout forward to 2030, which some stakeholders suggested would be possible under the right conditions.

Unabated gas generation

While levels of electricity from gas generation will reduce, as the main source of dispatchable generation at the scale needed today it will still be required for security of supply, filling shortfalls during periods of low renewable output.

The portfolio of gas-fired power stations provides less than 5% of Great Britain's generation in our clean power pathways for 2030, supplying 14-15 TWh of generation (in a typical weather year). Typically, gas would run in winter in periods with low wind and sunshine when renewable output is low. Generation could be concentrated in a few short periods through the year, with most of the fleet running over a few days delivering 1-2 TWh. Electricity from gas generation generally should not be produced for export in a clean power system.

Around 35 GW of unabated gas (broadly consistent with the size of the existing fleet) will need to remain on standby for security of supply. This requirement for gas capacity will remain throughout the early 2030s until larger levels of low carbon dispatchable power and other flexible sources are able to replace it. Our analysis meets current security of supply standards.

Some stakeholders raised the importance of understanding the challenge of operating and maintaining an aging gas fleet that is running less frequently. This also includes workforce considerations. Reform of current market mechanisms, such as the Capacity Market, could help enable the continued operation of unabated gas for security of supply. Some stakeholders also noted the notice periods needed to turn on the gas generation fleet and the importance of ensuring these assets remain fit to run with a very different operational profile.

Some stakeholders also spoke of the need to understand the potential suitability for conversion to low carbon dispatchable plants, which influences the way plants are operated and maintained in the near term.

We have considered the impact on gas networks in Section 2.5.

2.4 Electricity networks

A clean power system in 2030 will need to move more power over greater distances. Without grid expansion, it will not be possible to fully utilise renewables and gas will be needed instead. With no grid expansion, gas generation would only fall to 8.1% of generation, rather than to below 5% as needed for a clean power system, despite progress in other areas. Timely and complete delivery of all required network projects is a major infrastructure challenge.

The networks required for delivering clean power will need investments in transmission and distribution. These investments will fall into different categories driven by various factors. They include strengthening the transmission network to enable the efficient transfer of clean power from generation sites to areas of demand. Additional infrastructure will be necessary to connect individual power generators and meet specific demand requirements. Other projects are also required to ensure a safe, secure and resilient network. The scale of investment in all these categories is expected to be significant. Similarly, investments will be required in the distribution networks to connect new sources of power generation and demand. This will facilitate the safe transfer of power within the network, as well as to and from the transmission network.

The work required to connect individual power generators, meet specific demand requirements, and to ensure a safe, secure and resilient network will be identified through the reformed connections process. The high number of network reinforcements, connections and the associated enabling network and substation projects will require a coordinated and whole system approach to considering the network planning and delivery implications at both transmission and distribution levels. This may mean that additional projects required for clean power are identified later. More collaboration, coordination and understanding of the interactions across the whole network will be required and this will be facilitated by NESO.

Wider transmission for clean power

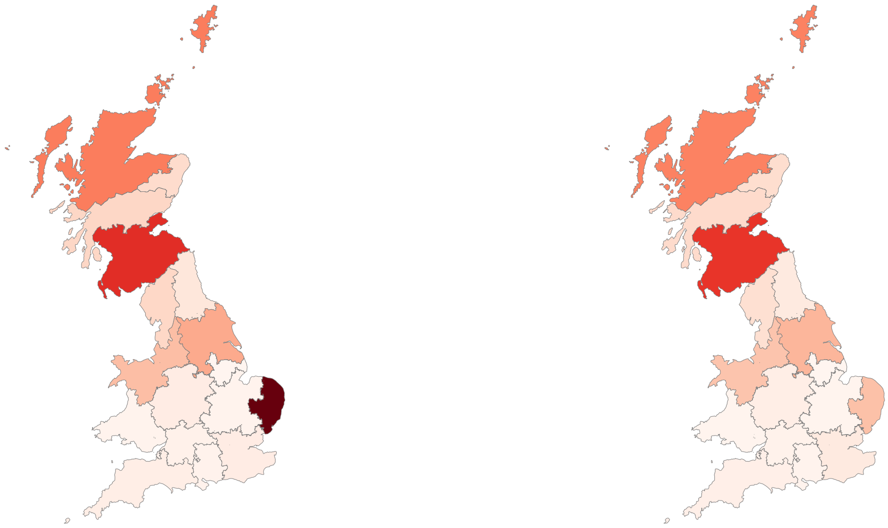
The wider transmission network build programme to 2030 was set out in the Pathway to 2030 report[10] in 2022. It requires up to £60 billion of cumulative investment to deliver around 1000 km of onshore and over 4500 km of offshore network and enabling projects. This would more than double the total built in the last 10 years. Alongside the 2030 network delivery, further reinforcements must proceed to support continued growth in demand and renewables in the 2030s, and progress needs to be maintained to ensure timely delivery of later network projects

The delivery of the 2030 transmission network is underway based on existing recommendations and plans. In the Pathway to 2030 report, 94 wider transmission projects were recommended across Great Britain. This has since been revised to 88 projects, after detailed design work by transmission owners (TOs) and NESO. All TO investment projects will need to be funded through the price control mechanism.[11]

For this report, we assessed whether the Pathway to 2030 recommendations would be able to deliver the clean power pathways set out in Chapter 3. We also considered the impact of any of these network projects being delivered after 2030 and the advantages of bringing forward any projects planned for after 2030, if feasible. We considered both the impact on our clean power metrics, especially any extra need for gas generation resulting from transmission constraints, and the added cost to consumers caused by constraints.

We conclude that to meet clean power in an efficient way in 2030, of the 88 wider transmission projects, 80 must be delivered by 2030.

10 Pathway to 2030 Report
11 The price control mechanism is a process led by Ofgem to balance the relationship between investment in the network, company returns and charges for operating the networks.



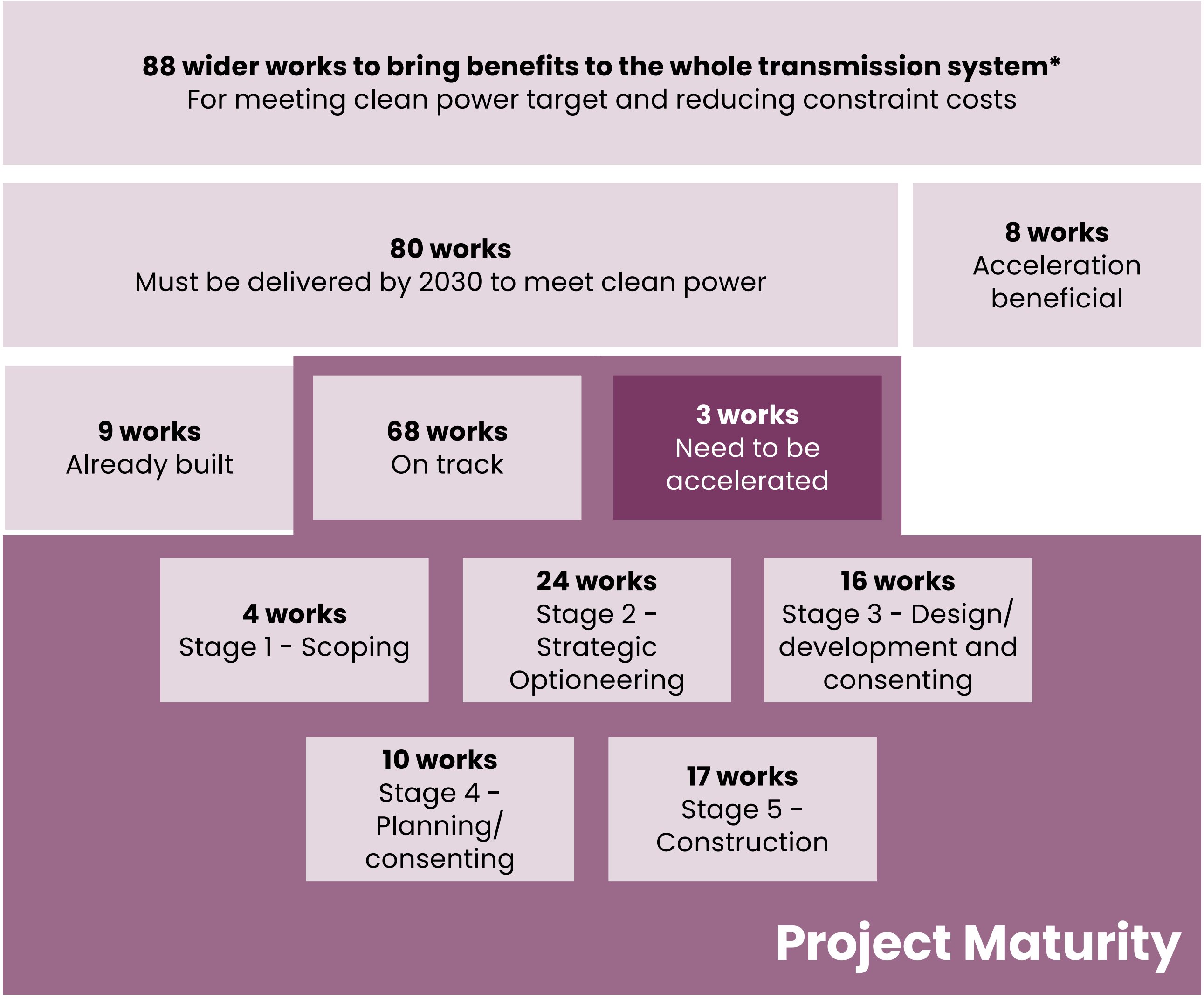
The network we have today is significantly limited in capability. The heat map shows the areas where clean power would potentially be constrained on the transmission network, resulting in about £12.7 bn in constraints in 2030 and 8.1 % unabated gas.

However, the timely delivery of 80 works recommended for 2030 will result in a threefold reduction in constraint costs in 2030 and 4.97% unabated gas usage across the year.

Figure 10: Potential constraint areas

To date, nine of these have been built and 68 are in development, with expected delivery dates by 2030 or earlier. Three projects identified as being critical to clean power have a current delivery date after 2030. These projects will need to be accelerated to 2030 delivery.

Project statuses are summarised below and the list of projects is provided in Annex 3.



**These are wider transmission network reinforcements - they may not include all works, for example, works driven by connection enabling works, operability etc.*

Significant investment in transmission and distribution networks is essential to connect generation, ensure system security and facilitate power transfer from generation sites to demand centres. The wider transmission network is crucial for clean power, and additional investment is necessary. Local network projects will be identified based on specific generation units through the reformed connection process. This may also identify other projects to ensure a safe and secure system.

In parallel, NESO will also continue to explore grid-enhancing technologies (GETS). GETS are hardware and software solutions that allow capacity to be increased along existing lines, allowing further capacity to be utilised ahead of and in parallel with network upgrading and new build. Some of these have already been deployed (e.g. smart valves etc.) and more are being explored.

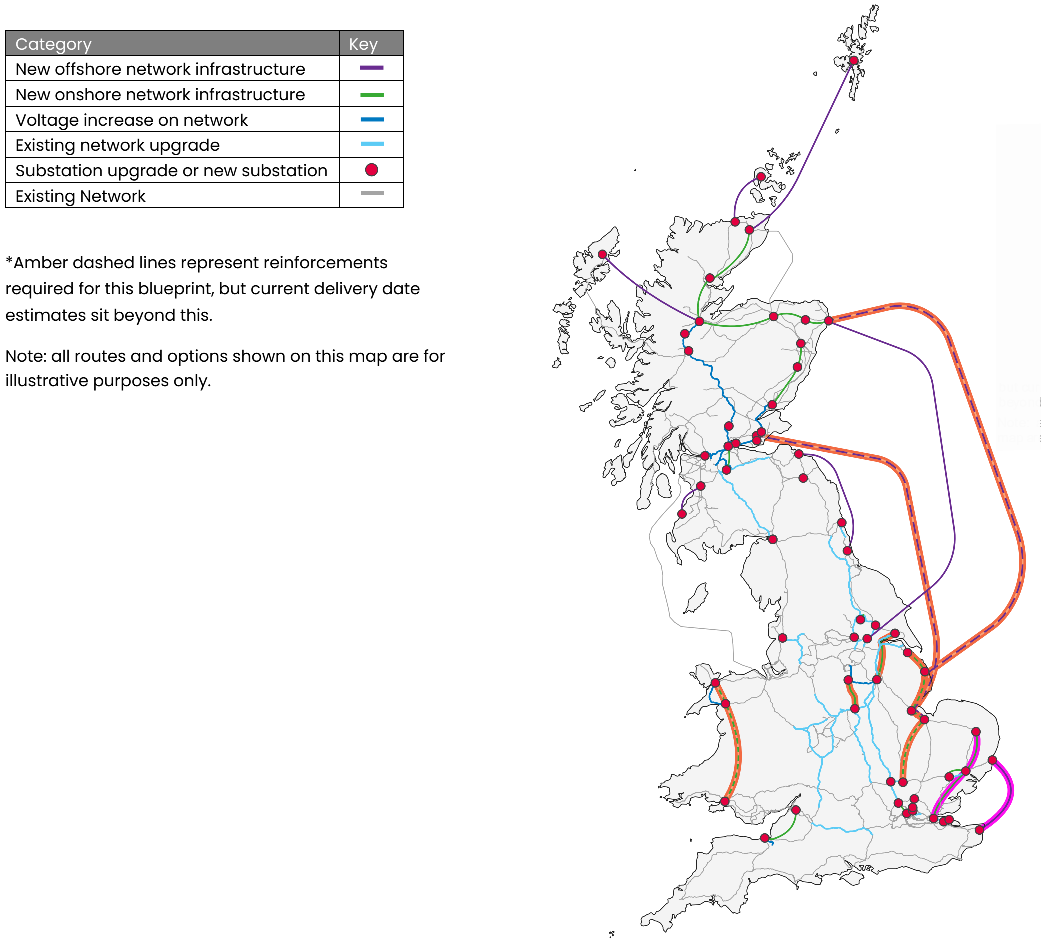


Figure 11: **Map of 2030 transmission network reinforcements for a clean power system**

The need for pace in delivering the clean power transmission network

As set out in the Electricity Networks Commissioner report,[12] speeding up the delivery of strategic transmission is both critical and challenging. Stakeholders understand that it is crucial to deliver at pace and that decisions made for clean power by 2030 must not inadvertently disrupt in-train critical programmes of project. To have a chance of bringing forward delivery dates on a number of key projects would require significantly accelerating and fast tracking Development Consent Order processes and changes to the Town and Country Planning Act.

Three projects[13] have been identified as critical to delivering a network which supports the clean power pathways, but at present have delivery dates after 2030. Support is therefore needed to bring these projects forward for 2030 delivery. These are projects in East Anglia and in the southeast that are critical for connecting offshore wind in the North Sea and supporting the flow of clean power. Our assessment suggests that without these projects, the clean power objective would not be achieved, leaving the clean power target short by around 1.6% in 2030 (assuming a typical weather year) and consumers could face extra constraint costs of around £4.2 billion in 2030.

12 gov.uk/government/publications/accelerating-electricity-transmission-network-deployment-electricity-network-commissioners-recommendations

13 These projects are Norwich to Tilbury (these projects have two codes in our network planning processes AENC and ATNC), Sea-Link (SCD1).

To bring delivery forward to 2030, urgent and significant action is needed on removing the key challenges to delivery - including regulatory funding, supply chain and accelerated planning processes.

Supply chains. Our stakeholder engagement has indicated some transmission owners are affected by challenges in securing the required supply chain capacity across the build programme. There is also a need to support enhanced ways of engaging with the supply chain, such as portfolio procurement. These barriers will need to be unblocked to enable timely delivery.

Distribution Network Operators. Stakeholder engagement highlighted the value in planning network development holistically, considering the needs of Distribution Network Operators. Taking this approach will lead to improved outcomes and efficiencies around network reinforcements. We further consider the distribution network in Section 2.5.

Minimising constraint costs. The network should be designed in a way to minimise constraint costs. The planned investment for 2030 will help to efficiently transmit clean power from where it is generated to where the demand is highest. However, the network will still have constraint costs, which vary in quantity depending on the pathways. This is where grid-enhancing technologies can maximise their contribution.

Bringing forward additional projects (beyond the 80 described above, which are needed to meet the clean power objective) would bring further benefit in reducing the use of unabated gas and a further reduction in constraint costs. However, it would be a very significant undertaking.

- From Pathway to 2030 there are eight further projects, with delivery dates beyond 2030.
- Six of these projects, we understand from TOs, could be accelerated towards 2030 and any such acceleration would bring reduced constraint costs. For example, if these projects could be accelerated, they are forecast to provide a significant benefit in reducing constraint costs by around £1.7 billion in 2030. However, accelerating them to 2030 is likely to be extremely difficult.
- Two projects are at an earlier phase of development and, we understand from TOs that they cannot be accelerated from their existing post-2035 delivery dates, although any acceleration will bring benefits.

We will continue to work with TOs on options for the acceleration of critical strategic infrastructure, including the option for additional offshore High Voltage Direct Current (HVDC) reinforcements where they bring value. A list of these projects is provided in Annex 2.

Of the 68 projects that are on track for delivery by 2030, we have further identified those which will have the biggest impact on the clean power metric and constraint costs were they to deliver after 2030. In many cases, the delay of even a single project until after 2030 could add over £0.5 billion to annual constraint costs and increase emissions.

	Further Flex and Renewables		New Dispatch	
2030 clean power pathways run with:	**unabated gas % in 2030**	**constraint costs in 2030, £billion**	**unabated gas % in 2030**	**constraint costs in 2030, £billion**
The 2024 transmission network (assuming no further deployment)	**8.1%**	**£12.70 billion**	**7.7%**	**£10.90 billion**
The network currently expected for 2030 (not including AENC/ ATNC/SCD1)	**6.6%**	**£7.79 billion**	**6.2%**	**£6.58 billion**
The network required for clean power, including the three critical projects being delivered in 2030	**4.97%**	**£3.57 billion**	**4.99%**	**£2.84 billion**
The network if all 7 further projects were accelerated to 2030	**4.1%**	**£1.86 billion**	**4.1%**	**£1.07 billion**

Table 1: **Constraint costs and unabated gas % under different pathways**

Compounding delays of multiple projects can easily escalate these by billions of pounds, adding to the risks for the clean power goal. Further analysis is presented in Annex 2.

2.5 Distribution networks for clean power

Distribution networks are critical for meeting clean power in an efficient way in 2030. Connecting additional clean power sources, such as solar and wind, will play an important role in displacing the need for unabated gas.

The distribution network is managed by distribution network operators (DNOs), who are responsible for the infrastructure that delivers electricity from the transmission network to homes and businesses. GB has six main DNOs (Electricity North West, Northern Powergrid, SP Energy Networks, Scottish and Southern Electricity Networks, UK Power Networks and National Grid Electricity Distribution). In addition, there are independent DNOs (IDNOs) that can connect in at either transmission or distribution.

Developing new distribution network infrastructure (including substations and circuits) is generally easier than transmission infrastructure due to several factors:

- **Lower voltage levels:** Distribution networks operate at lower voltages, which simplifies construction and maintenance compared to the high-voltage transmission networks.
- **Radial configuration:** Distribution networks are often designed in a radial configuration, meaning power flows in one direction from the substation to consumers, reducing complexity in design and construction.
- **Proximity to end users:** Distribution networks are closer to end users, resulting in shorter distances between substations and consumers, which minimises the amount of infrastructure needed.

- **Simpler protection schemes:** Distribution networks have lower fault currents and simpler protection schemes, making it easier to design and implement new circuits.
- **Regulatory processes:** The regulatory and permitting processes for distribution networks are often shorter than those for transmission networks, expediting approval and construction timelines.
- **Planning:** Generally fewer planning and DCO applications are required at lower voltages as many new distribution connections require upgrades to existing overhead lines rather than new routes and are operating at lower voltages.

While the above bullet points highlight why DNO networks can be a key enabler for accelerated delivery, it should be noted that there are significantly larger volumes of connections required to install the same generation capacity at distribution rather than at transmission.

DNOs supplied the volume of renewable generation in their connection queue leading to 2030, allowing us to confirm the assumptions in our pathways. The information we received from them suggested that there are two to three times more projects awaiting connection in the queue than required in our pathways. However, for some renewables in certain regions, there is currently an undersupply of queued projects.

DNOs also provided the volume of generation currently in the queue that could be accelerated and connected if the transmission reinforcement requirement was removed. We used this volume to identify the total volume of solar and wind generation in the pipeline that had the potential to be accelerated and brought forward to connect by 2030 if the queue could be revised to meet targets for clean power in 2030.

We then tested the impact of accelerating the volume of additional renewable generation identified in the pipeline by 2030 and what it could do to the clean power metric. Our analysis showed that this decreased the proportion of unabated gas generation across the year to between 0.5-0.8% unabated gas across our pathways.

This additional volume of renewables on the distribution network results in a greater utilisation of batteries connected to the distribution network, as they charge with excess solar and wind energy during the day and discharge the stored energy at night. Note that this will have a distribution network impact that may limit distribution capacity to connect new renewable generation.

Accelerating additional solar and wind generation in the distribution network pipeline is critical to reaching clean power at pace and reducing the risk of under delivery of renewables.

NESO will work with the DNOs to review the volume of generation that requires minimal or no additional network investment at transmission and can be accelerated, provided they align with government's plan for clean power by 2030.

2.6 Gas, hydrogen and CO_2 networks

In 2030, gas-fired generators continue to be of vital importance to the operation and security of the energy system, because of their ability to bring large volumes of flexibility through fast start-ups and shut-downs. The upstream gas networks are therefore critical to providing that security.

Our gas network analysis shows that the gas transmission network can absorb the impact of the gas-fired generation fleet's start-up behaviour, for both summer and winter conditions. Our gas network analysis is presented in Annex 2.

Stakeholders had concerns that additional requirements of gas generation would require the cancelling or postponing of asset outages (compressor stations etc.). We note that operating the NTS with a relatively high opening linepack,[14] to mitigate unexpected unavailability, may require more facilities to be operationally available, potentially impacting the availability of outage windows.

Delivery of transport and storage infrastructure required to support low carbon dispatchable power for 2030 is critical. In this timeframe there is some optionality across CCUS and Hydrogen to Power, but both rely on critical infrastructure.

There are currently no major hydrogen or CO_2 transportation pipelines in operation in Great Britain. However, projects are in development which are linked to Track 1 industrial clusters.[15]

The key to the success of developing these projects is getting government funding, signalling and policy to develop the projects that will facilitate more private investment.

14 Linepack is gas stored within the pipes of a gas transmission or distribution network.

15 HyNet and East Coast Cluster were selected in 2021 as part of the Government's cluster sequencing process to deploy carbon capture and storage in a minimum of two industrial clusters in the mid-2020s.

2.7 Network access

Network access involves the planning of outages of electrical assets and equipment (e.g. circuits and breakers) on the power system to carry out maintenance and improvement works. Outages of critical infrastructure are needed to deliver works on the system safely. There is a physical limit to the number of outages that can take place at any one time due to the impact on system security and costs borne by consumers. Any increase in work taking place must be carefully managed to ensure that the power system remains secure and stable.

Approximately 8,000 outages take place on the electricity transmission system each year. Typically, 40% of these will have been agreed 12 months ahead of delivery, with the remainder mostly requested and agreed in the year that the outage takes place.

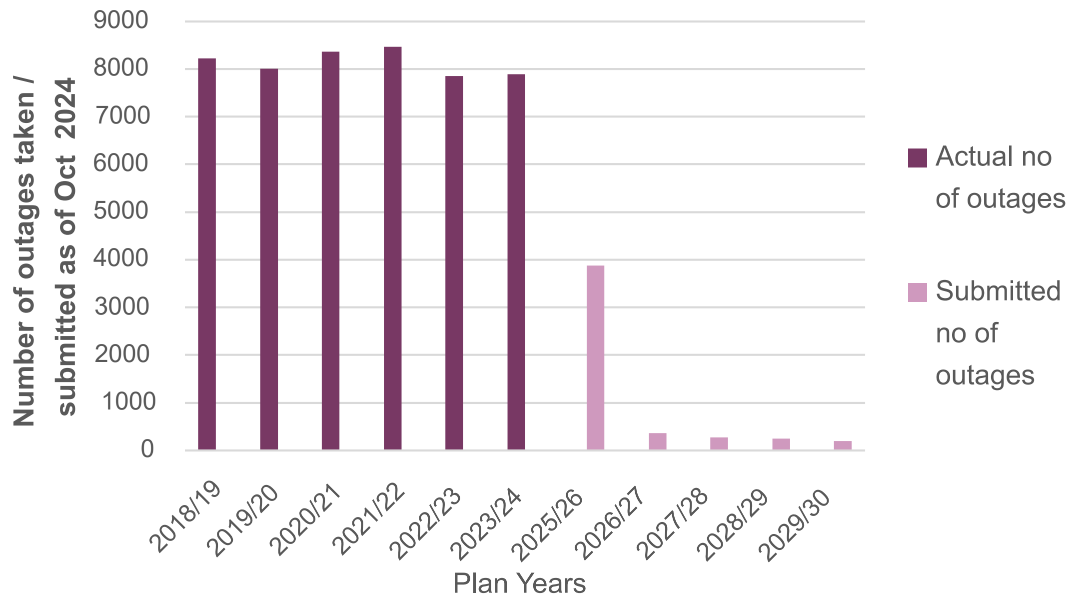


Figure 12: **Number of outages taken / in plan**

A more strategic approach to system access planning across industry will be required to provide assurance around the deliverability of clean power 2030 and to address the network access challenges in timescales where there are a greater number of options available to minimise costs. As well as providing a maximum amount of system access through an optimised plan across years, action should also be taken to maximise the amount of work that is carried out within each outage window. Furthermore, less intrusive ways of working such as off-line build and temporary lines will be required.

Spatially, there are also outages in regions of the network that can cause system constraints as they reduce the amount of generation capacity that can be transferred from one area of the network to another. To manage this and ensure the power system remains secure and efficient, NESO operates within a market to reduce or increase generation in one area and then balance that action in another. It is essential that the outages on electricity network assets are planned and coordinated effectively to ensure new connections and equipment are delivered in an optimised way that allows as many projects to be accelerated and delivered as possible, whilst minimising the associated constraint costs.

Further detail on our analysis is presented in Annex 2.

2.8 Connections

Connections reform

Delivery of a clean power system in 2030 will require an installed generation and storage capacity of around 210-220 GW and significant levels of new demand connections to the electricity network across transmission and distribution. In section 4.3, we consider the reforms that are required to connections processes (both for queue management and wider network-related reforms) to deliver the right technology, in the right location at the right time. These reforms are broad and deep. They are largely being conducted through formal open code governance processes which necessitates extensive industry engagement and feedback, as well as complex assessment of potential actions and associated impacts.

The indicative timeline for connections reform runs through to spring 2025, following which significant work will be required to issue new connection offers in line with the updated rules and government's plan for clean power by 2030. It is imperative that the reform timeline remains on track, with all parties playing their part to ensure that projects needed for 2030 and beyond can progress in a timely manner without undue uncertainty or delay.

Connections queue

The current connection queue has a greater volume of projects to 2030 than is required in our clean power pathways, across the key technologies.

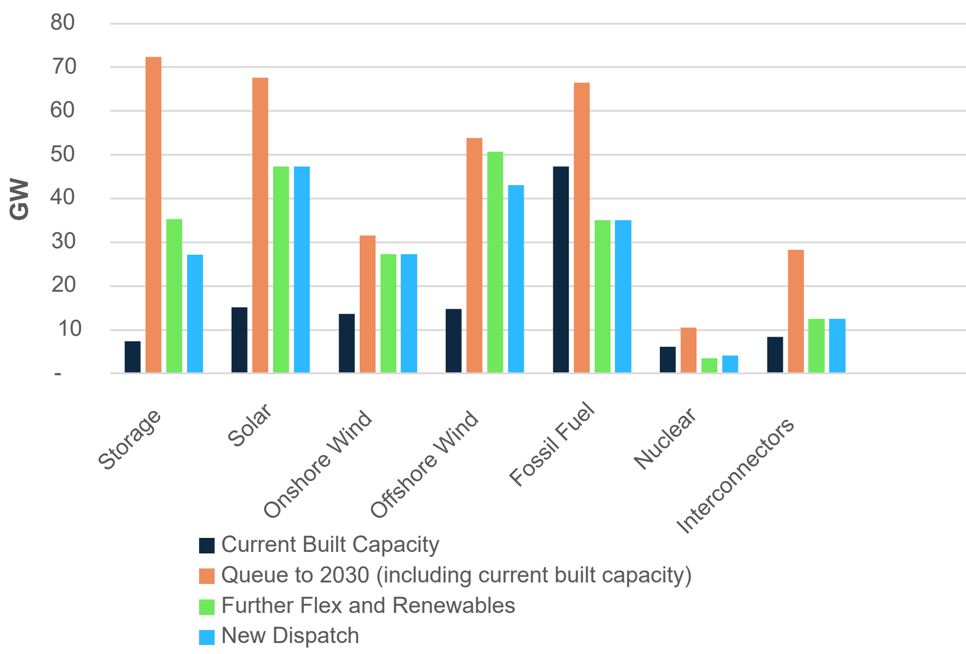


Figure 13: **Current connections queue against clean power pathways by technology (GW)**

Central to the proposed connections reform is the creation of a direct link between the technology and capacity needed, by location, in the government's plan for clean power by 2030, and the connection offers that are made.

The spatial maps below show the capacity and technology needed to align with our Further Flex and Renewables and New Dispatch pathways.

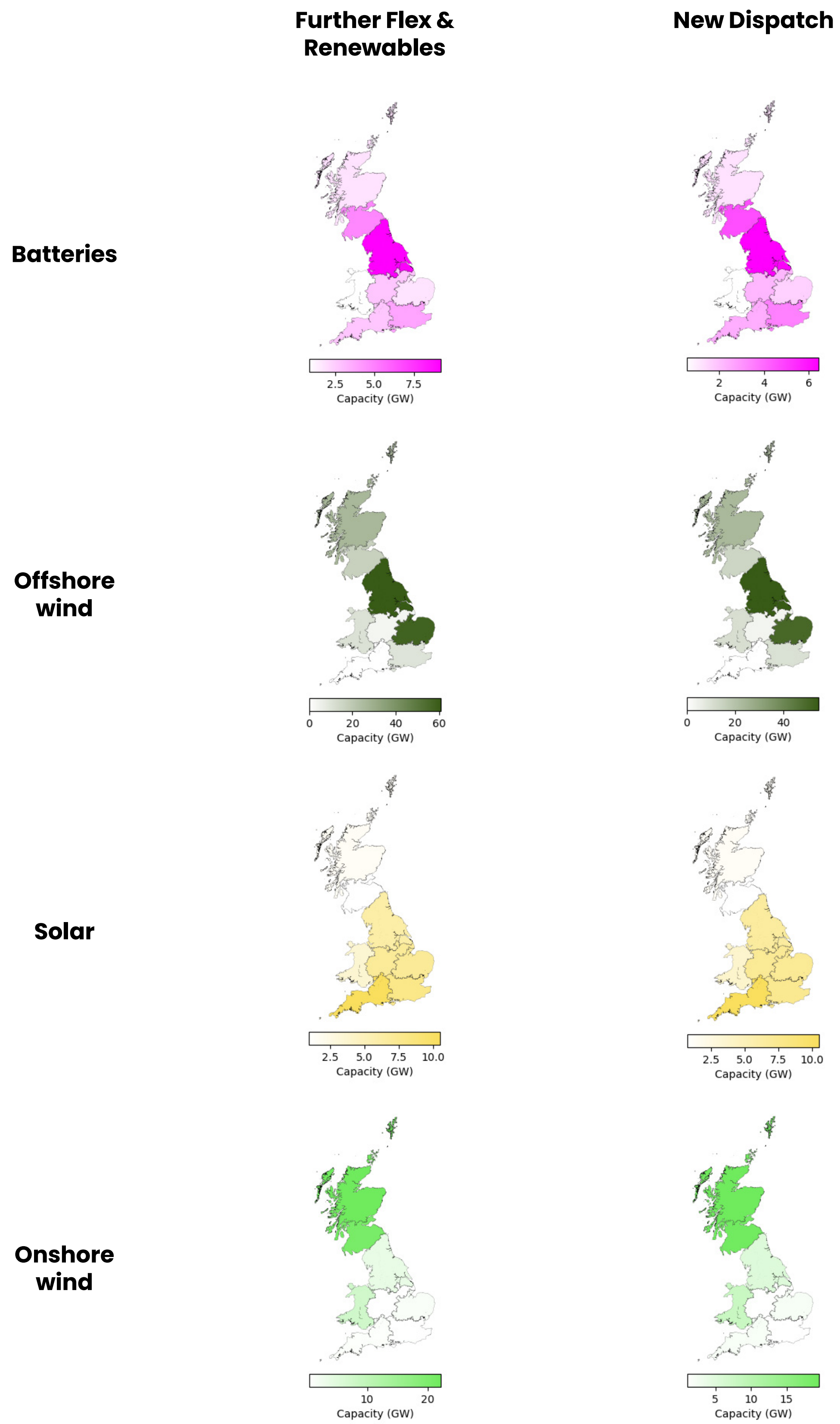
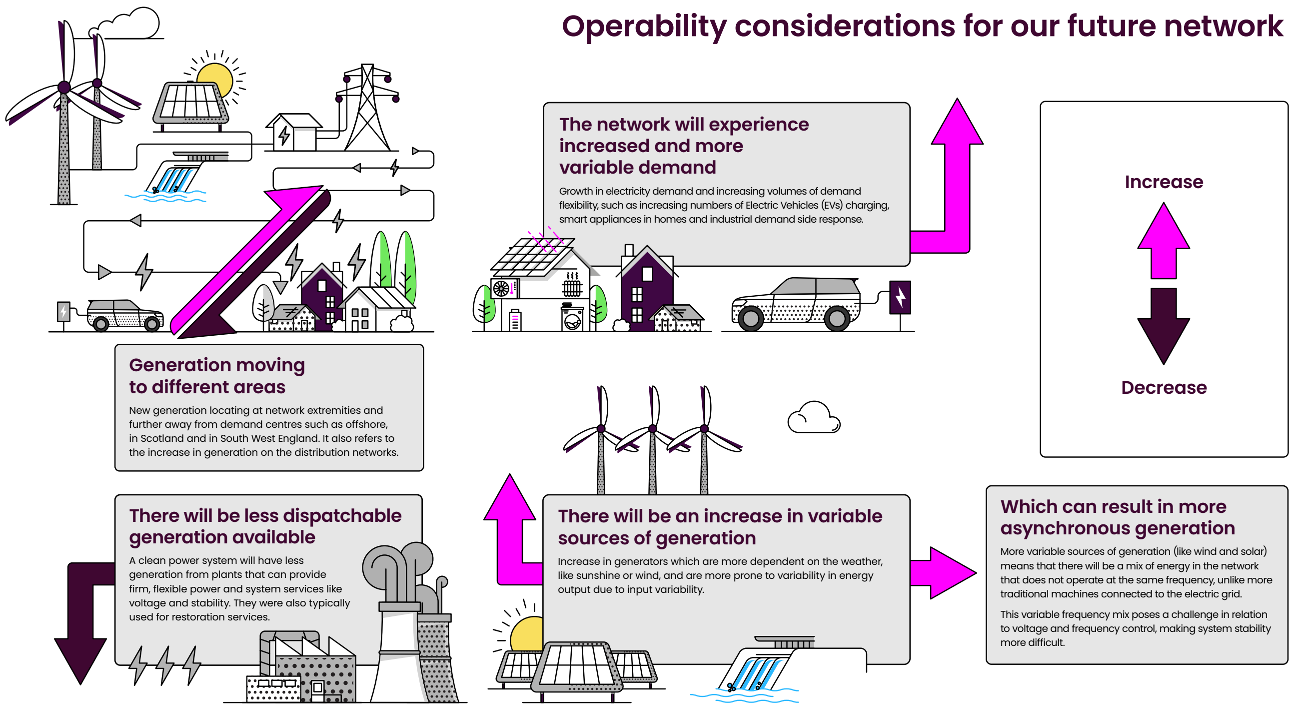


Figure 14: Spatial capacity maps

2.9 System operability

Electricity network operability is maintaining a stable, reliable and efficient power grid. It means ensuring the system can handle fluctuations in supply and demand, integrating renewable energy sources and responding to potential disturbances or faults. As Great Britain transitions to a clean power system, the operability challenge evolves.



Action is already being taken to ensure a stable, reliable system. As NESO, we will be able to operate the electricity system with zero carbon for specific hours in 2025. Achieving year-round operation of a clean power system will require acceleration of regulatory changes and enablers to ensure sufficient new assets and services are in place by 2030.

Traditional fossil-fuelled generation exhibits technical characteristics that have allowed system operators to successfully manage secure and safe electricity systems. As these types of generation decrease, the characteristics they have need to be replaced by other technologies and solutions.

In Great Britain, NESO has already taken big steps to prepare for a safe and reliable decarbonised electricity system. Through this work we understand the actions that need to be taken for reliability and safety, and we are confident that the cost of the provision of these services is lower than it would be on conventional power stations if they were only running to provide the services.

To operate a clean power system safely, securely, economically and efficiently requires resolution of operability challenges across stability, frequency, thermal constraints, voltage and restoration.

- **Stability:** To ensure the system can securely and reliably withstand unplanned events, for example the loss of a generator or a fault on an overhead line, there needs to be enough 'inertia' and 'short circuit level'. With the move to renewable generation, NESO needs to increase the number of technologies that can provide these services, such as additional synchronous condensers or batteries or renewable devices with grid forming inverters. With the establishment of our network services procurement (NSP) markets, we have the mechanisms in place to procure the services we need.
- **Frequency:** As there is less 'inertia' on the system, our ability to maintain the system frequency close to 50 Hz to balance real-time supply and demand requires a quicker response. NESO has already started this transition and our current services are pioneering in delivering the initial frequency response within one second. Hence, we are in a good place to understand how to manage the frequency of the system as we move to clean power. There will be a requirement to increase the volume of these services through our established frequency markets
- **Voltage:** The voltage on the system must be maintained within acceptable operational limits using reactive power. All the new generation required to connect to deliver clean power must have a minimum range of voltage control; this includes battery energy storage and renewable sources of power. Voltage control in a clean power system does become more complex and further voltage control devices will need to be installed across the system to supplement the capability provided by the new connections. Working with the transmission owners (TOs), we will identify and secure/source these voltage control devices and services as required.
- **Thermal constraints:** In operating an efficient electricity system, there are times when the physical capacity of the network cannot transfer the amount of electricity required. When this happens, generation output on one side needs to be reduced and this is called a 'constraint'. Network investment involves a cost of upgrading the network, but brings a benefit in reducing the costs of these constraints. On top of investment, the use of other commercial and technical techniques can reduce these costs. As we progress towards 2030, NESO will assess and deploy existing techniques as well as embracing new and innovative grid enhancing transmission solutions that increase the capacity of the network.
- **Restoration:** NESO has an obligation, by 31 Dec 2026, to be able to restore 60% of British transmission demand within 24 hours and 100% within 5 days after a shutdown. Clean Power 2030 pathways will not compromise this ability. The restoration strategy will include non-traditional generation for restoration services and an annual assurance framework to ensure compliance with the Electricity System Restoration Standard (ESRS).

Managing operability in a clean power system will require different and innovative approaches. NESO has begun making these changes and will work collaboratively with industry in developing and implementing them to run the future clean power system securely and efficiently. Our detailed operability analysis is presented in Annex 3.

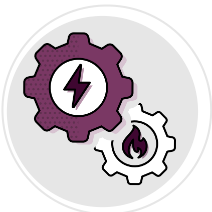
2.10 System operations

The NESO Electricity National Control Centre (ENCC) plays a crucial role in maintaining electricity supplies for consumers by constantly monitoring and balancing the supply and demand for electricity in real time. This operation ensures that the power grid remains safe and stable, preventing disruptions. The ENCC also coordinates responses to unexpected events, such as equipment failures or sudden changes in demand, ensuring that consumers receive a consistent and dependable electricity supply. Enabling the efficient operation of the system along the pathways detailed in this report will require a significant acceleration of developments to how the ENCC operates this considerably changed system.

Applying a digital-first mindset means we will use and share data more effectively and our systems, processes and people will leverage the right tools, technologies and training to operate a clean power system. An example of this is our ability to access increasing volumes of demand side response. We will achieve this by ensuring we receive accurate data which then supports these services being properly represented across our systems and processes alongside more established generation assets, enabling cost-effective balancing actions.

NESO recognises that we have not always been able to take full advantage of new technologies connected to the network as quickly as the industry needs, for example batteries, due in part to insufficient capability of legacy IT systems. However, we are confident that, through this analysis and other ongoing workstreams, we have identified and are in the process of instigating the changes required within the Control Centre, and support functions, that will allow us to operate a clean power system in 2030. Our investment in digitalisation and Artificial Intelligence (AI) will need to increase to realise this.

Our activities will fall broadly within the following categories:



Systems

Our tools will need the ability to integrate whole system data sources into accurate forecasts & models to enable efficient decision-making in an increasingly decentralised power system.

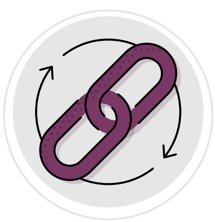
Work to incorporate primacy rules & the visibility of Distributed Energy Resources (DERs) will require acceleration to ensure effective co-ordination of DNO-connected services.

Continuing development of our Open Balancing Platform & Volta project are needed to ensure effective bulk dispatch & whole energy optimisation.

Data

We are continuing to develop an integrated approach to data standards & sharing across industry to enable whole system optimisation. This approach will be enabled by continued investment in our Virtual Energy System (VirtualES) data sharing infrastructure.

Continue to identify and progress innovation projects focused on system and data opportunities for 2030. Analysis has identified accurate forecasting and modelling as one of the key system functionalities required.



Process

Ongoing reviews of all Control Room processes to enhance efficiency of operational co-ordination with our customers.

We are ensuring our people & processes remain agile to respond efficiently to any delays to key investments, ensuring that new capabilities are delivered when required.

Transparency

Our ability to efficiently answer market queries with technical proficiency needs to be enhanced to build trust across all operational interfaces & with end consumers.

We are accelerating efforts to make sharing of data on Control Room decision-making more proactive.

People

We will increase the support provided to our highly trained & experienced Control Room staff by accelerating investment to enhance our data analysis & operational co-ordination capabilities with dedicated roles in these areas.

Chapter 3. Pathways to clean power

Our pathways demonstrate that it is possible to move to a renewables-dominated clean power system by 2030 without compromising security of supply. The pathways include a combination of flexibility, low carbon dispatchable power plants and a back-up fleet of gas capacity to meet current reliability standards.

The combined higher levels of offshore wind in the 'Further Flex and Renewables' pathway and new dispatchable power in 'New Dispatch' will both be needed soon after 2030. An appropriate approach may therefore be to aim high on both, reducing the risks of under delivery for the portfolio as a whole and reducing reliance on any single project.

Adding even more clean power capacity can reduce use of unabated gas, but only by a fraction of its generating potential. This implies that, at the margin, more deployment of clean power sources, particularly variable and firm ones, will tend to add to system costs.

3.1 Our clean power pathways

As set out in Chapter 1, we present two main pathways to clean power in 2030. Both involve increased electrification of heat, transport and industry – a reductionist approach that slows down electrification to lessen the challenge of clean power would undermine the core objectives of cutting energy costs and supporting net zero. One pathway, Further Flex and Renewables, sees 50 GW of offshore wind and no new dispatchable plants. The other, New Dispatch, has 43 GW of offshore wind and new dispatchable plants (totalling 2.7 GW, using either hydrogen from low carbon sources or carbon capture and storage (CCS)).

These pathways were developed from the analysis set out in the Future Energy Scenarios, with adjustments based on the greater challenge of clean power, our deeper assessment of the 2030 pipelines and our stakeholder engagement for this report.

Stakeholders encouraged development of a wider set of sensitivities and emphasised the importance of some technologies for the period beyond 2030, even where their 2030 role is limited. Based on feedback and our pipeline analysis, we reclassified a proposed pathway with 55 GW of offshore wind as a sensitivity and added a further sensitivity with more new dispatchable generation.

Our clean power pathways push the limits of what is feasibly deliverable, but there are some flexibilities at the margin. For example, onshore wind and solar could substitute for offshore wind; more demand-side response could substitute for batteries; more hydrogen or CCS could substitute for most other supply options.

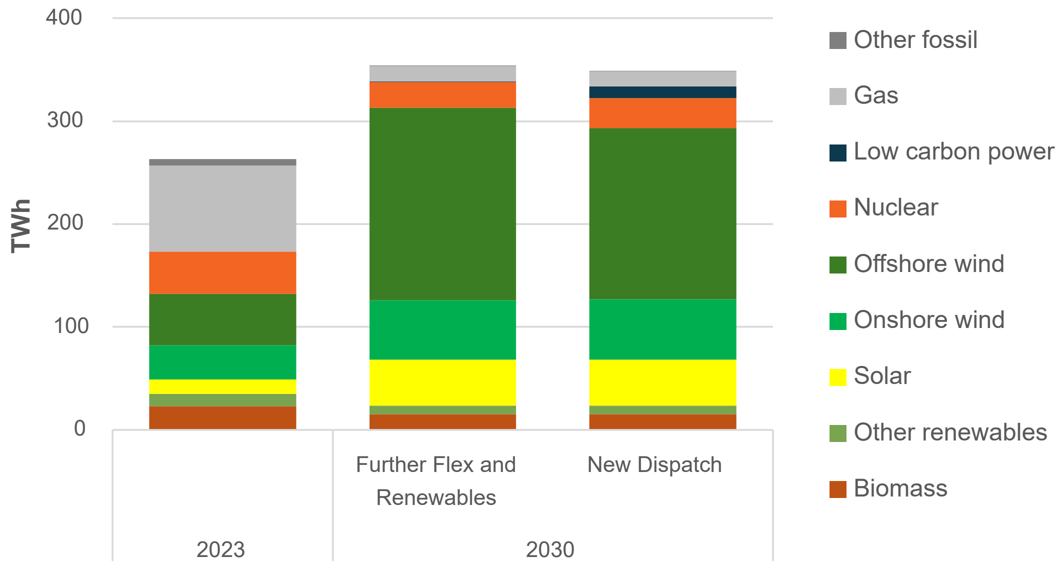


Figure 15: Generation mix for a clean GB power system in 2030

Fuel / technology type (GW)		2023	2030 Further Flex and Renewables	2030 New Dispatch
Variable	Offshore Wind	14.7	50.6	43.1
	Onshore Wind	13.7	27.3	27.3
	Solar	15.1	47.4	47.4
Firm	Nuclear	6.1	3.5	4.1
Dispatchable	Biomass/BECCS	4.3	4.0	3.8
	Gas CCS/Hydrogen	0	0.3	2.7
	Unabated gas	37.4	35.0	35.0
Flexibility	LDES	2.8	7.9	4.6
	Batteries	4.7	27.4	22.6
	Interconnectors	8.4	12.5	12.5
	Demand-side flexibility (excl. storage heaters)	2.5	11.7	10.4
Annual demand (TWh)		**258**	**287**	**287**

Table 2: Capacity by technology in the clean power pathways (GW)

3.2 Security of supply

It is non-negotiable that the power system must remain secure. Our pathways demonstrate that it is possible to move to a renewables-dominated clean power system by 2030 without compromising security of supply. The pathways include a combination of flexibility, low carbon dispatchable power plants and a back-up fleet of gas capacity to meet current reliability standards.

To maintain security of supply, we anticipate that most existing gas generators will need to remain on the system, with new power stations potentially required to replace retiring ones. However, their use (and therefore emissions and expenditure on gas) drops dramatically. To stay open and maintain availability, they will need to cover their fixed (non-fuel) costs with other support, for example through the capacity market. If new gas-fired plants are needed, they must be hydrogen-ready or CCS-ready from the start, meaning the plant is in a suitable location and retrofit is technically and commercially feasible.

In line with our annual security of supply assessments and capacity market modelling, we test across different weather conditions, plant outages and network outages, looking across the year and at specific periods of system stress (e.g. wind lulls in cold snaps in winter).

We have also looked at the implications for the upstream gas network, which would experience larger swings at shorter notice. We model over various time intervals and both nationally and regionally, also considering stress events such as the loss of a compressor. In this analysis, the gas network remains within safe operational limits.

Great Britain's electricity infrastructure is resilient to current climate conditions, but future challenges posed by climate change bring additional risk, especially considering the necessary changes in generation and consumption patterns for a clean power sector. Traditionally focused on security and adequacy, the infrastructure must also be resilient to high-impact, low-probability events, such as severe weather, which are expected to become more frequent and intense due to climate change. NESO's new Office for Resilience and Emergency Management will provide whole system coordination, assessment and analysis for system resilience and preparation for emergencies across the GB energy industry.

3.3 Insights from our clean power pathways

Our clean power pathways see Great Britain become a net exporter of power and reduce the share of gas generation to below 5%. Both pathways have core commonalities, reflecting that many of the big changes needed to 2030 are clear – they both see a huge expansion of flexibility of both demand and supply, get the majority of clean power from wind and solar, and retain a gas fleet of similar size to today for security of supply.

The two pathways involve somewhat different ways of reaching clean power, implying different risks, challenges and opportunities, both at the portfolio and at the project levels.

- Delivering new clean dispatchable plants by 2030 involves particular project risks, given these are first-of-a-kind technologies for Great Britain. Partly reflecting those risks, these plants are also likely to involve a higher need for government support initially.
- If delivered, new dispatchable power would reduce supply chain pressures elsewhere. For example, the New Dispatch pathway needs to contract a further 9 GW of offshore wind in the next one-to-two years, compared to 19 GW for Further Flex and Renewables, which would be above the record amount of 11 GW.
- The Further Flex and Renewables pathway has lower fuel costs but has to produce more power overall to compensate for curtailment, constraints, higher exports and storage losses given the greater share of generation from variable sources. These effects result in higher aggregate annual system costs compared to the New Dispatch pathway, even though the per MWh costs of offshore wind are lower than for CCS. These results reflect our central assumptions, and could change under different assumptions.
- The New Dispatch pathway would leave the British system somewhat more exposed to volatile international gas prices. Gas (whether for unabated plants or those using CCS or CCUS enabled hydrogen) would still be used in 47% of periods, rather than around 15% in the Further Flex and Renewables pathway. Under current market arrangements, this would feed through to wholesale price setting in those periods.
- There may be different industrial benefits and new jobs under the two pathways, as well as different opportunities for GB to demonstrate climate leadership.

	Further Flex and Renewables	New Dispatch
Emissions ($MtCO_2$) (excluding BECCS)	5.2	5.3
Carbon intensity gCO_2/kwh (excluding BECCS)	15	16
Imported fuel dependency (%)	19	23
Hours with gas (unabated or with CCS) running over a typical year (%)	15	47
System cost (£/MWh)	133	126
Curtailed and constrained (TWh)	48	44

Table 3: **Key stats from our pathways**

The combined higher levels of offshore wind in Further Flex and Renewables and new dispatchable power in New Dispatch will both be needed soon after 2030. An appropriate approach may therefore be to aim high on both, reducing the risks of under delivery for the portfolio as a whole and reducing reliance on any single project.

Our analysis shows that dispatchable plant has an oversized value for displacing unabated gas generation, reflecting its ability to target its outputs at times when otherwise unabated gas would be used. To maximise this value, dispatchable plants should not operate at full capacity all year round. This needs to be considered when designing relevant contract terms.

Modelled seven-day hourly generation profiles today and in 2030 for illustrative weeks across the seasons highlight the changing role of unabated gas, weather dependent renewables and flexible sources. Unabated gas plants generate far less frequently than today, making up less than 5% of the total annual generation in our modelling. However, there will be periods in 2030 where they play a critical and sustained role over several hours or days – as can be seen for the illustrative winter week in Figure 17, while unabated gas is barely used in the illustrative weeks for other seasons. Clean dispatchable plant (blue in the Figure) and other flexibility (pink) play key roles in meeting peak demand and in periods with lower wind and solar output (green).

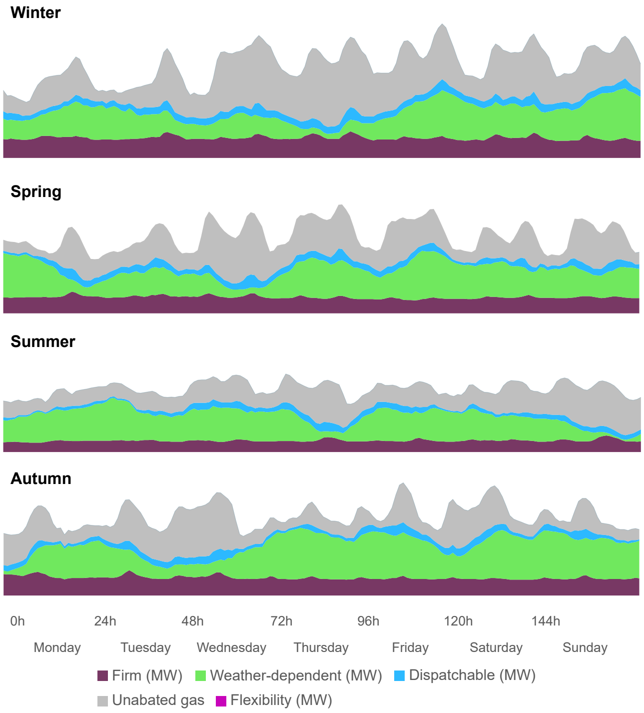


Figure 16: **Modelled 7-day hourly generation profiles for 2023**

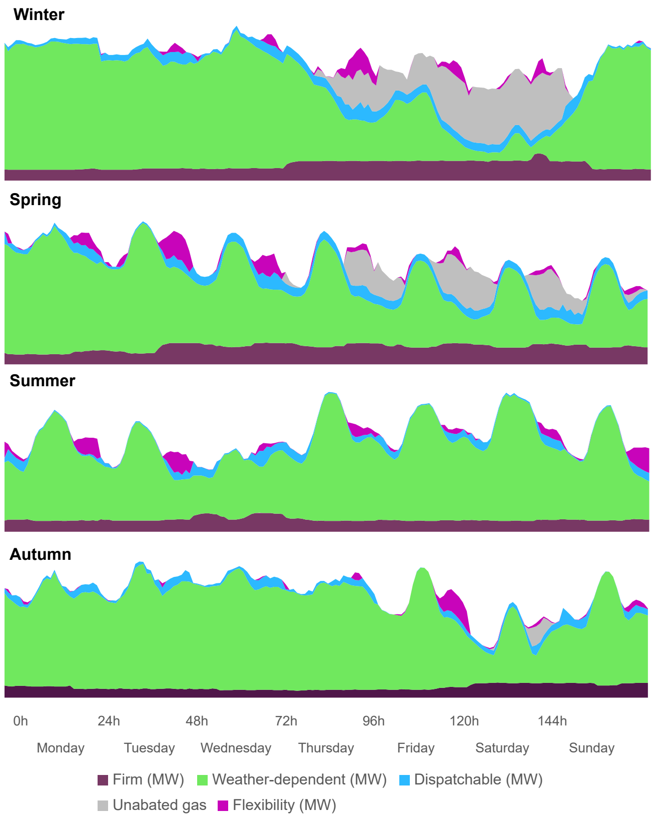


Figure 17: 2030 Further Flex and Renewables

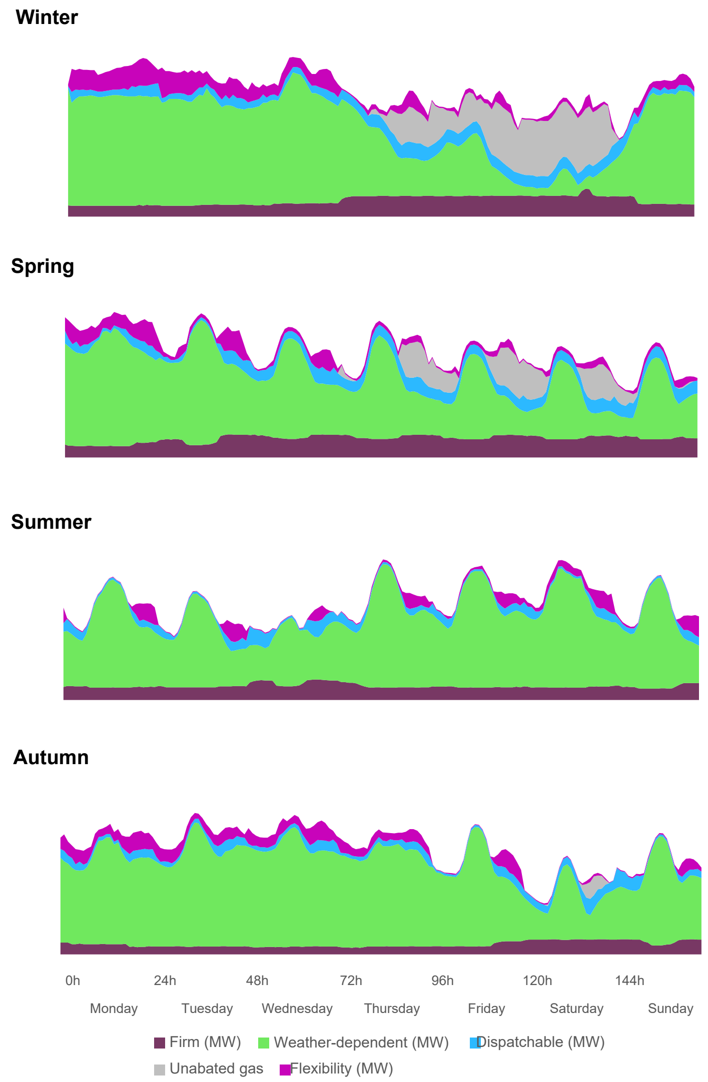


Figure 18: **2030 New Dispatch**

Different supply and demand mixes also result in different pinch points on the network, where the highest unresolved constraints occur. In both pathways, there is a significant pinch point in the Midlands leading to clean power in Scotland being constrained.

- This is particularly the case in the Further Flex and Renewables pathway (although helped by the deployment of long-duration storage), which also sees a pinch point in East Anglia due to the higher offshore wind alongside interconnectors.
- In the New Dispatch pathway, the constraints are the lowest, as the dispatchable plant with CCUS, being in one of the CCUS clusters, is better located to use the planned electricity transmission network.
- The Very High Renewables sensitivity has the highest constraints due to the significant volume of renewable generation connected in Scotland and East Anglia in particular.

3.4 Insights from our clean power sensitivities

Once a clean power system is reached by 2030, further reducing the share of unabated gas below 5% by building more clean power capacity becomes very difficult. This reflects that, in a clean power system, unabated gas is only operating in less than 20% of the hours of the year, so only power supplied in those particular hours will further reduce use of unabated gas. We have explored this challenge and others in our sensitivities.

We find limited impact from further increasing flexibility:

- **Batteries:** Even a doubling of battery power (GW) and capacity (GWh) from levels in our pathways would only reduce unabated gas use by less than 0.1 percentage points. The lower levels of battery deployment In New Dispatch (still more than quadruple current levels) still support a system with less than 5% of unabated gas, while reducing the level of investment required and overall system costs. Improving the roundtrip efficiency of batteries slightly reduces unabated gas use (by less than 0.1 percentage point). These sensitivities indicate that good market design to encourage optimal deployment and use of batteries can help keep costs down.
- **Interconnection:** We find that more interconnection with neighbouring markets can bring some benefits in reducing curtailment (i.e. more 'excess' power from renewables that would have been wasted can be exported) and in enhancing security of supply. But it does not reduce use of unabated gas.

Adding clean power capacity can reduce use of unabated gas, but only by a fraction of its generating potential. This implies that, at the margin, more deployment of clean power sources, particularly variable and inflexible ones, will tend to add to system costs.

- **Variable renewables:** Generation from wind and solar tends to be concentrated in hours where gas is not running, so adding more to our clean power pathways has a very limited impact on unabated gas use. Furthermore, much of the extra generation would be curtailed or exported at low cost (since it is produced at times of excess), so more renewables at the margin will tend to push up costs, unless accompanied with more demand that is flexible enough to take advantage of these times of excess power. Our Very High Renewables also explores increased demand. With 14 TWh of additional demand and 29 TWh of additional renewable output compared with Further Flex and Renewables pathway, annual gas generation remained at under 5%.
- **Firm generation:** . Including 1.8 GW of additional firm capacity in 2030, such as from nuclear small modular reactors, would provide around 13 TWh of generation and reduce the share of unabated gas by 0.9 percentage points (3 TWh). Much of the remaining 10 TWh would be lost to curtailment or exported at low cost, implying an increase to overall costs of the power system.
- **Dispatchable generation:** Similarly, a 1 GW increase in dispatchable generation would only be able to displace 0.5 percentage points (1-2 TWh) of unabated gas. It would also run at some times for export at high prices. The low load factor involved implies a relatively high cost per unit of generation, but it would add less to system costs than the increases in variable renewables or inflexible generation, given the ability to save on fuel costs when not running.
- **Weather:** The dispatch modelling for our clean power pathways considers what would happen in a typical weather year.[1] We have also carried out modelling to assess security of supply (adequacy) requirements that consider more extreme weather years, including extended periods of low wind, and variations in plant outages. This ensures that we have sufficient available generation to operate the system safely and securely under a range of different conditions. Our modelling shows that our clean power generation portfolios provide a level of reliability that is similar to what we have today, based on loss of load expectation (LOLE), and are well within the current reliability standard of 3 hours LOLE per year. There is also the possibility that a system that would meet our clean power metrics in a typical wind year would not meet them in a low wind year.

1 In our modelling we have used weather from 2013. The use of a single representative weather year is common in power system modelling, and we have used this alongside other security of supply metrics. We use the year 2013 because it represents a typical British weather year, characterised by low temperatures and high winds in winter and a mild summer.

We have also used our modelling capabilities to explore variations in how the system is run, keeping the demand and supply mix the same. These demonstrate that, at the margin in a clean power system, choices that affect how the system runs may become more important than trying to build ever more clean capacity.

- **System optimisation:** Our modelling approximates how the system is dispatched, and allows for some inefficiencies in this, for example because market participants do not have perfect foresight. To explore the impact of more efficient dispatch decisions we tested how model results changed with a shift from one-day to seven-day foresight. This favours storage and demand flexibility, which can then avoid the need for gas-fired generation more effectively. This test sees gas use reduce from 5% to 3.5% in our pathways, while also bringing material cost savings. The possibilities here warrant further investigation which we have underway.
- **Dispatch of gas plants:** To limit generation from unabated gas for export, our modelling includes a £25 /tonne carbon differential for Great Britain against connected markets. Increasing this differential can have large impacts on unabated gas use, at the extreme reducing it to only 1%. The carbon price is not a policy recommendation, and other options could achieve similar ends. In designing a suitable policy, or defining what is considered an acceptable strategic role for unabated gas, it will be important to consider the impacts on security of supply, costs to consumers and the risks of carbon leakage.

For the power system to be clean, it is not enough to build all the required components: they must also be used in a way that is clean. As part of the plan for clean power by 2030 the Government, working with NESO, should consider how it will ensure the system runs as a clean system.

Chapter 4. Critical enablers

In Chapter 2 we have identified some of the key technology-specific actions needed to reach clean power by 2030. Many challenges are common across different technologies, requiring holistic thinking about how they can be overcome. Our analysis and engagement have highlighted six cross-cutting enablers where action is needed:

Markets and investment: Various market arrangements and investment support schemes are in the process of, or will need, reform to reach clean power and operate the system efficiently. Decisions must provide stability and confidence to underpin the large amount of investment required, while supporting innovation and efficient operation of the system. An element of competition will help to keep costs down.

Planning, consenting and communities: Significant volumes of projects need to pass through the planning system to start construction on rapid timescales, while maintaining community consent which is vital to the mission. Given that construction for many of the required projects needs to begin in the next 6-24 months to be in place by 2030, upcoming planning reforms will need to streamline and speed up processes.

Connections reform: The connections queue must be formed of ready-to-connect projects that align with government's plan for clean power by 2030 and, once developed, the Strategic Spatial Energy Plan (SSEP) and future iterations. We have begun the process of connections reform and will develop the SSEP based on government's plan for clean power by 2030.

Supply chains and workforce: Acute supply chain and workforce challenges must be overcome across nearly all generation, storage and network projects. Policy certainty, visibility of the future market and swift funding decisions are needed to ensure developers can mobilise the supply chains and workforce needed. Over the medium term, greater strategic coordination can enable delivery while supporting the growth of domestic supply chains and a skilled workforce to meet the growing pipeline of projects.

Digitisation and innovation: Prioritised and coordinated action is needed across the sector to drive digitalisation and common governance is required for orchestration of a sector-wide digital and data plan. Work has started on a common data sharing infrastructure for the sector, but this needs to be accelerated through policy and incentivisation of adoption. Accelerated AI adoption and transformative innovation need to be prioritised to align with government's plan for clean power by 2030.

NESO as a partner in delivering clean power: NESO will play a central role in delivering clean power. Putting the government's plan for clean power by 2030 into operation will require coordinated action across the energy industry and its institutions, with NESO working as a partner with Government, Ofgem and key decision makers. This includes supporting Energy Code Reform, developing our implementation and engagement plans and reviewing our operations to ensure alignment with the plan.

This chapter sets out our high-level assessment of the challenges and opportunities in this space and the action that is needed to deliver. As highlighted above, close collaboration will be needed between UK, Scottish and Welsh governments, particularly in relation to planning and consenting.

4.1 Markets and investment

Where are we now?

Since privatisation in the early 1990s, the GB electricity market has facilitated competition, investment, and innovation, with significant benefits to consumers. The Contracts for Difference (CfD) scheme, introduced in 2012, helped drive down the cost of offshore wind and propelled the UK to the forefront of the clean power transition, supporting over 19 GW of offshore wind capacity by 2024. Alongside this, the Capacity Market has supported investment into new build of capacity, providing security of supply as coal was phased out.

However, the market arrangements that underpin our electricity system were designed for the former age of large, centralised dispatchable generators. As the system evolves, we are observing ever higher constraint costs and inefficient outcomes across the market. In 2022, the government launched the Review of Electricity Market Arrangements (REMA) to ensure that the GB electricity market is fit for the future. NESO is part of the REMA Programme Board.

Where do we need to get to?

To deliver clean power by 2030, GB will need to mobilise and deploy an average of over £40 billion of investment annually in energy infrastructure over the next five years.

Having effective market arrangements and investment support mechanisms in place will be essential to unlocking this investment, while ensuring consumer value, low carbon operations and security of supply. This must be achieved in the context of a system which:

1. Encompasses assets which are increasingly geographically dispersed, connected at distribution level, automated and responsive to changes.
2. Contains significant volumes of assets supported by increasingly diverse investment support mechanisms, with different incentives that will impact on their operational decisions in different ways.
3. Is increasingly interconnected to continental markets.

A range of initiatives are already underway to deliver this, including: the new cap and floor for long duration storage that is needed to unlock investment; reforms to the balancing market to enable new types of flexibility and demand side response to compete on a level playing field; and the REMA programme, which is considering how the existing CfD, Capacity Market and wholesale market arrangements need to evolve to recognise the changing nature of the system.

What are the challenges and opportunities?

In developing this report, we engaged closely with investors, developers, industry bodies and academics. There was near unanimous agreement on the scale of the challenge and the importance of clear stable market signals and investment support needed to mobilise the capital required to deliver the significant increase required.

There were a variety of views on the benefits of fundamental reform to the wholesale market arrangements to move away from the national pricing model to a more granular level, e.g. through zonal pricing. Alongside this, many market participants considered that the introduction of significant reforms to market arrangements could create sufficient uncertainty to risk delivery of the technology pathways identified in this report, at best increasing the required cost of capital to deliver the investment and, at worst, stymieing the investment completely. Others suggested that there was already uncertainty around the future direction for the wholesale market, CfD and Capacity Market, and a swift decision on the future direction is needed.

The importance of supporting consumer and demand side flexibility enabled by digitisation was recognised as critical for delivering clean power, and some stakeholders have expressed that more granular wholesale pricing is critical for unlocking flexibility.

Actions needed to drive change

Market reform

There is currently uncertainty around the future of market arrangements and investment support which could act as a barrier to delivering clean power by 2030. Investors and market participants are likely to need clarity on these future arrangements at a suitable level to enable investment decisions in the very near future. The upcoming cap and floor decisions, design of future CfD allocation rounds, ongoing reforms to the balancing mechanism and REMA programme are all opportunities to provide such clarity.

It will be important to provide stability and confidence in the future direction of market reform to underpin the large amount of investment required, while supporting innovation and efficient decisions on the way to, and on reaching, a clean power system.

On the specific issue of wholesale market arrangements, ESO's Net Zero Market Reform[1] work has highlighted where current market design is driving inefficient outcomes and higher costs for consumers. As we move towards a clean power system, it is increasingly clear that the current arrangements will not be fit for purpose as they do not provide the right information or incentives to market participants, leading to inefficient outcomes. A locational pricing model is likely the best way of mitigating the risks and maximising the opportunities of a decarbonised power sector. Any such change would need to be accompanied by clarity on changes to other investment support elements of the market (e.g. CfDs, Capacity Market etc.) and any transition arrangements. There is a critical need for clarity on this via the REMA programme.

Unlocking flexibility

Reforms to the market supported by digitalisation and innovation are also required to unlock consumer and demand flexibility. Our clean power pathways will require demand side flexibility at peak to grow by 4 - 5 times current levels. Achieving this will need to build on the progress and innovation seen in this sector in recent years. Collaborative action across the Government, NESO, Ofgem, Elexon as the market facilitator and industry is needed to ensure demand side flexibility is considered on the same level as areas such as network build and new technology investment.

Market participants highlighted the following necessary actions and areas of focus:

- **Putting in place underpinning digital infrastructure, product policies, standards and governance, alongside access to high quality data.** Smart meters, smart appliances and EVs with vehicle-to-grid (V2G) capability will provide the foundations of this system, ensuring that consumers can participate in and benefit from demand side flexibility. To achieve this, higher levels of smart meter penetration will be needed. Consumer and industry concerns about data and privacy must be addressed. Smart appliance policies and standards must be accelerated.
- **Creating routes to markets for flexibility and facilitating continued innovation.** In parallel, market design needs to ensure flexibility is sufficiently rewarded, with markets that are open and accessible. Demand side flexibility can help operate the electricity system. As such, we need to ensure that demand side flexibility can compete in markets where it can meet system operability needs.[2] Wholesale market reform is key to ensuring that market participants with the ability to shift their demand are incentivised to act flexibly: delivering the market-wide half-hourly settlement (MHHS) programme will be critical to unlocking this. Market coordination is also required across NESO, DNOs and wider flexibility markets to ensure that flexibility providers and aggregators can stack revenue and operate seamlessly.

1 Net Zero Market Reform

2 NESO will be publishing its 'Routes to Market Review for Demand Side Flexibility' report in the coming months which will expand on its commitments.

- **Ensuring consumers can reap the benefits with consideration of the distributional effects.** For consumers to ultimately benefit from demand side flexibility, they need to have the ability to respond to a price signal. This includes industrial and commercial Demand Side Response (DSR), whereby price signals need to reflect the system value and incentivise a shift from business-as-usual activity. Our pathways assume that innovative tariffs or other retail offerings are the default from 2028, but innovation in the market to provide similar services and increased choice for consumers could deliver greater volumes of flexibility. Changes to retail regulations may also be needed to manage any complexity brought by multiple appliances and technologies and fairly pass through the value to consumers' bills. Changes must be mindful of potential negative impacts on vulnerable and low-income consumers.

Significant growth in distributed flexibility will be fundamental in delivering a decarbonised electricity system and ensuring clean and affordable energy for all. To deliver this goal at the pace required to deliver clean power, greater alignment is needed between local and national markets and services to make this a reality. We look forward to working collaboratively with Elexon as the Market Facilitator, alongside Government, Ofgem & DNO's to develop more coordinated market opportunities for all providers of flexibility in the future.

Supporting investment

Our analysis in Chapter 5 sets out the major investment programme needed for a clean power system. These are dominated by renewable investments, followed by network investments, storage and other low carbon capacity. Alongside markets, well targeted and carefully designed investment support mechanisms will play a pivotal role in mobilising the private capital needed to reach clean power by 2030:

- **Low carbon power:** Renewable generation will be the backbone of the new system and needs to be deployed at least twice as fast as ever before. An element of competition should help keep costs down, but this needs to be balanced with the needs of a clean power system in 2030 and beyond. Finding ways to maximise visibility of the future market will support the required investment at least cost, including in the supply chain. A clear strategy for contracting renewables over the coming three years could provide maximum certainty for investors and the supply chain.
- **Supply side flexibility:** With relatively long build times, rapid decisions are needed on the cap and floor mechanisms for interconnectors and the long duration storage to unlock investment in the capacities required to deliver clean power.
- **Low carbon dispatchable capacity:** Clear pathways are needed for the deployment of first-of-a-kind (FOAK) technologies such as power CCS and hydrogen to power. For these technologies to deploy successfully, investment support for the necessary infrastructure (including transport and storage) and power generation business models will need to be in place to enable construction to start swiftly.
- **Networks investment:** Quick and consistent decisions are needed to unlock investment in vital network projects for 2030. Clarity is also needed on the policy and regulatory funding mechanisms and incentives for these projects, providing certainty of revenues and target dates across transmission and distribution sectors.

Supporting the continuation of unabated gas for security of supply

Our full considerations on unabated gas are set out in Annex 1. Gas generation will play a vital role in ensuring security of supply in 2030 and beyond. As gas generators will run at significantly lower load factors than today, we would expect them to become more dependent on revenue support from the Capacity Market or an alternative, such as a strategic reserve mechanism. The future of the Capacity Market and/or the introduction of a strategic reserve should be considered alongside wider market reforms through the REMA programme. As part of this, it will be important for the Government, NESO and Ofgem to constantly monitor the effectiveness and value for money of any arrangements, ensuring there is a plan in place to manage the impact of plant exits from the market on capacity adequacy. A decision is needed in time for the publication of the Capacity Market Parameters in July 2025.

NESO's voltage, stability, reserve and response markets

Annex 3 sets out our plans for adapting our core operability markets.

The 'Voltage' and 'Stability' sections of Operability Annex 3 outline future requirements for reactive power and stability services respectively. The recently developed long-term markets for both voltage and stability are available to meet our firm long-term requirements. The mid-term markets will also be available to meet shorter-term closer to real time requirements based on their current implementation status. Both markets will enable service provision through clean generation sources.

The 2030 frequency requirements detailed in the Operability section of this report will be met through NESO's response and reserve services. We have already designed the services we need to secure and operate a clean power system and such services will continue to be procured through a transparent and competitive auction process. Details can be found in the Markets Roadmap. As we move to more intermittent and less synchronous generation, the volume required from these services will likely increase. We will continue to review our requirements and enhance our services as necessary to meet the changing needs of the system.

4.2 Planning, consenting and communities

Where are we now?

Most of the energy infrastructure required to deliver clean power by 2030 is already in the development cycle. However, an independent report[3] commissioned for ESO in spring 2024 suggested that only 6 GW of onshore wind, 15 GW of offshore wind, 10 GW of solar and 10 GW of battery storage had obtained the relevant planning consent as of April 2024. Engagement with the TOs has shown that of the network projects required, 16 projects are currently awaiting planning and consenting decisions and 28 projects are at an earlier stage of development, prior to planning and consenting.

The research also suggests it currently takes, on average, 21 months to issue a planning decision for offshore wind in England and 15 months in Scotland. For onshore wind, it takes 15 months to receive a decision after applying to local planners and 35 months at the national level.

Communities will be at the heart of the delivery of net zero in Great Britain and the planning process is a key route through which they can have their say on plans for energy infrastructure in their area and raise concerns about the impact on their local environment.

Where do we need to get to?

Unprecedented volumes of clean energy infrastructure projects are needed to meet the Government's energy ambitions. Construction for many of these projects needs to begin in the next 6-24 months. Considering the time it has taken for significant energy projects to get planning consent in recent years, those timelines look challenging. Engaging and bringing along local communities that host energy infrastructure will remain key, both in enabling delivery and maintaining widespread public support for the clean power mission.

What are the challenges and opportunities?

We established a Societal Delivery Forum to understand the views of organisations representing local communities, the natural environment, land use specialists and the planning sector to inform our advice to the Government.

Participants highlighted several consistent challenges around societal and consumer acceptance, engaging local communities, resourcing of local planning authorities and statutory consultees, ensuring the right data is available to make decisions and the experience of consenting major energy projects. Opportunities for improvement through greater coordination between developers in the building and development of infrastructure, better engagement with statutory consultees and the Government's upcoming planning reforms were put forward.

The government has begun to take steps in the planning system to enable clean power – including the removal of the moratorium on onshore wind in England, and the recently announced joint UK and Scottish Government consultation on changes to the planning regime to support energy infrastructure.

Actions needed to drive change

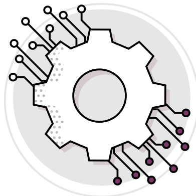
The planning and consenting processes for energy infrastructure needs to be shorter to ensure delivery by 2030. The current approach which can take in excess of two years for approval on some types of projects, and longer in some cases, poses a significant delivery risk. To have a good chance of being built in time. The next 6-24 months are critical for projects to clear planning and move into construction. Expediting the planning process, while maintaining community consent will be vital to delivering on the clean power mission, and maintaining momentum for projects needed after 2030.

3 Research commissioned by ESO and carried out by Regen in July and August 2024. This is based on connection queue and planning information from April 2024 and so figures may have changed since then. It should also be noted that, due to data availability this does not reflect all projects in the planning cycle. Research results are presented for illustrative purposes only.

Improved coordination and transparency between developers and statutory consultees and ensuring there is sufficient capacity in the system will help enable acceleration. As will cooperation between all levels of government: national, devolved and local.

Community consent and maintaining public support is vital to the delivery of net zero in Great Britain. Those asked to host energy infrastructure should continue to be effectively engaged throughout the development process, even as it accelerates, and should feel tangible benefit from the critical role their areas play in building a clean, secure and low-cost electricity system.

4.3 Connections reform



Where are we now?

The connections queue currently comprises a greater volume of projects than required for 2030 across our pathways. However: a) not all of those projects may be 'ready' or committed to progressing; and b) there may be projects with connection dates after 2030 that could usefully contribute to the 2030 system, for example with lower delivery barriers or lower costs. Some progress has been made over the last 12 months in addressing connections issues at both transmission and distribution levels. In addition, plans have been set out by NESO to move away from the concept of a 'first come, first served' approach to connections queue management, to one which will see us connect demand and the required generation in a timely and more strategic process.

Building on the plans set out by ESO earlier this year, further work is in train across NESO, DESNZ, Ofgem and industry to ensure that, in support of a clean power system, connections queue processes bring forward the right technology in the right location and when it is needed.

Further actions beyond queue reform have been set out in the joint Government and Ofgem Connections Action Plan and the previous Government's Transmission Acceleration Action Plan, with a focus on ensuring that projects with a connection offer can then be connected and energised in a timely and efficient manner.

Where do we need to get to?

To get to a clean power system by 2030, the generation and technology mix that is set out across our pathways needs to connect to the electricity system in the next six years. We need a reformed connections process that reflects the needs of the clean power mission.

What are the challenges and opportunities?

Delivering net zero will require connecting new capacity and new types of customers more quickly than at any time since the current process was established. In addition to a 'fit for purpose' process for issuing connection offers and managing the connections queue, consideration must be given to the implications of the volume of connections, as well as significant shifts in the nature of connecting customers and their needs.

The high number of connections and the associated enabling network and substation works will require a coordinated and whole system approach to considering the network planning and delivery implications at both transmission and distribution levels. More collaboration, coordination and understanding of the interactions across the whole network are required.

Given the dynamic nature of the path to clean power in 2030, action is also required to ensure that the codes and methodologies governing the approach to managing connections provide clarity and certainty for developers, while being appropriately flexible to the changing needs of the system and future strategic plans for the period beyond 2030.

Consideration should also be given to whether the open codes governance process is, in itself, sufficiently flexible and adaptable to be effective in enabling the required pace and scale of reform.

Actions to drive change

Delivering a clean power system by 2030 requires a connections process which is aligned to government's plan for clean power by 2030.

As such we have also published, for consultation, details on how we propose to align the reformed connections process with strategic energy plans (initially government's plan for clean power by 2030, and then the first Strategic Spatial Energy Plan, SSEP). The scope of our connections reform proposals includes all projects connecting at transmission level, and any generation and storage projects connecting to the distribution networks that impact upon the transmission system. Consideration will also be given to the treatment of demand connections with regards to the queue and the interaction with the generation connections.

We set out in that consultation our view that the connections process and reformed connections queue should align with the technology, capacity and regional requirements for clean power as set out within Government's clean power plan (at both a transmission and distribution level), and then with subsequent strategic plans like the SSEP. The Government's clean power plan can help ensure the efficiency of the new connections queue and that 'ready'[4] and strategically aligned projects are connected efficiently to achieve clean power. This could be achieved through including capacity requirements for different technologies connecting at transmission and distribution networks, and that the pathways within the clean power plan clearly separate the proposed mix of transmission and distribution technologies, by capacity and location.

However, the transition to net zero emissions across the economy by 2050 does not stop with achieving clean power in 2030. Projects needed beyond 2030 are in development now and require clarity on their connection agreements too. This could be achieved through the government's clean power plan providing clarity on the pathway upon which connection offers can be based for the period 2031-35.[5] Including this 2031-35 pathway in the clean power plan will provide a 10-year time planning horizon for the reformed connections queue, thereby providing longer-term investment clarity that will help ensure an efficient transition towards net zero targets beyond 2030 (including the Sixth Carbon Budget targets), while also facilitating an efficient transition to the first SSEP.

We set out more detail on the connections reform enablers in Annex 2.

Looking beyond 2030, we will publish our first SSEP by the end of 2026. It will build on the government's action plan for clean power by 2030 to support the energy transition efficiently and securely, provide greater clarity on the nation's future energy requirements, and achieve net zero ambitions in line with government targets. Once the first SSEP is in place we will then use the SSEP to prioritise future connection offers aligned to the SSEP.

4 By 'ready' we mean projects that meet the new criteria we propose to apply to the current connections queue and future applications, that would require projects to demonstrate that they have secured appropriate land rights in order to receive a confirmed connection offer and a place in the reformed connections queue.

5 We are proposing that the 2031 to 2035 pathway for connection offers should be based on the Holistic Transition scenario within our Future Energy Scenarios 2024 (FES24) to 2035.

4.4 Supply chain and workforce

Where are we now?

The global race to decarbonise is straining international supply chains and compounding skills shortages. Notably, the offshore wind sector, as well as the broader electrical component supply chain, face pronounced challenges. Shortages of construction workers and engineers across Great Britian further exacerbate project construction delays and increasing costs.

Where do we need to get to?

The Government has recognised the transition to a decarbonised energy system as an opportunity to create jobs and grow the economy, delivering wider benefits to Great Britain. However, those benefits can only be fully realised if action is taken to unblock the differing supply chain and workforce challenges for projects on the critical path to 2030.

What are the challenges and opportunities?

The supply chain and workforce challenges associated with the transition to a net zero energy system are already well described and understood.[6]

Our analysis has identified supply chain and workforce challenges across almost all technologies required to reach clean power by 2030. For example, delays in sourcing electrical components such as cabling, transformers and switchgear are hampering the delivery of network infrastructure, while the Offshore Wind Industry Council suggests more than 100,000 skilled roles are required to deliver 50 GW of offshore wind (up from 32,000).[7]

Stakeholders engaged as part of our Clean Power 2030 activity have reinforced that there are significant obstacles to accessing Original Equipment Manufacturer (OEM) supply chains, parts and materials coupled with limited domestic manufacturing and ports capacity. Securing engineers, digital specialists and construction workers is increasingly difficult due to the high demand for these skills across the economy, both domestically and globally.

Long-term policy certainty and greater collaboration were recognised as having potential to alleviate these challenges. Stakeholders also acknowledged the need to balance delivery at pace, which may depend on "buying in" parts and skills in the near term and developing local capacity which may deliver longer-term benefits to the British economy.

Actions to drive change

Our analysis and engagement with industry have identified three areas where action could help to alleviate supply chain and workforce pressures:

- **Providing consistent, long-term policy certainty and line of sight to funding to unlock investment.** In the near term, making swift investment decisions (e.g. on networks, the cap and floor or FOAK funding) can enable developers to sign supply chain contracts. Over the longer term, government's plan for clean power by 2030, SSEP and future carbon budget strategies can send the long-term signals for supply chain companies and workers to invest or train in Great Britain.
- **Exploring the opportunities for a more strategic approach to procurement and manufacturing.** This includes considering how the supply chain needs from the whole sector could be articulated centrally to investors and exploring further opportunities for central purchasing where this provides greater value for money and assurance over delivery. Finally, there may be opportunities to build strategic domestic supply chains where conditions in Great Britain mean this makes sense.

6 Green Jobs Taskforce (2021); Mission Zero - Independent Review of Net Zero (2023)
7 Crown Estate (April 2024)

- **Exploring a broad range of options to address specific skills gaps.** In the short term, this could include targeted options to address domestic workforce shortages in key sectors, such as offshore wind. A sector skills plan could help provide the trained workers the sector needs.

4.5 Digitalisation and innovation

Where are we now?

In recent years, advancement in technology and innovative practices have enabled progress towards digitalisation of the industry. Some industry participants have introduced a digital-native approach to traditional methods and the market has been adopting digitalisation at an increasing pace, although it remains nascent compared other industries. NESO too has enhanced its interaction with the wider industry through digitalisation, such as the modernised balancing mechanism, better open data practices and greater transparency via connections platforms. However, most if not all these efforts remain siloed within organisational or sector-specific priorities rather than whole system objectives.

The Energy Digitalisation Taskforce's call for a unified digital ecosystem has resulted in further progress; for example, DESNZ's Automatic Asset Registration Programme and the NESO-led pilot of data-sharing infrastructure (DSI), both of which are expected to enable rapid digitalisation opportunities by providing foundational digital capabilities.

Broader, sector wide innovation initiatives such as SGN's Intelligent Gas Grid and NESO's Crowdflex (demand flexibility) highlight some of the great work that is being done that can support a better understanding of a future digital grid, a fundamental step towards a clean power system.

Where do we need to get to?

To deliver clean power, we need a sector-wide strategic digitalisation plan that is actionable and delivered. This needs clarity of required outcomes, prioritisation of digital solutions and an aggressive delivery programme backed by policy and regulation to drive adoption and investment where it's most urgently needed.

While robust, safe and prompt data sharing is crucial, we must also focus on platforms and technologies that accelerate progress. One essential technology area is a strategic shift towards responsible AI for better decision making in energy planning, supply chain optimisation, market and domestic flexibility and forecasting. At NESO, we are launching a portfolio of transformative AI initiatives under two programmes (Volta and Vanguard) that focus on strategic energy planning, connections, control room operations and forecasting accuracy.

Our policy and regulatory systems must be able to realise the benefits of digitalisation by defining and revising rules and regulations where appropriate. For example, initiatives like the market-wide half-hourly settlement (MHHS) must be realised promptly to support the flexibility the system needs.

Further, innovation must target transformative change that the sector can mobilise behind, such as grid enhancing technologies and demand side signals. This should be supported by a unified approach to scale innovation through conducive policies, regulations and targeted support.

What are the challenges and opportunities?

The rapid global introduction of new technologies, both in the hardware cleantech space as well as in the digital realm (i.e. AI Large Language Models (LLMs)) presents both challenges and opportunities. Timely action is critical.

Current digitalisation and innovation efforts are often siloed and lack supportive adoption policies and pathways to operational use, making it difficult to scale ideas. Additionally, the sector faces challenges with data quality, availability and sharing, which restrict opportunities to develop and test new solutions.

To meet the clean power target, our analysis raised four key outcomes innovation is required to realise. These include better utilising existing grid capacity (for example, with super conductors), new flexibility sources and reducing overall demand through energy efficiency, as well as using AI to enable the above. It is vital that industry comes together and identifies, then prioritises the key outcomes in a coordinated way that enables market-driven innovative solutions to emerge.

Maximising commercial opportunities for digital products and services could further support wider industry digitalisation, as well as foster shared capabilities and products from innovative incumbents and start-ups.

Actions to drive change

Our engagement with industry experts and leaders has led us to identify five core actions that are crucial for transformative change:

- **Unified digitalisation plan:** The sector develops and delivers on a system-wide digitalisation strategy aligned with government's plan for clean power by 2030, ensuring cohesive progress and prioritisation.
- **Enhanced data sharing:** Focus on robust and scalable data-sharing infrastructure, supported by policies and investments that encourage widespread adoption across the sector.
- **Responsible AI integration:** Develop and implement responsible AI to revolutionise decision making in energy planning, supply chain optimisation, market flexibility, grid management and forecasting. This requires the support of clear policies, technology partnerships and investments.
- **Transformative innovation initiatives:** Prioritise transformational and scalable innovation projects that can significantly accelerate progress to clean power and beyond 2030. Support these initiatives with heightened financial, policy, regulatory and industry backing to ensure broad adoption.
- **Maximise commercial opportunities for digital products and innovation:** Identify and remove barriers to create a dynamic marketplace for digital products and services, leveraging open data sharing and transparency to foster innovation from all. For example, sharing of data on open data portals by NESO and other organisations has already led to AI and technology-based products to be available in the market to solve industry challenges.

These actions are imperative steps towards creating a resilient, innovative and digitally advanced energy sector.

4.6 NESO as a partner in delivering clean power

Where are we now?

NESO was established on 1 October 2024 as a publicly owned system operator, with new responsibilities in strategically planning the whole energy system and giving advice to government and Ofgem. The Government has also committed to establishing Great British Energy as a publicly owned clean energy company and the Clean Power 2030 Unit, tasked with delivering clean power by 2030.

Where do we need to get to?

Delivering clean power will require clarity on roles and responsibilities across key organisations in the energy sector. We need to ensure that our strategy and operations are aligned with government's plan for clean power by 2030 and work effectively with new institutions within the industry to drive forward delivery to 2030.

Where are the challenges and opportunities?

The whole energy system is interested in understanding the implications of a clean power plan and what this means for consumers, communities, networks and industry codes. Stakeholders are also seeking certainty on what organisations will need to do and how they will interact in delivering clean power. Many stakeholders want to see a coordinated delivery approach and governance arrangements that clarify the different roles and responsibilities for clean power.

NESO can act as an enabler for this greater collaboration and coordination and support the Government, Ofgem and the wider industry in providing clarity and establishing the frameworks for success.

Actions to drive change

To deliver on the clean power plan effectively and in a coordinated manner, we as NESO will:

- Work with the Clean Power 2030 Unit and Ofgem to agree NESO's role in delivering the clean power mission and how progress will be monitored, ensuring this is communicated to industry.
- Following the publication of government's plan for clean power by 2030, rapidly develop our implementation plan, setting out how we will play our part in delivering the clean power mission, including reviewing our own operations, processes, systems and investment plans across all areas to reflect on the impacts to ensure alignment with government's plan.
- Put in place an ongoing plan of engagement with industry and key stakeholders to ensure an ongoing conversation about NESO's role in the delivery of the clean power mission, in line with our broader remit as the strategic planner for the energy sector and provide advice to the Government.
- Work with Ofgem to continue to push forward energy code reform and help to identify the direction of future code changes for clean power provided through the Strategic Direction Statement (SDS) and assess how code change can be more effective and responsive to changing system or market needs.

Chapter 5. Costs and benefits of a clean power system

Delivering a clean power system by 2030 will support wider and longer-term efforts to reduce greenhouse gas emissions on the path to net zero and can bring multiple benefits without increasing costs to consumers.

Carbon: Our pathways reduce emissions of carbon dioxide to below the level in the Climate Change Committee's net zero pathway. The CCC's pathway is what is needed for the UK's Nationally Determined Contribution to the global Paris Agreement. Clean power can enable full decarbonisation of other sectors, such as transport and heat, through the adoption of electric vehicles and heat pumps, sending a clear and encouraging message to consumers that the technology they are adopting is clean.

Preparing for the 2030s: Our pathways make a step change in the deployment rates for renewables. This will ensure the system is able to keep pace with accelerated electrification through the 2030s, which is expected to add approximately 19 TWh per year to demand (equivalent to the output of around 5 GW of offshore wind). Progress on new technologies, such as carbon capture and hydrogen, is also essential for decarbonising the wider economy.

Investment: Clean power can support wider economic objectives. It will involve an annual investment programme of £40 billion plus that can support economic opportunities and new jobs across the UK. New networks and an abundant supply of clean power can enable growth in other sectors, including the growing digital and data economy.

Electricity costs: A crucial determinant of overall costs will be the impact of the Government's new approach to clean power. If it can provide greater visibility and greater confidence while unblocking barriers and easing delivery, there may be opportunities for costs to fall. Conversely, if supply chains become excessively stretched, costs could escalate. Taking a neutral view over these effects, our analysis shows that overall cost to consumers would not increase as a result of the move to a clean power system. Other factors will also impact electricity bills to 2030, including a reduction in legacy policy costs (as contracts expire) and energy efficiency improvements.

Wider benefits: A clean power system reduces Britain's reliance on energy imports, as well as bringing about environmental benefits, such as cleaner air and the potential to reduce pressures on water systems. More broadly, delivering clean power by 2030 would send a strong signal internationally, given the importance of clean power in global efforts to tackle climate change.

5.1 Climate, carbon and electrification

Carbon budgets

Clean power 2030 will significantly reduce carbon emissions in the British power sector. Power sector emissions in our pathways are 5 $MtCO_2e$ in 2030,[1] less than a third of those in a counterfactual case with no increased decarbonisation efforts[2] and reduced by more than 90% against 1990 emissions. Power sector emissions in 2030 are below the level in the CCC's pathways to net zero,[3] as required for the Nationally Determined Contribution (NDC) under the Paris Agreement and the Sixth Carbon Budget.

Achieving these emissions reductions in the British power sector would help close the current policy gap to meeting carbon budgets and the NDC, as identified by the CCC.[4] The CCC's latest progress report highlights the need to increase installation rates of renewables and for 'a credible overall strategy' for decarbonising the power sector. Action is also needed to address policy gaps in other sectors beyond power.

There is a corresponding drop in the carbon intensity of power generation, from over 140 gCO_2/kWh in 2023 to around 15 gCO_2/kWh in 2030 in our pathways. With carbon dioxide removal from biomass with carbon capture and storage (BECCS) netted off, net carbon intensity in 2030 would be around 5 gCO_2/kWh in the Further Flex and Renewables pathway (with one unit converted to BECCS) and below zero in the New Dispatch pathway (with two BECCS units).

Our clean power metrics are about meeting demand and reducing unabated gas to very low levels, so do not themselves require removal from BECCS. Removal from BECCS would help with wider efforts to reach the UK's NDC and carbon budgets. Decisions over the timing and scale with which to pursue BECCS should reflect the wider carbon strategy for meeting those targets, rather than be driven by the clean power goal for 2030.

Electrification

More broadly, clean power is the foundation for wider electrification and achieving net zero. Throughout our analysis for this report, we assume progress in the electrification of heat, transport and industry, including the use of clean power to produce green hydrogen and to support carbon removal. This aligns with the carbon budgets and path to net zero, as set out by the CCC. As a result, increasing amounts of energy demand are being met by a clean power system rather than carbon-intensive fuels such as gas, petrol or diesel, driving further emissions reductions beyond the power sector. The displaced emission in residential heating and road transport by 2030 could reach 17 $MtCO_2$/yr based on our clean power pathways.

Accelerating build rates now for renewables is crucial to enabling the continued growth of demand due to electrification, which is expected to add approximately 19 TWh per year, in the 2030s, to the demand, the equivalent of the output of around 5 GW of offshore wind.

1 Excluding emissions from combined heat and power and from waste to energy and before removal of emissions from BECCS. This aligns to the CCC's emissions accounting, which attributes these emissions to the industry and waste sectors respectively and identifies removals separately.

2 Carbon emissions in the Counterfactual reported here are slightly lower than carbon emissions in the Counterfactual in FES 2024. This is due to the higher carbon price assumption in the economic analysis for Clean Power 2030. The same carbon price was assumed for all pathways, so clearer conclusions can be drawn on how such pathways differ from the Counterfactual in terms of cost.

3 As reported in Progress in reducing UK emissions - 2023 Report to Parliament.

4 As reported in 2024 Report to Parliament

Climate leadership

The UK has a strong track record of climate leadership, including being the first country to pass comprehensive climate legislation and legally binding emissions targets through the Climate Change Act (2008). The UK was also the first G20 country to set a net zero target and hosted the COP26 climate talks in Glasgow in 2021, which were a focal point for global adoption of net zero targets.

A commitment to clean power by 2030 would solidify the UK's position as a global leader. Having been the first G20 country to phase out coal-fired electricity generation, aiming for clean power by 2030 would place the UK at the forefront among economies decarbonising from historically fossil fuel-based systems. This leadership is particularly significant given the crucial role of electricity generation in global net zero pathways.

5.2 Wider environmental and local community impacts

Impacts of building clean power infrastructure

Power projects have significant impacts on the wider environment and local communities, making it crucial to consider these factors in their development. Conducting thorough environmental impact assessments, engaging with stakeholders and affected local communities and implementing mitigation measures can help minimise negative impacts and enhance projects' sustainability. The planning and consenting process for new generating sites and infrastructure development covers local environmental factors such as noise, vibration, visual impact, flood risk, heritage, ecology and waste management.

In a clean power system, more power needs to be transported over greater distances from generation sites to areas of demand. This requires various technologies, such as overhead lines, underground lines and subsea cables. Each technology has distinct technical characteristics and environmental impacts:

- Overhead lines are usually the cheapest to build but have a visual impact through pylons and wires.
- Undergrounding is more expensive and involves environmental disturbance and potential damage during installation.
- Subsea cables are also costly and require connections to the onshore network, while posing challenges in the marine environment.
- Furthermore, long-term energy infrastructure may occupy valuable sites that could be used for other purposes.

However, it is possible to minimise and mitigate these impacts. Having a clear plan for clean power allows for considering the environment holistically across the programme, making choices that collectively minimise potential negative impacts to the environment and communities and can support solutions that are positive for nature overall.

The proposed plans in this report minimise new onshore infrastructure. We are prioritising reinforcement of existing infrastructure and have identified some marine cabling by 2030. This was a core part of the network plans that form the basis for proposals in this report: those plans consider ways to maximise and upgrade the existing network first and only once this reaches a limit are new lines considered. Strengthened engagement between developers, local authorities and communities is vital for building trust, addressing community concerns and incorporating them into network plans to minimise overall impact on local people.

Air quality, water and land and seabed use

Fossil fuel-based and biomass power plants emit air pollutants, such as particulate matter (PM), SOx and NOx from their combustion processes. These have damaging effects on human health and the environment. Shifting to renewable energy sources reduces pollution and improves air quality, leading to better public health and environmental outcomes. Electrification of heat and transport further reduces air pollution from boilers and vehicles, particularly in urban areas.

Water is a valuable resource that is expected to be under increasing stress as the effects of climate change progress. A shift to clean power brings benefits for water since thermal generation technologies, such as gas-fired generation, can have higher water requirements for cooling compared to wind and solar. On the other hand, power CCS and CCS-enabled hydrogen production consume significant amounts of water.

Overall, a clean power system can reduce pressure on water supplies. The CCC anticipates that shifting to low carbon electricity generation could lead to a 10% decrease in water use in power generation by 2050 (including electrolysis). This is contingent on new nuclear capacity using sea water over fresh water, while different areas of the country will face different challenges, including availability of salt and fresh water and water quality. Accelerated construction timelines for new generation and network build may also place pressure on water systems. Consideration and planning for water availability, quality and efficient use will be important as Great Britain progresses towards a clean power system. Designing plants to maximise water efficiency, such as using seawater for cooling, can also help minimise water-related challenges.

The use of land and the seabed need to be considered for new generation and network assets. A 25 GW increase in offshore wind could occupy approximately 8,600 km^2 of sea space.[56] Offshore wind farms may cause seabed disturbance and noise pollution during installation, while floating wind farms reduce these impacts but may pose risks to marine habitats due to anchoring systems.[7] However, potential positive environmental impacts have been identified as well, such as the creation of artificial reefs that attract more marine life than natural reefs.[8] Onshore wind with a capacity of 27 GW would require around 3,000 km^2 of land, representing 1% of the total Great Britain land area. Approximately 99% of this land area would remain available for other uses between the turbines, allowing for shared land use, such as agriculture and pasture. Only a small portion, approximately 30 km^2, would be occupied by the turbines.[9]

In the longer term, the Strategic Spatial Energy Plan (SSEP) will provide an understanding of the spatial requirements of Great Britain's future energy system by mapping the quantities and location of energy infrastructure, while taking into account cross-sectoral demands on land and sea. This includes considering requirements for agricultural production, transport, water availability and nature recovery to help inform decision making.

5 AURES_II_case_study_seabed_auctions.pdf
6 Scotland awards seabed rights for massive amounts of offshore wind, most of it floating | WindEurope
7 670791d6196cc689841fc02e_ODI_Offshore Wind Energy Industry Review WEB_compressed.pdf
8 Reviewing the ecological impacts of offshore wind farms | npj Ocean Sustainability
9 How can landowners harness onshore wind power opportunities -Towers & Hamlins

5.3 Investment

Gas-fired power generation costs are primarily driven by fuel and carbon emissions, with some capital investment, while renewable costs are dominated by upfront capital investments. A clean power system therefore involves a shift from operating costs, largely from imports of gas to capital cost, requiring significantly increased investment.

Our pathways for a clean power system in 2030 envision considerable levels of investment, some of which is already underway, driven by current contracts, commitments and expansion plans for generation, storage assets and network infrastructure. In the clean power pathways, offshore wind represents the largest component of investment, with average annual investment of around £15 billion from now to 2030. Networks, onshore wind, solar and storage are other large investment items, though each less than half the scale of offshore wind.

Average annual investment of over £40 billion to 2030 represents a material increase on investment levels in recent years, with average annual investment around £30-35 billion higher over 2025-2030 than over 2020-2024. This is an increase in investment of over 1% of GDP for the entire economy. Wider electrification efforts will further drive national investment.

The main differences in investment between pathways reflect differences in capacity assumptions, as set out in Chapter 3, with similar onshore network investment assumed across scenarios. There are significant uncertainties around the precise level of investment, given wider uncertainties over project costs, as illustrated by significant variations in contracted strike prices over recent renewables auctions. We present relatively cautious (high) estimates reflective of the higher prices in the most recent auction.

Most of the investment is expected to come from the private sector, highlighting significant local economic and job opportunities. Furthermore, this investment also leads to substantial savings in operating costs, as explored in the next section.

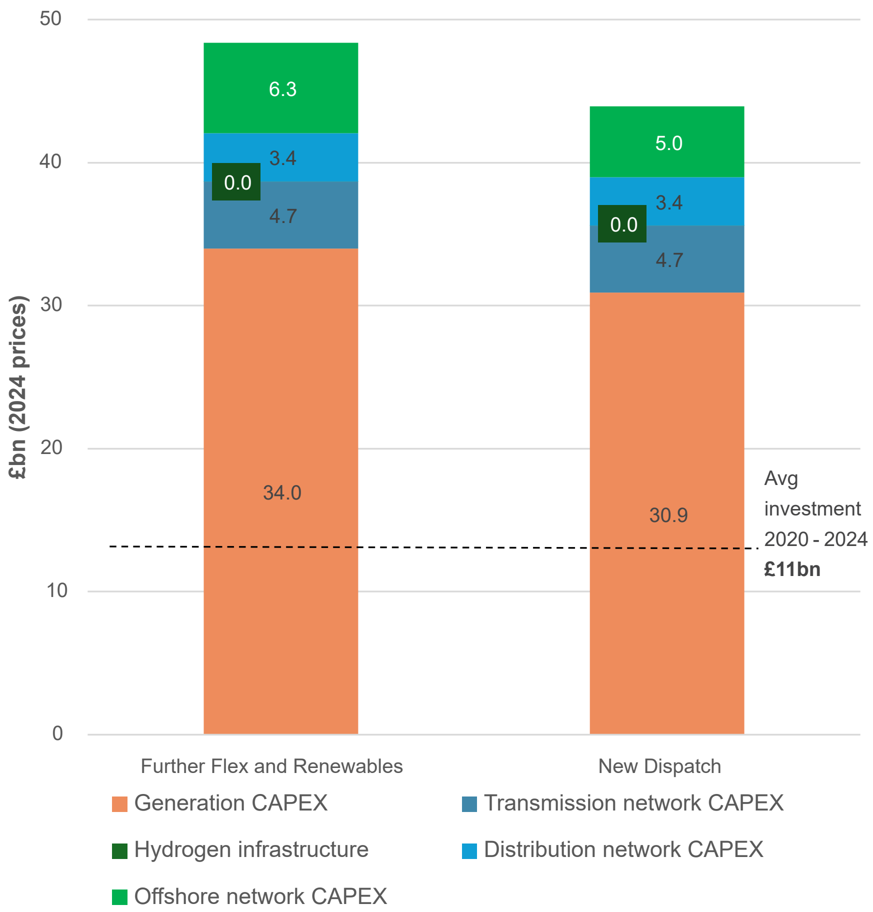


Figure 19: **Average annual investment system costs in clean power pathways 2025-2030**

5.4 Costs

While at the macroeconomic level, the shift to clean power will be seen as an increase in investment, for consumers it will be felt through its effect on electricity prices and bills. These will reflect the underlying costs of the electricity system, just one part of which is investment (or 'capital') costs, which will be recovered through sales of electricity per unit (for example, per kWh, which is roughly the amount of electricity needed to run a dishwasher cycle or a laptop all day, or per MWh, which would power a household for around four months).

Approach to our cost analysis

In our cost analysis, we focus on how electricity costs per unit can be expected to change in a clean power system. We compare how costs will change compared to the current system, how they may differ between our pathways and relative to the Counterfactual with no acceleration in delivery. We break down our cost estimates between their component parts, which include:

- **Generation costs.** The combined capital and running costs of the power plants providing generation to the system, which we break down into three components:
  - **Capacity costs.** These include the annualised investment cost of building new generating and storage capacity and the costs of operating and maintaining it, but not the fuel or emissions costs attached to use of fuels such as gas or biomass.
  - **Fuel costs.** The cost of buying and burning fuel in the plant to generate electricity.
  - **Carbon costs.** The cost of buying emissions permits under the UK's Emissions Trading Scheme.
- **Net import costs.** The cost of imports and income from exports of electricity bought from and sold to neighbouring markets over interconnectors.
- **Network costs.** The annualised capital costs and operating costs of Great Britain's transmission network,[10] distribution network, offshore network, hydrogen infrastructure for power generation and CO_2 transport and storage, which are utilised by the power generation technologies under consideration.
- **Constraint costs.** Thermal and voltage/stability costs, which make up the majority of the balancing costs and the ones most likely to change as the system develops.

Our pathways to clean power involve increased electrification, which leads to a higher share of British energy demand being met by power, displacing costs in other parts of the energy system. For electric vehicles, this is likely to reduce energy costs, as it could for heat pumps depending on prevailing gas prices. However, we do not attempt to estimate these effects in this work, which focuses on the costs of electricity.

How costs flow through to prices, and ultimately bills, will depend on policy design. Under current policy arrangements, there will tend to be an increase in the cost of support mechanisms such as contracts for difference (CfD), with offsetting falls in wholesale power costs. This reflects the change in underlying costs, with renewables having lower running costs and higher upfront costs. While we can identify some expected changes that will affect prices (not just costs), we do not attempt to estimate an actual electricity bill given the heavy dependence on policy choices.

10 Onshore enablers were not included in the analysis due to challenges in obtaining the relevant data.

Overall system costs in a clean power system

In estimating how costs will change compared to today's system, there are multiple effects to take account of. Power will be generated from different means with different underlying costs. More will be generated, not just to service growing demand, but because some will be curtailed, exported or lost during storage cycling. Also, there are costs to be covered in expanding the networks and storage infrastructure.

Looking across these effects in 2030, our analysis suggests a slight increase in total system costs for our New Dispatch pathway, equivalent to around £10 /MWh. This overall cost can be broken down between the different elements:

- **Cost of generation.** Contract prices for wind and solar in recent auctions (£71-83/MWh) are an indicator of the underlying per MWh costs of these new plants and of what consumers will pay for them. These are lower than the cost of generating from existing gas-fired power stations (£123/MWh at current projected 2030 gas prices and carbon prices)[11]. Combined with higher costs assumed for dispatchable power and recognising that not all the displaced generation is from gas, this shift implies a system-wide reduction in the average costs of generation of around £15 /MWh.
- **Curtailment.** The clean power pathways involve higher levels of curtailment when variable and firm generation combined is greater than needed to match demand. This means that, although each unit of generation is lower cost, more of it is needed, pushing up the average cost of meeting demand. We assign no value to this curtailed generation but note there may be opportunities for new flexible demand sources to put this unused clean electricity to positive use. Curtailment adds around £5 /MWh.
- **Net Exports.** Our pathways to clean power see Great Britain become a net exporter of electricity. Exports will be greatest at times of high renewable output, which under current arrangements imply relatively lower prices. So, while exporting will recoup some costs compared to curtailment, it will still involve some net cost to the British system overall. This effect adds around £5 /MWh.
- **Storage.** Our pathways to clean power build a large amount of new storage and use it regularly, which involves round-trip efficiency losses. These are important in reducing the overall cost of the system, for example reducing curtailment and the need for high-cost dispatchable and gas-fired generation. However, the investment and round-trip losses involve new costs, which together increase system costs by around £10 /MWh.
- **Network and constraint costs.** The major expansion in the network in our clean power pathways involves a large investment that will be paid back through increased charges per MWh. Also by 2030, some existing costs will be paid off and others will be spread over a larger demand base. Constraint costs will also change, although provided the full planned network expansion is delivered these need not increase to 2030. Together, these imply rising costs of around £5 /MWh.

Our cost estimates are anchored on the latest auction and DESNZ's published generation cost estimates, with more details set out in Annex 4. We also consider the possibility that costs could differ from these, including using high and low sensitivities for capital costs. The latest renewable auction saw higher prices than the previous one. Should costs fall back towards earlier contracted levels then system costs for a clean power system would be lower than our estimates.

11 **All the cost and price estimates in this report are in a 2024 price base, stripping out the effects of inflation.** Our 2030 gas price projection is around 100 pence/therm, as used in the Future Energy Scenarios. Our carbon price projection of £147/tCO_2 is based on independent forecasts, as used in the Future Energy Scenarios, plus a UK carbon price underpin of £25/tCO_2.

A particular risk we consider is that the need to contract and then build a large amount of generating capacity in a short period, especially for offshore wind, could lead to an escalation in CfD strike prices. Our analysis is based on an assessment of the pipeline of potential offshore wind projects and the potential for inframarginal rents from the CfD auction.[12] In an extreme case where all offshore wind projects are paid in line with the costs of the most expensive project and costs are further pushed up 25% due to supply chain pressures, average costs of the electricity system could increase by a further £15 /MWh. To keep overall costs down, it is therefore vital that an element of competitive pressure is maintained and that high inframarginal rents are avoided.

Impact of clean power on consumer energy bills

While our system cost analysis points to a slight increase from a move to a clean power sector, there will be direct benefits offsetting these, suggesting that overall costs to consumers would not increase from the shift to a clean power system (as summarised in Table 4 below). Specifically, in our clean power pathways, gas sets the price less frequently. The resulting reduction in wholesale prices would lower payments and infra-marginal rents for generation with low marginal costs, such as existing nuclear plants and those receiving Renewable Obligation Certificates (under current market arrangements). Our analysis points to this reducing average electricity prices by around £10 /MWh under a clean power system. This reduction would not happen without the shift to clean power.

Further bill reductions can be expected as levies for older renewable support schemes, such as the Renewables Obligation and Feed-in Tariffs, reach the end of their contractual periods. Some of the plants with these contracts may need new support for repowering, but this would be at much lower levels than in the legacy contracts and could come with an opportunity to increase output relatively cheaply. This effect would happen even without a shift to clean power and would reduce average prices by around £10 /MWh by 2030, with continuing falls through the 2030s.

There are also additional opportunities to reduce bills through energy efficiency. For example, our clean power pathways involve an efficiency improvement in lights and appliances for households that sees typical electricity usage drop by c. 5-10%.

More generally, bills will be affected by gas and carbon prices, though the move away from gas as the predominant price setter for electricity would greatly reduce the risk of major price spikes. Price spikes are passed on to consumers, as seen during the gas price crisis of 2022, when energy bills increased dramatically due to high gas prices. While gas prices fell into 2023, prices remained very high as forward hedging locked in higher costs. As a result, the electricity price cap for 2023 was between £150 -200 /MWh higher than implied by a system cost analysis akin to those in this chapter (consumers were protected from much of this cost through the Energy Price Guarantee, with the cost falling on the public finances instead).

While these sorts of very high price spikes are hard to predict, the shift to clean power would greatly reduce the exposure for consumers and the public purse.

The translation of clean power costs into bill impacts depends on policy choices, including how and when costs are reflected in prices and how they are distributed among different consumers. These choices will affect both current and future consumers, as well as the allocation of costs between gas and electricity consumers. The impact on bills may vary among consumers, such as those with electric vehicles or electric heating and those who have more flexibility in their electricity usage. Potential distributional impacts across residential and business users should be carefully considered when designing policies in this area.

12 Our analysis was developed with Baringa using their proprietary offshore wind CfD auction model. Infra-marginal rent refers to the extra payment (above costs) received by lower cost projects that get paid the same strike price as the more expensive projects that set the clearing price in the CfD auction.

Table 4: Costs in 2030 in the New Dispatch pathway compared to today's system (figures rounded to the nearest £5/MWh)

Cost component	Direction of impact	New Dispatch v today's system
Average cost of generation, per MWh produced	↓	- £15 / MWh
Higher curtailment (at times of 'excess' wind/solar)	↑	+ £5 / MWh
Exporting at low cost (at times of 'excess' wind/solar)	↑	+ £5 /MWh
Building storage and round-trip losses	↑	+ £10 / MWh
Grid expansion and constraint costs	↑	+ £5 / MWh
		Total = + £10 / MWh
Bill components resulting from clean power pathways		
Merit order effect reducing infra-marginal rents	↓	- £10 / MWh
Other bill changes to 2030		
Falling legacy policy costs	↓	- £10 / MW
Energy efficiency improvement in typical households	↓	c. 5-10% consumption

Cost comparisons between clean power pathways

As well as exploring how costs change compared to today's system for our clean power pathways, we also explore the differences between pathways and against the Counterfactual that falls short against national carbon targets. We find similar costs across all options, within the bounds of uncertainty, as set out in Figure 20 on the following page.

If gas prices remain similar to those of mid-October 2024 (around 100 pence/therm) and carbon prices rise in line with our projection, costs would be slightly lower in the Counterfactual. However, this would be mostly offset by the merit order effect described above, implying that there is no material cost advantage for the Counterfactual unless gas and/or carbon prices are at materially lower levels.

Between the clean power pathways, New Dispatch is expected to be slightly lower cost. This reflects the reduced investment in renewables and storage and lower curtailment and exports, as it has a greater ability to match dispatchable generation to demand. However, there are other factors to consider (as set out in Chapter 3), such as higher continuing exposure to gas prices (albeit still much lower than today).

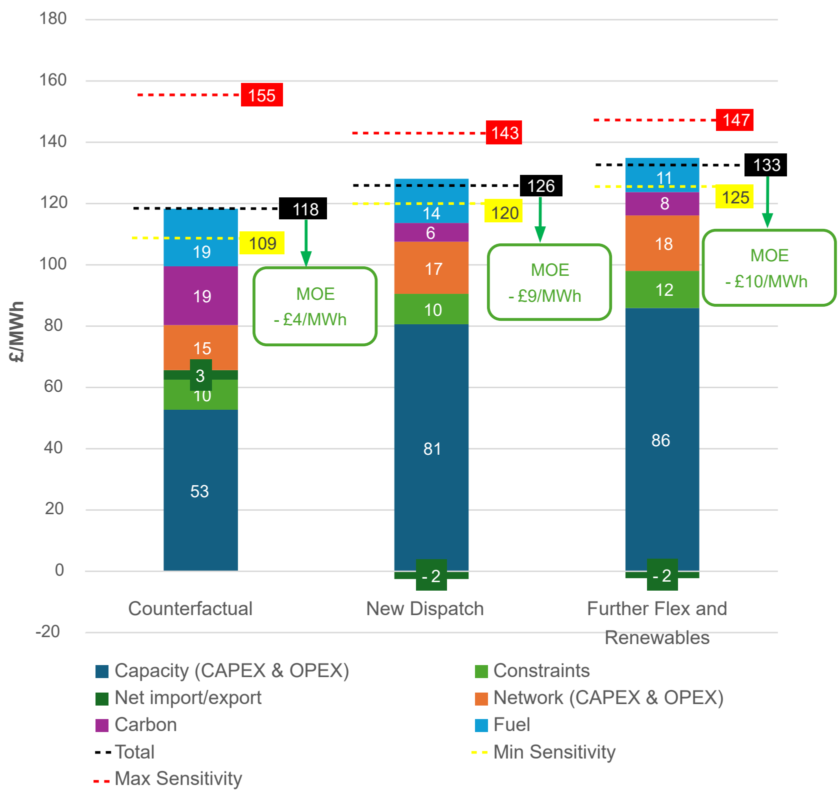


Figure 20: 2030 Annuitised system costs per useful unit of electricity with sensitivities

MOE = Merit order effect, reducing payments to some older plants

Our sensitivity analysis assesses the impact of key assumptions, including gas price projections, investment costs and CO_2 transport and storage costs. The uncertainty bars demonstrate the range of uncertainty, with the Counterfactual being particularly sensitive to gas price assumptions. For the clean power pathways, the range between the lower and upper bounds is smaller, given less sensitivity to gas prices, which outweighs greater sensitivity to capital cost assumptions.

There may be scope to further optimise the pathways to reach clean power at lower cost. For example, more demand side response could cut costs associated with curtailment, exports or storage losses, as could a further rebalancing from renewables to dispatchable generation. It may be also possible to have less, or more efficient, storage without compromising the high value it brings to the system.

We also note that there are wider opportunities and risks attached to the clean power mission to the extent that the mission can unblock barriers to delivery. There may be opportunities to reduce costs, to access cheaper capital and/or to increase competition. However, there are also risks that the accelerated pace reduces competitive pressure, increases supply chain tightness or otherwise increases costs. Managing these risks and opportunities will be a key challenge for the Clean Power 2030 Unit.

Protection from gas price volatility

The unit system costs projections above are based around our central gas price case, assuming gas prices in 2030 remain at similar levels to those in 2023.

If gas use for power generation remained at the levels of 2023 and gas prices were raised to the peak levels in 2022 (300 p/therm on average), this would add around £12 billion to annual electricity system costs in Great Britain. In the partly decarbonised Counterfactual, we estimate this gas price shock would add around £10 billion, while in the clean power pathways it would only add around £5 billion. The flow-through to electricity bills is likely to be more exaggerated given the dominant role of gas-fired generation in price setting in the Counterfactual, compared to in our clean power pathways for 2030 (Figure 21).[13]

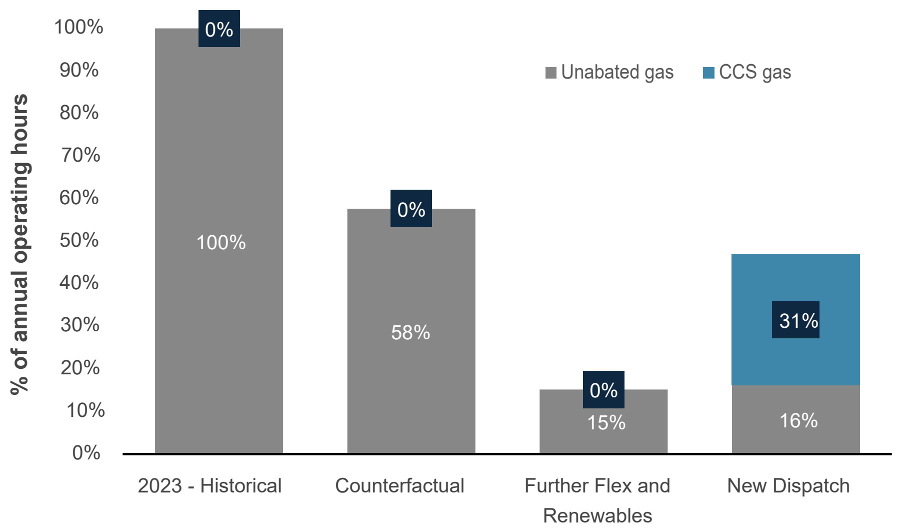


Figure 21: **Percentage of annual operating hours where gas-fired generation is used**

Gas market impact

The gas volume required to supply the gas-fired generation fleet in our clean power pathways is relatively small, compared to typical historical or current gas flows both within the British gas network and in a global market. It is not anticipated that clean power activity would lead to any significant impact on the day-to-day functioning of the gas market. Situations involving a significant national-scale increase in gas-fired generation can be anticipated in advance, based on weather conditions, allowing the gas market to price in the expected rise in gas demand.

In addition to the gas demand from gas-fired generation, there will also be a level of gas demand for hydrogen production and, more widely, for heating. Therefore, gas assets will remain a vital part of national infrastructure for some time, even in a clean power world.

13 Figure 21 shows the share of hours in which gas-fired generation operates at all. It will still be only a fraction of total generation even in these hours.

5.5 Reducing Great Britain's reliance on energy imports

Shifting to a clean power system by 2030 will significantly reduce Great Britain's reliance on energy imports for electricity generation, through several means:

- Great Britain is expected to transition from being a net importer of electricity in 2023 to becoming a net exporter by 2030.
- The amount of gas-fired and biomass generation is reduced in our clean power pathways, reducing the need for imported gas and biomass as fuel sources.
- The use of clean power for electrifying heating and transportation will further displace imports of gas and oil, reducing overall reliance on imported energy in the British energy system. However, the heating and transport sectors will still require significant amounts of gas and oil, with continued reliance on imported energy supplies.

As a result, even though Great Britain's production of oil and gas is expected to fall from now to 2030, reliance on imported fuel for power generation will reduce significantly by 2030 compared to today (see Figure 22), returning to levels last experienced in the mid-2000s.

How imports and exports are affected more broadly will depend in part on how far expansion of supply chains takes place within the country or overseas.

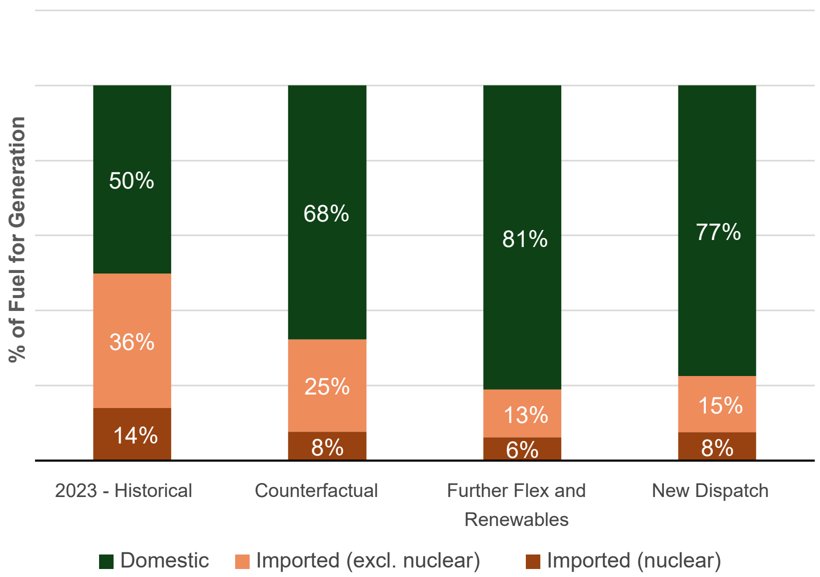


Figure 22: Split of imported and domestic fuel for generation

Wind, solar and hydro are considered British energy resources. Generation from fossil fuels and biomass are split between British and imports in line with the economy-wide shares for these fuels. Nuclear is separately identified, as its fuel is imported, but is a very small percentage of overall nuclear generation costs.

5.6 Impact on the wider British economy

The power system is a key enabler of sustainable economic growth. Households and businesses rely on access to electricity for their day-to-day needs, while increasingly demanding clean power. The transition to a clean power system by 2030 will have significant impacts on the wider national economy. While quantifying these impacts can be challenging due to the importance of wider factors, we have considered some of the key macroeconomic effects:

- The **large increase in capital investment** for clean power could potentially boost GDP and employment rates either locally or across Great Britain, but this is dependent on wider macroeconomic policy and supply side capabilities to respond to this scale-up in demand.
- The transition to a decarbonised power sector by 2030 presents a significant economic opportunity for creating and expanding **green jobs**. The low carbon energy and renewables sector in the UK has already witnessed significant growth, with employment reaching 74,000 in 2022, an over 20,000 increase from previous estimates in 2015.[14] This upward trend is expected to continue at pace. The Climate Change Committee's Net Zero Workforce (2023)[15] report presents a wide range of employment opportunities, projecting between 4,000-192,000 jobs in low carbon energy, CCS and hydrogen.
- Transitioning to a clean power system is likely to lead to a shift in the UK's **trade position**, as the country changes from a net importer to an exporter of power and reduces natural gas imports. However, this may be offset by higher imports, for example of parts and materials, influenced by the increase in capital investment.
- **UK competitiveness** will be impacted by the changing difference between British and overseas electricity prices. If consumer and industrial electricity bills reduce under the clean power pathways, it can provide economic benefits, particularly for large industrial power users, making them more competitive internationally. This of course depends on wider policies and how European power prices evolve.
- The transition to a clean power system presents **industrial opportunities**, including direct investment, a stable market for supply chains and opportunities for major power users seeking clean energy.
- **Public finances** will see some changes due to investment in clean power, but the majority will be delivered from the private sector, backed by contracts that are paid for from energy bills. Some of the potential public spending requirements, for example for CCS, have already been identified and funded by the Treasury. Reduced emissions from a clean power system decrease permit demand in the power sector's Emissions Trading Scheme, but these permits are available for sale to other sectors. Given expected price increases by 2030, the power sector is projected to raise £1.5-2 billion in 2030 (compared to £5.8 billion in 2023) even in a clean power pathway. At the same time, revenues from the Crown Estate will continue to grow due to offshore wind leasing.

5.7 Conclusion

Our analysis describes pathways to a clean power system for Great Britain by 2030 that involve a major investment programme without increasing costs to consumers, while largely breaking the link with volatile international gas prices. As well as being a major direct contributor to UK carbon targets, it would enable accelerated progress in other sectors. And it would involve development of the tools, policies and momentum to drive through 2030 to meet the ongoing challenges ahead.

This report has set out potential pathways for clean power. The Government will now reflect on those pathways and put forward its own plan. Then the hard work will begin to deliver against that plan while ensuring good value for consumers, developing opportunities across the country and building public trust and support for the clean power mission.

14 ONS Low Carbon and Renewable Energy Economy (LCREE)
15 CCC (2023) – A Net Zero Workforce

Glossary

AGR	Advanced Gas-cooled
AI	Artificial Intelligence
ASTI	Accelerating Strategic Transmission Investment
BECCS	Bioenergy with Carbon Capture and Storage
BM	Balancing Mechanism
CAPEX	Capital Expenditure
CCC	Climate Change Committee
CCS	Carbon Capture and Storage
CfD	Contract for Difference
CHP	Combined Heat and Power
CO_2	Carbon Dioxide
CSNP	Centralised Strategic Network Plan
DACCS	Direct Air Carbon Capture and Storage
DESNZ	Department for Energy Security and Net Zero
DNO	Distribution Network Operator
DSI	Data Sharing Infrastructure
DSR	Demand Side Response
ENCC	Electricity National Control Centre
EPR	European Pressurised Reactors
ESO	Electricity System Operator
ESRS	Electricity System Restoration Standard
EV	Electric Vehicle
FES	Future Energy Scenarios
FOAK	First of a Kind
GETS	Grid-enhancing Technologies
GW	Gigawatt
GWh	Gigawatt Hour
HT	Holistic Transition (Future Energy Scenarios pathway)
HVDC	High Voltage Direct Current
IBR	Inverter-based Resources
IDNO	Independent Distribution Network Operator
LAES	Liquid Air Energy Storage
LDES	Long Duration Energy Storage
LLM	Large Language Models
MHHS	Market-wide Half-hourly Settlement
MWh	Mega Watt Hour
NDC	Nationally Determined Contribution
NESO	National Energy System Operator
NTS	National Transmission System
OEM	Original Equipment Manufactuer
OPEX	Operating Expenditure
PHES	Pumped Hydro Energy Storage
PP	Percentage Points
REMA	Review of Electricity Market Arrangements
SMR	Small Modular Reactors
SPS	Strategy and Policy Statement
SSEP	Strategic Spatial Energy Plan
TO	Transmission Owner
TWh	Terawatt Hours
V2G	Vehicle-to-Grid
VirtualESZ	Virtual Energy System

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