Pathways and challenges to decarbonising the GB power sector

Prepared for Policy Exchange

March 2024

About this report

Aurora Energy Research has been commissioned by Policy Exchange to conduct analysis on the pathways to Net Zero in the power sector in Great Britain. The analysis is designed to present technical routes to reach Net Zero power on different timelines and highlight their practical limitations and the barriers to their implementation.

Three scenarios are presented in this report:

- BAU – a scenario following the current trajectory of policy development and market environment for the GB power sector generally aligned with Aurora's regularly published Central scenario
- NZ30 – a scenario aiming to deliver Net Zero in the power sector by 2030
- NZ35 – a scenario aiming to deliver Net Zero in the power sector by 2035

The Net Zero scenarios represent technical routes to reach the Net Zero power targets, not predictions of how the sector will develop. Analysis of these pathways indicates that power sector Net Zero by 2035 is possible, but not plausible unless coherent policy action, market design and financial support is enacted at a large scale and high speed; with power sector Net Zero by 2030 being an infeasible target.

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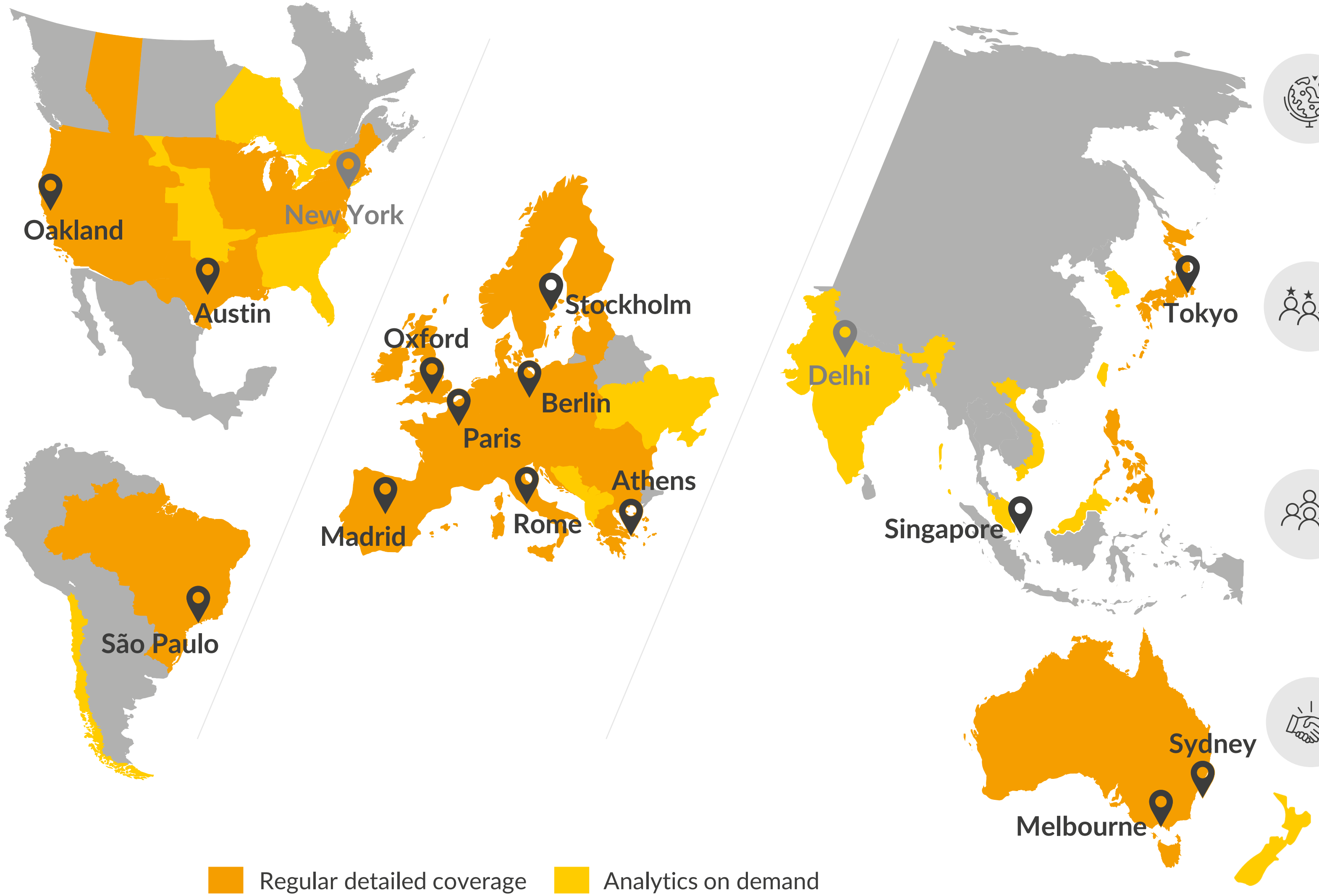

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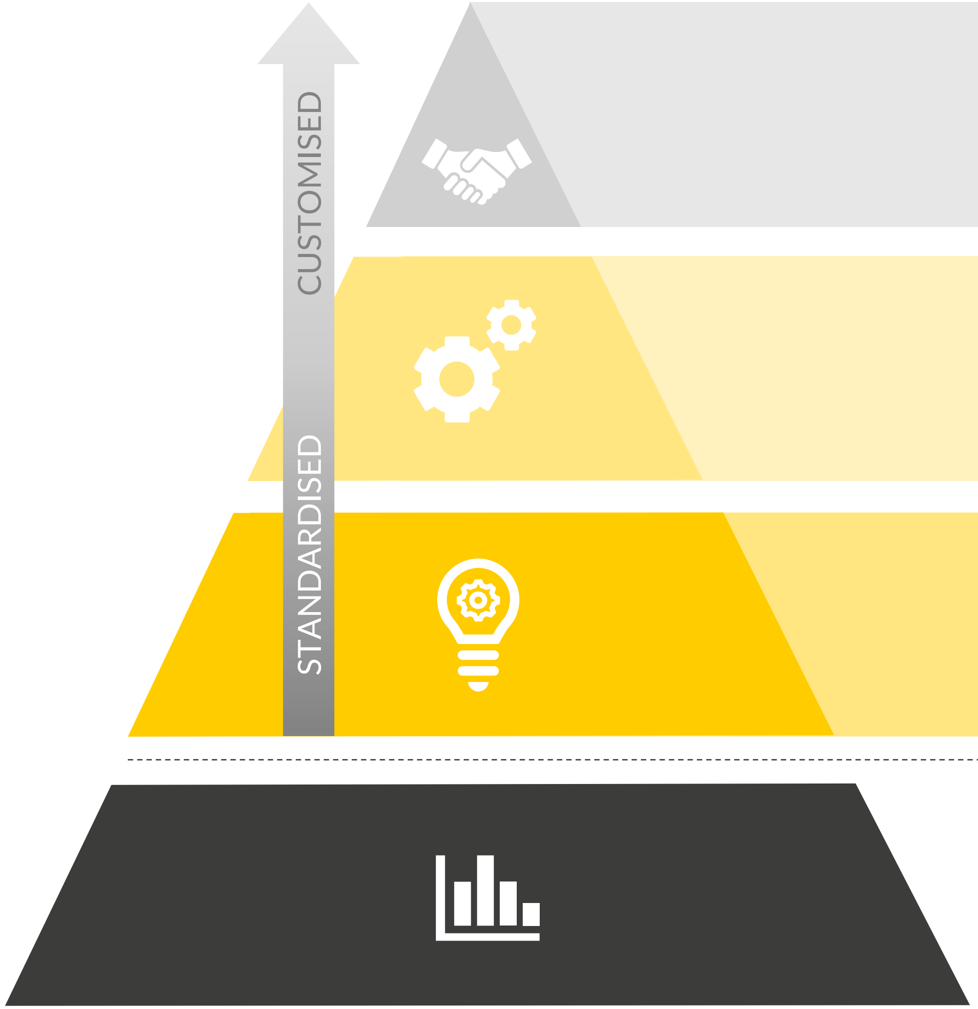

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Developed over 10 years, 40+ dedicated modellers

Source(s): Aurora Energy Research

Contents

Technological and policy barriers are unlikely to be overcome to reach Net Zero in the power sector within the timescales of current political targets

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Technology deployment is essential to reach Net Zero…

1. **Accelerated renewable capacity buildout is essential to meet Net Zero**
   Over 70GW (c. £105bn capital) of additional renewables capacity required
2. **Flexible technologies and long-duration storage are required to complement renewable buildout**
   Reaching at least 14GW of batteries and 8GW long-duration storage capacity
3. **Network build must accelerate to match renewable capacity to ensure generation can be utilised**
   Transmission capacity between Scotland and England must increase by 14.5 GW
4. **To meet Net Zero and ensure security of supply, negative emissions technologies are required to offset unabated gas generation**
   3.3GW capacity of biomass with carbon capture and storage by 2035

… however, this must be accompanied by policy reform

1. **Planning and development times must be decreased to enable decarbonisation through the rapid deployment of renewables and grid upgrades**
   Reduction in planning times and development hurdles for projects
2. **Market design must be transformed to suit a renewables and flexible generation led system**
   Access to revenue streams for new technologies and market reform certainty
3. **Clear routes to market and access to revenue streams with policy backing will be required to mobilise financing**
   Implementation of planned support schemes to enable large capital deployment
4. **System integration of renewables and flex-led system**
   Transformation of system management as operability shifts with new composition

Source(s): Aurora Energy Research

Despite ambitious political targets, achieving Net Zero in the power sector under the current policy and market environment is unlikely before the 2050s

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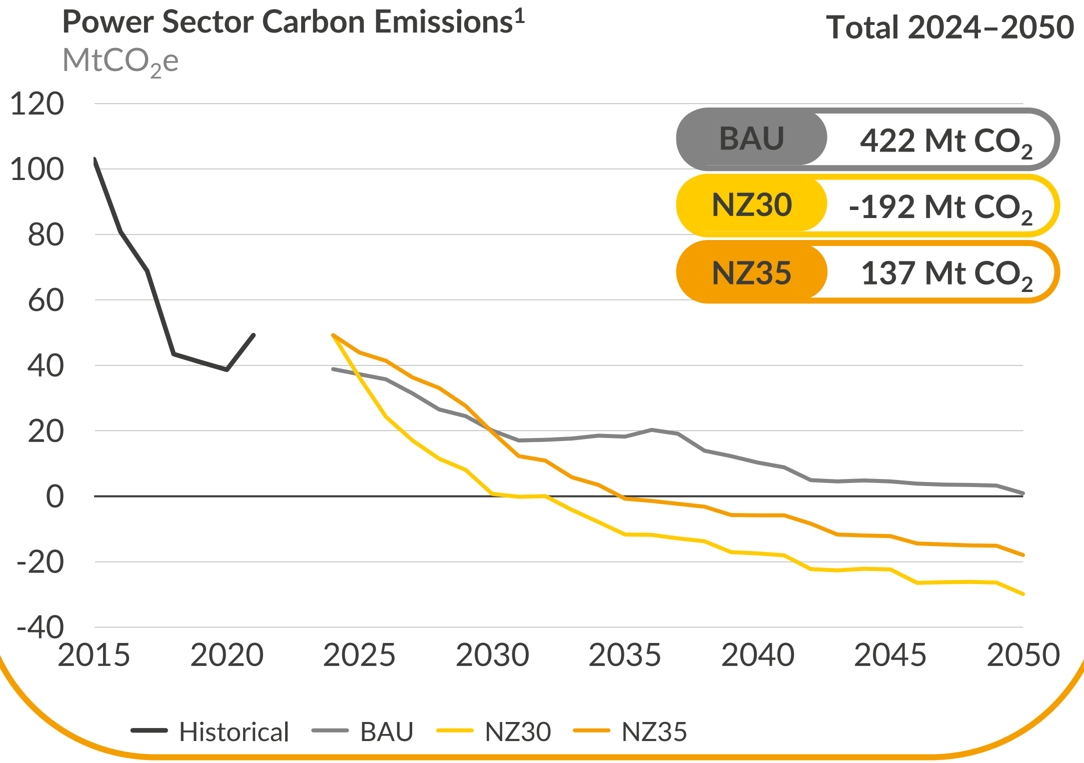
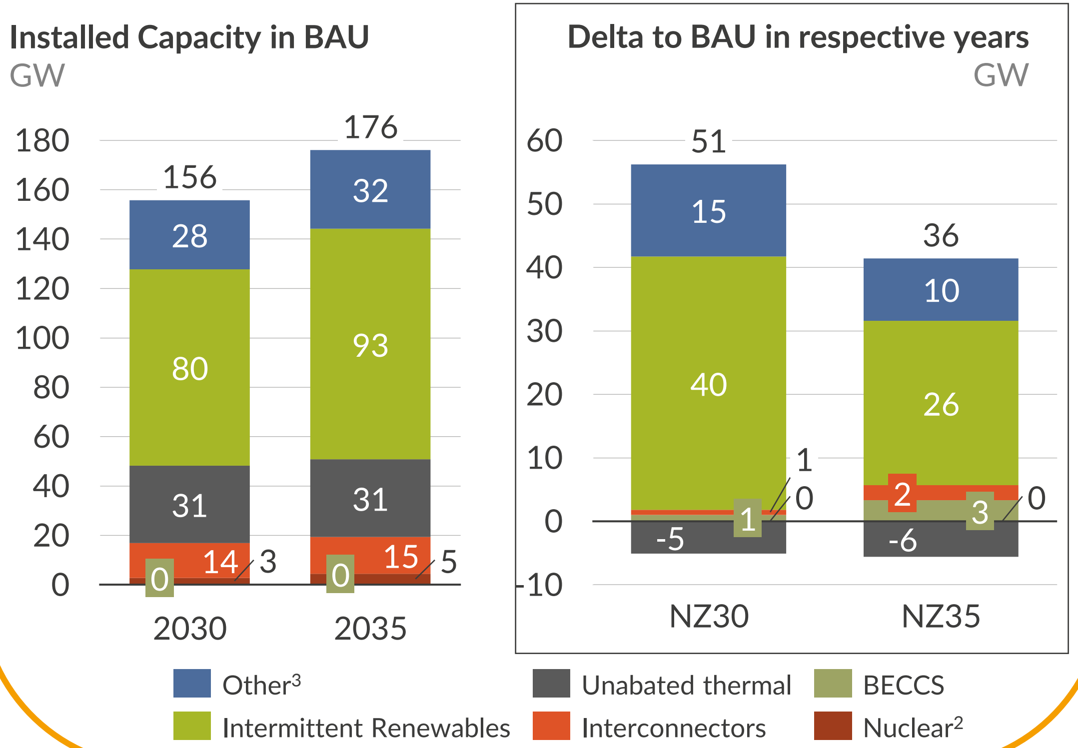
Net Zero power is unlikely to be reached before the 2050 given current policy direction

- Under current policy, GB is not set to reach Net Zero until 2051
- Net Zero power could be reached by 2035, although significant new interventions are required. Achieving Net Zero power before this is likely to be infeasible due to limited time to achieve the transformation



Reaching Net Zero in 2030 or 2035 would require extensive system change

- Net Zero in 2035 would require a rapid increase in renewables deployment alongside enabling technologies, including BECCS
- However, Net Zero in 2030 would require unrealistic acceleration of renewables deployment, and direct intervention to restrict unabated gas



1) Includes negative emissions from BECCS assuming a factor of -941 gCO2 /kWh; BECCS capacity initially offsets emissions, then generates greater negative emissions as the system decarbonises (renewables, gas CCS, hydrogen). 3 GW of additional BECCS expected post-2030/2035 for growing demand.; 2) Assumes Hinkley Point C, Sizewell C and Bradwell B delays, with an upsizing of expected future capacity; 3) Includes capacity from storage, demand-side response (DSR), hydrogen peaking plants, hydrogen CCGTs, biomass and gas CCS .

Source(s): Aurora Energy Research

Intensive and accelerated policy support is required for achieving Net Zero Power

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Extensive policy intervention and central support is required to reach power sector Net Zero

- **Accelerate Development:** Streamline planning and development processes to reduce early-stage project timelines.
- **Stabilise Markets:** Implement market design reforms that provide consistent revenues for flexible technologies and predictable network charges for renewable developers.
- **Invest in Innovation:** Increase policy support for early-stage technologies, including finalizing the long-duration energy storage (LDES) mechanism and expanding carbon capture and storage (CCS) clusters.
- **Address Operability:** Proactively address operational challenges in a system increasingly dominated by renewables and flexible generation.
- Coherent policy action, market design and financial support if enacted at a large scale and high speed **could potentially enable a Net Zero 2035** target to be reached if legislative action is taken imminently
- **Net Zero power in 2030 cannot realistically be reached**, as the combination of legislative timeline, planning, permitting and project development and supply chain limitations means that it is infeasible for the necessary system overhaul to be completed in this timeframe

Source(s): Aurora Energy Research

All scenarios result in a diverse power system, however matching network build is necessary to enable renewables deployment

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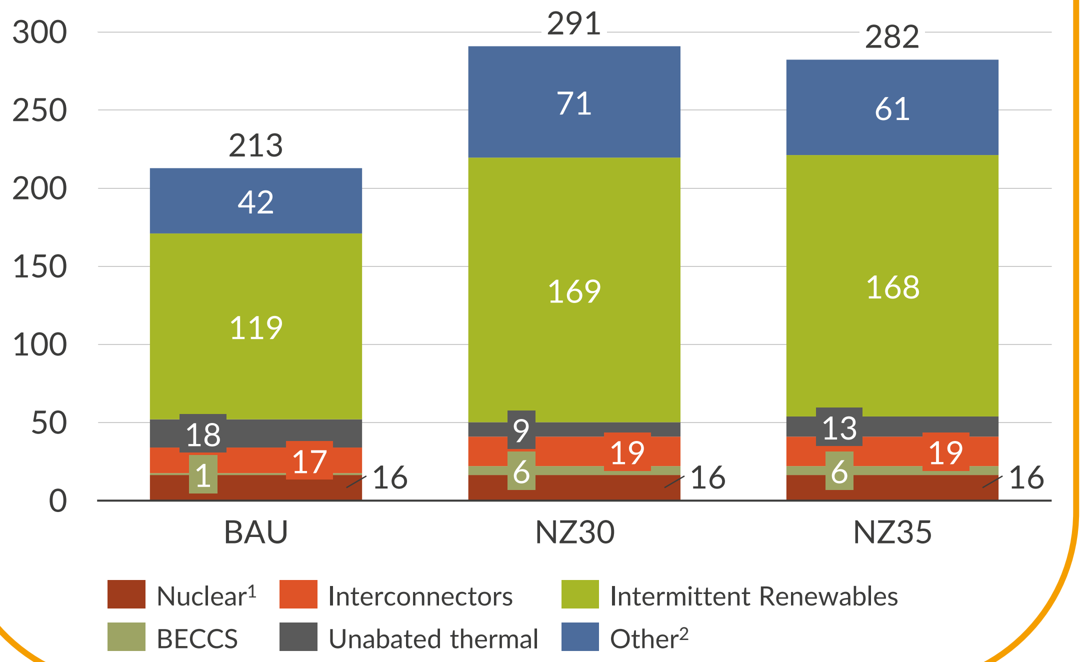
Whilst a shift in system composition is necessary to reach short-term Net Zero, the long-term capacity mix remains consistent

- To reach Net Zero accelerated deployment of renewables, flexible technology and networks are necessary
- Targeting Net Zero power earlier results in more renewables and less unabated gas as less offsetting negative emissions technology is available

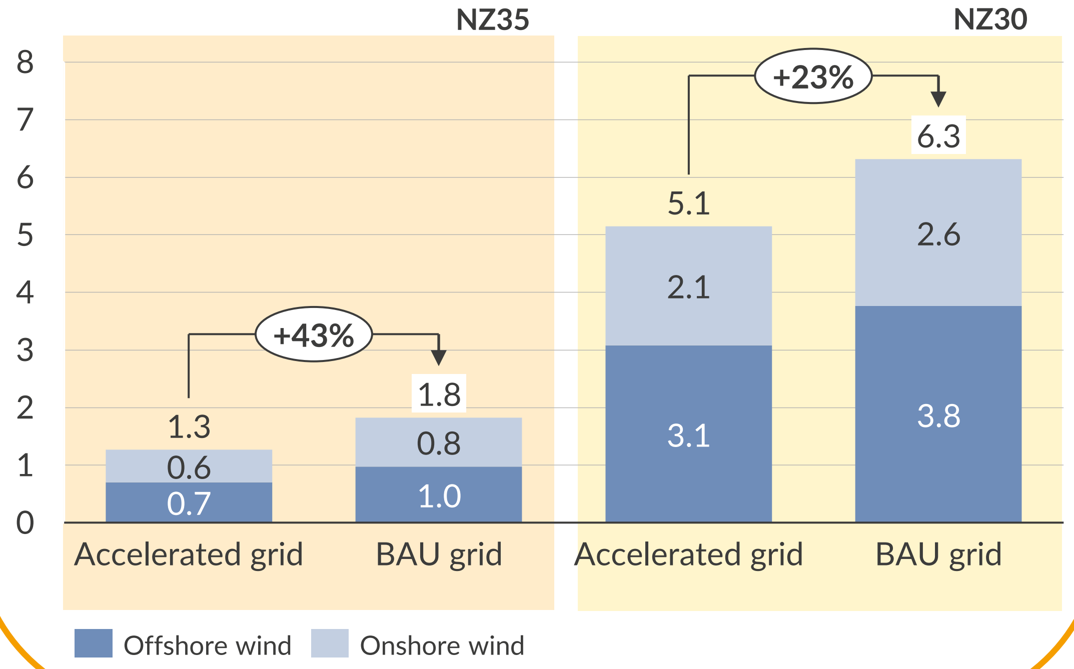
Installed capacity in 2050, GW



Net Zero power scenarios are not successful without sufficient network build to transport renewables

- Expanding grid capacity is vital to prevent wind curtailment as renewable generation increases.
- A 2030 Net Zero target risks significantly higher wind curtailment than a 2035 target, even with current grid build acceleration targets.

Yearly average wind volumes for 2025–2035, TWh



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Source(s): Aurora Energy Research

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The UK has beaten all its carbon budgets to date, but will have to significantly increase ambition to meet upcoming budgets

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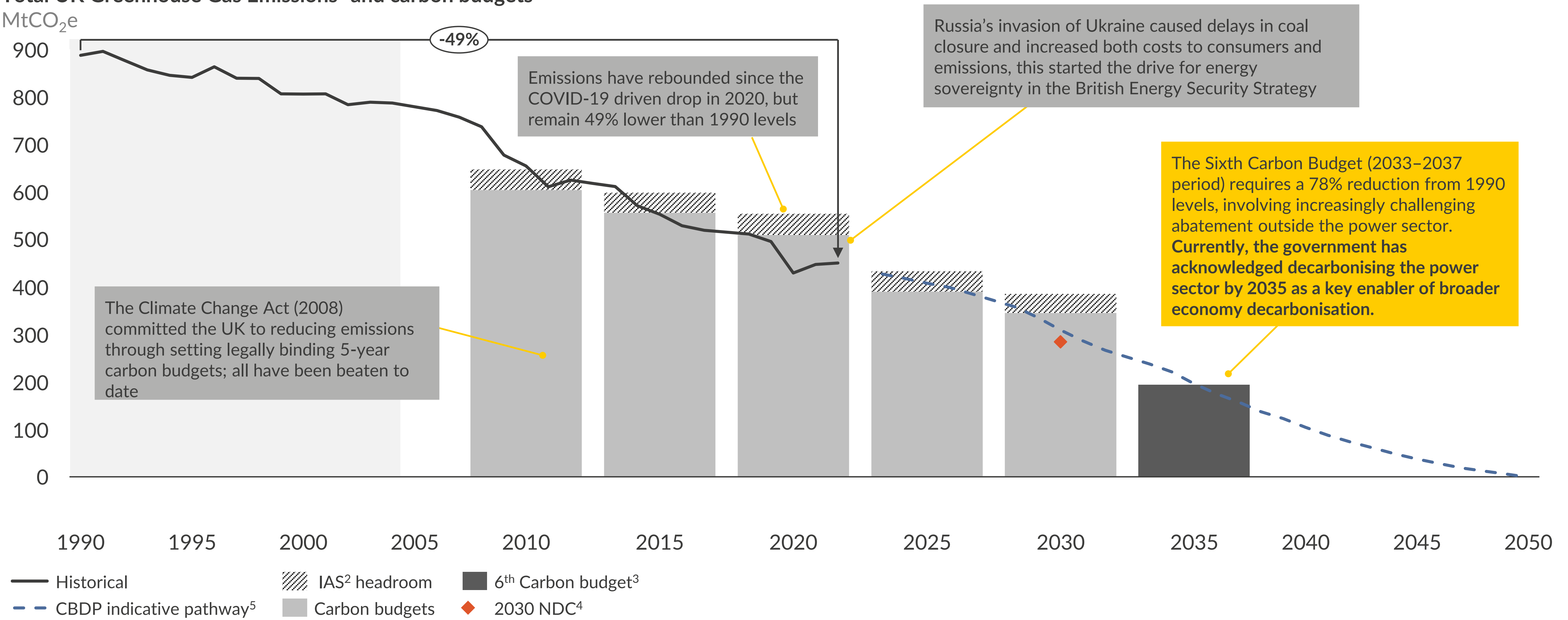
The Sixth Carbon Budget was enshrined into law in April 2021 in line with CCC's recommendation aligning emissions targets with the Net Zero ambition. The power sector delivered half of the emissions reductions over 1990–2021, with a 70% reduction in power sector emissions intensity.

Total UK Greenhouse Gas Emissions[1] and carbon budgets

$MtCO_2e$



1) Includes UK territorial emissions and international aviation and shipping (IAS) emissions on an AR5 basis, including peatlands 2) International aviation and shipping 3) CCC's 6th Carbon budget includes IAS emissions 4) Nationally Determined Contributions exclusive of international aviation and shipping as per UN convention. 5) The Carbon Budget Delivery Plan (CBDP) projection which includes only quantified plans.

Source(s): Aurora Energy Research, DESNZ, CCC

The Labour Party's energy policy shares the same stated objectives as the Conservatives, with differences on pace and means

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The Labour Party's energy policy, first outlined fully in June 2023, envisioned a number of ambitious advances over current policies. A number of these have since been scaled back. In particular, public funding for green projects has been reduced from £28bn/year to £4.7bn/year

Sector	Current policy	Labour policy	Scale of additional delivery challenge
Demand	▪ **ECO**[1]: latest round to insulate 250k homes/year	↑ "**Warm Homes Plan**": intend to insulate 1mn homes/year	◑
Low Carbon Generation	▪ Power sector Net Zero by 2035 ▪ **Offshore wind:** 50GW by 2030 ▪ **Onshore:** effective ban on new build in England ▪ **Solar:** 70GW by 2035	↑ 100% clean power by 2030 ↑ **Offshore wind:** 60GW by 2030 ↑ **Onshore:** 35GW by 2030, lifting effective England ban ▬ **Solar:** 50GW by 2030, equivalent to current trajectory	●
Finance	▪ **UK Infrastructure Bank:** launched 2021, invested £1bn in energy out of £22bn capital; criticised as under-ambitious	↑ **GB Energy**: public investment company to de-risk large projects, funded by one-off £8.3bn grant	◑
Supply Chains	▪ UKIB invests in supply chain projects; CfD[2] Supply Chain Plans, etc.	↑ **National Wealth Fund**: £7.3bn to invest in ports and manufacturing	◑
Grid	▪ Strategic planning of energy system[3], FSO[4] as "architect" ▪ **5-point Plan**: reduce connection queue by prioritising ready projects and reforming application process	▬ Similar proposals on system planning and connection times ↑ Reduce pressure on grid through the "**Local Power Plan**"	◔
Planning	▪ Reduce offshore wind approval times from 4 to 1 year[5] ▪ Simplified marine planning approval under Energy Act 2023	↑ Reduce planning times for renewables "from years to months" ↑ Require local authorities to proactively identify sites ↑ Update NPSs[6] and streamline the NSIP[7] regime	◑

1) ECO: Energy Company Obligation; 2) CfD: Contracts for Difference; 3) As proposed under the Centralised Strategic Network Planning (CSNP) framework and the Offshore Transmission Network Review (OTNR); 4) FSO: Future System Operator; 5) As proposed under the Offshore Wind Acceleration Taskforce; 6) NPS: National Policy Statement; 7) NSIP: Nationally Significant Infrastructure Projects.

Source(s): Aurora Energy Research, DESNZ, Labour

Aurora's Net Zero by 2030 scenario ensures a stable grid with minimal reliance on unabated gas and less renewables build-out than Labour's targets

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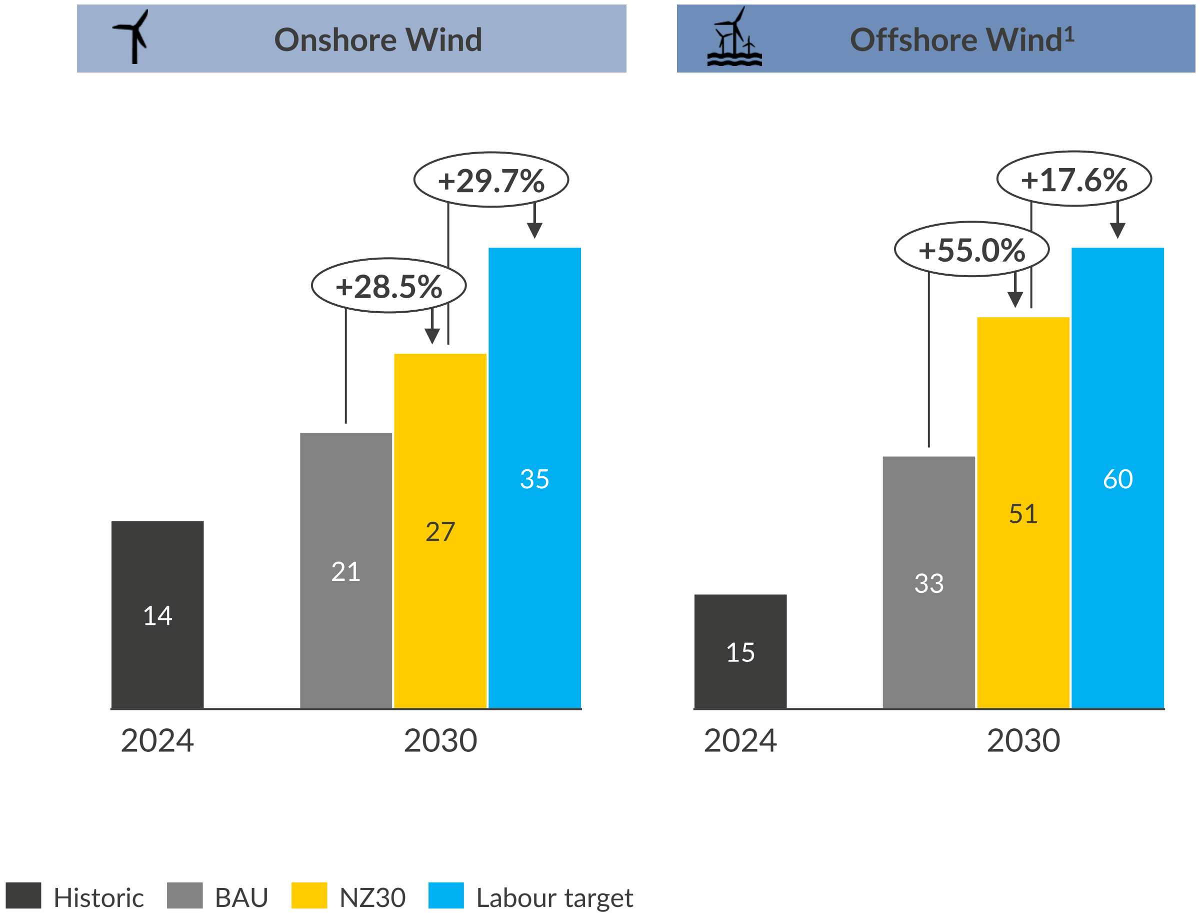
Capacity of key technologies
GW



- The UK has an ambitious goal of net-zero emissions in the power sector by 2035, including targets of 50GW of offshore wind by 2030 and 70GW of solar PV by 2035.
- In contrast, Labour's policy calls for 100% clean power by 2030, including aggressive growth in key low-carbon generation technologies, supply chains, and related grid and planning updates. Labour's targets would necessitate unprecedented expansion in installed capacity for these technologies by 2030.
- Aurora has modelled a 'Net Zero Power by 2030' (NZ30) scenario that, while not aiming to meet Labour's specific targets, outlines a least-effort pathway to decarbonisation. This approach would rely on biomass energy with carbon capture and storage (BECCS) to offset minimal unabated gas emissions.
- Consequently, Aurora's scenario envisions less demanding build-out requirements for electrolysers, offshore wind, solar PV, and onshore wind (particularly given England's effective ban on onshore wind).

1) Includes floating offshore wind;

Source(s): Aurora Energy Research, Labour

This report presents three scenarios: Business-as-usual and scenarios to reach Net Zero in the power sector by 2035 and 2030

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Business-as-usual (BAU)

Business-as-usual assumes a trajectory based on the current economic and policy landscape.

- BAU generally aligns with Aurora's Central market scenario, including:
  - Aurora's Central commodities forecast
  - Technology capacities determined by Aurora's Central view on existing, announced and future policy, and the likelihood of their implementation, combined with economically-optimal asset deployment
  - Recent delays to new nuclear plants
  - the results of renewable subsidy and Capacity Market auctions
  - and the implementation of interconnectors and other subsidies
- There is no explicit target for Net Zero within this scenario and it reaches this milestone in 2051

Net Zero 2035 (NZ35)

To reach Net Zero in 2035, there are several deviations from BAU.

- The target to reach Net Zero in 2035 is a designated outcome of this scenario, with input actively chosen to reach it
- Key scenario alterations to BAU include:
  - Increased demand, reflective of a wider Net Zero landscape
  - Increased renewables buildout
  - Higher carbon pricing
  - Reduction in generation for unabated thermal assets
  - Increased grid capacity to allow for effective integration of renewables
- Unabated gas is still required for security of supply, with the associated carbon emissions offset by BECCS

This scenario could potentially be achieved if coherent policy action, market design and financial support is enacted at a large scale and high speed

Net Zero 2030 (NZ30)

Further accelerating Net Zero in the power sector to 2030 requires more extreme policy action and is likely to be out of reach.

- To reach Net Zero in 2030, even more intervention is required further to the 2035 case
- Key scenario changes over the Net Zero 2035 case are as follows:
  - Renewables buildout must be accelerated forward, reaching 118GW by 2030
  - Grid buildout is accelerated to match
  - Active measures are taken to remove unabated gas, including higher carbon prices and the removal of CHP plants
- CHP must be replaced or converted to biomass, which will impact areas outside the power sector
- BECCS is key to this scenario and must run at baseload due to the limited availability of alternatives to unabated thermal generation

This scenario requires a massive acceleration in deployment which is considered infeasible

Source(s): Aurora Energy Research

The current market framework has GB on a course to reach Net Zero only in 2051, far beyond political targets

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BAU

GB is on course to reach power sector Net Zero in 2051, far beyond political targets, due to headwinds in deployment of RES and enabling technologies

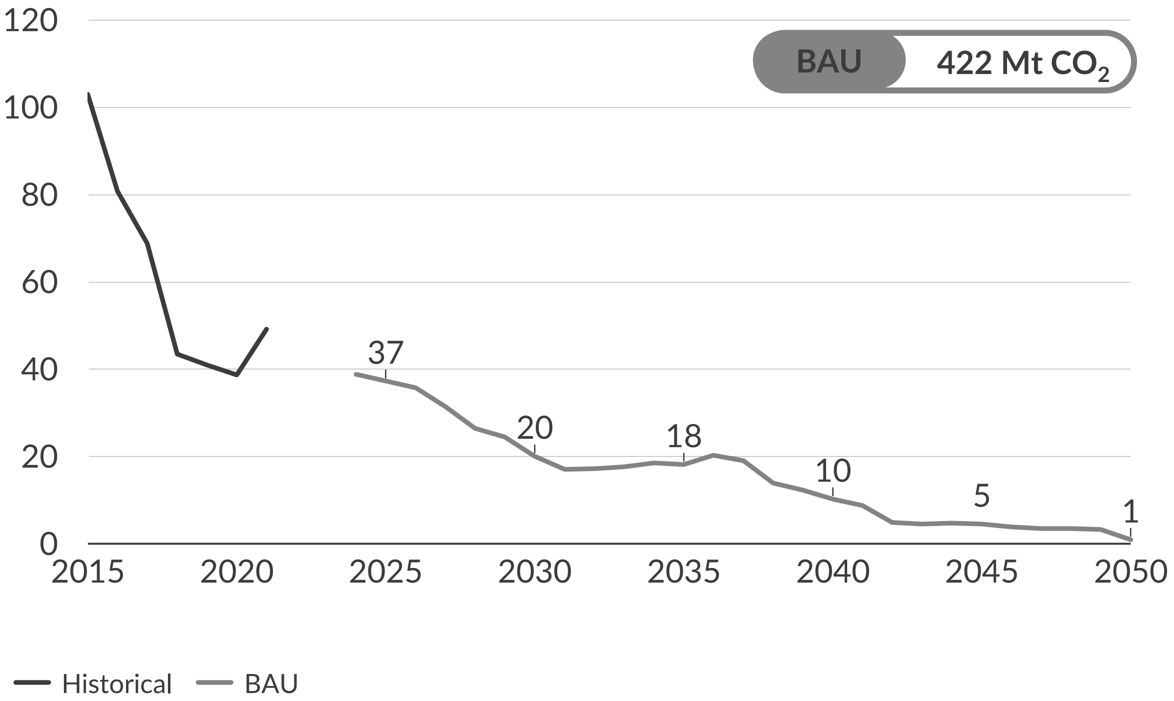
- Power sector carbon emissions are set to fall across the scenario horizon, with increasing renewable generation and a reduced in unabated gas
- However, recent auction rounds and planning delays suggest the rate of deployment will not reach levels require to reach Net Zero timeline targets

Nuclear generation is set to fall between 2024 and 2035, whilst unabated gas generation is required for security of supply

- Recent nuclear plant construction delays of Hinkley Point C will lead to a reduction of nuclear generation to 20TWh in 2030
- Unabated gas generation continues to be necessary to provide firm power, and as such continues to be procured within the Capacity Market

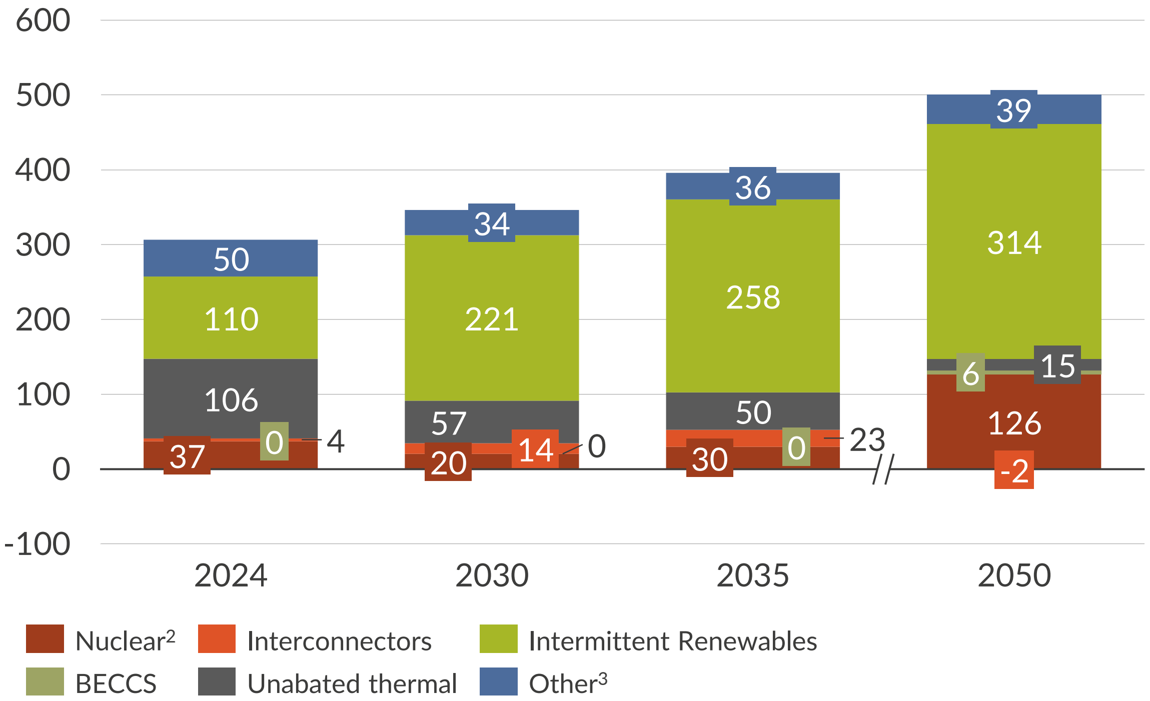
Power Sector Carbon Emissions[1] **Total 2024–2050**

$MtCO_2e$



Electricity Production and Net Imports

TWh



1) Includes negative emissions from BECCS assuming a factor of -941 gCO2 /kWh; 2) Assumes Hinkley Point C, Sizewell C and Bradwell B delays, with an upsizing of expected future capacity; 3) Includes generation from storage, demand-side response (DSR), hydrogen peaking plants, hydrogen CCGTs, biomass and gas CCS .

Source(s): Aurora Energy Research

To reach Net Zero in 2035 or 2030 requires a sharp reduction in short-term carbon emissions

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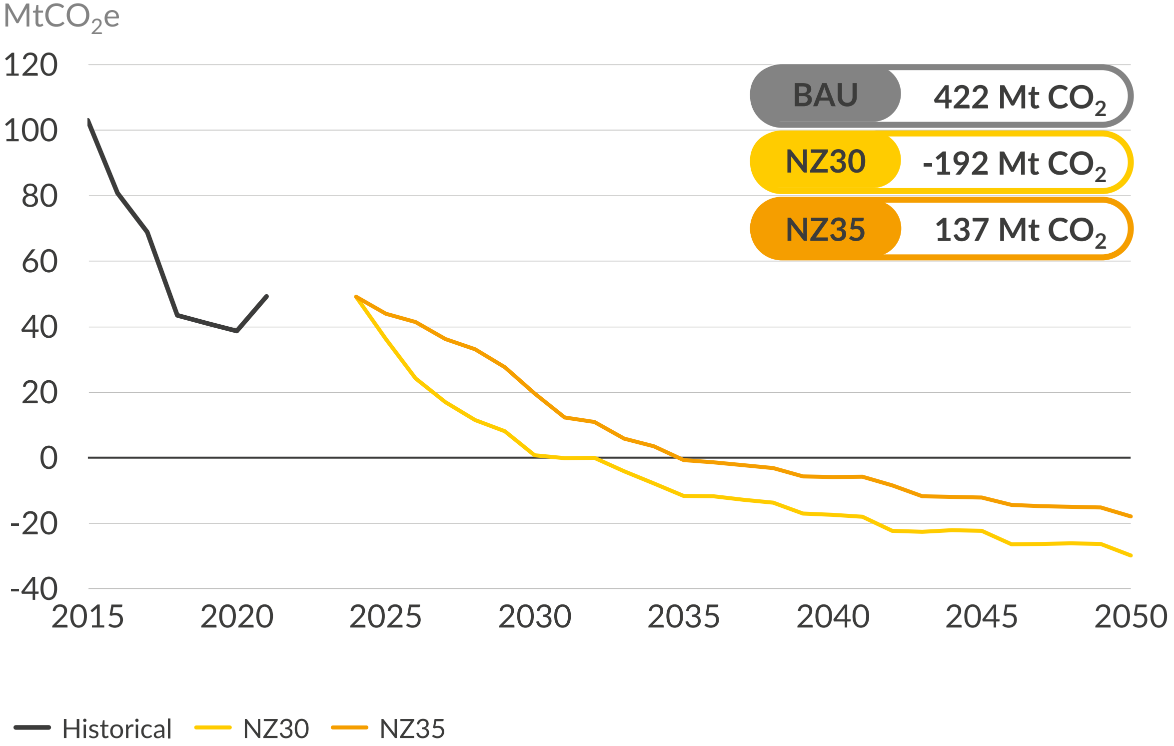
NZ30, NZ35

To reach Net Zero in 2035 or 2030 requires significant intervention, as the historic reduction in power sector emissions has flattened in recent years

- The 2035 scenario reaches Net Zero in this year, with an increased rate of consistent emissions decline across this time horizon
- The accelerated scenario reaches close to Net Zero in 2030, and maintains its lower emissions throughout the scenario horizon

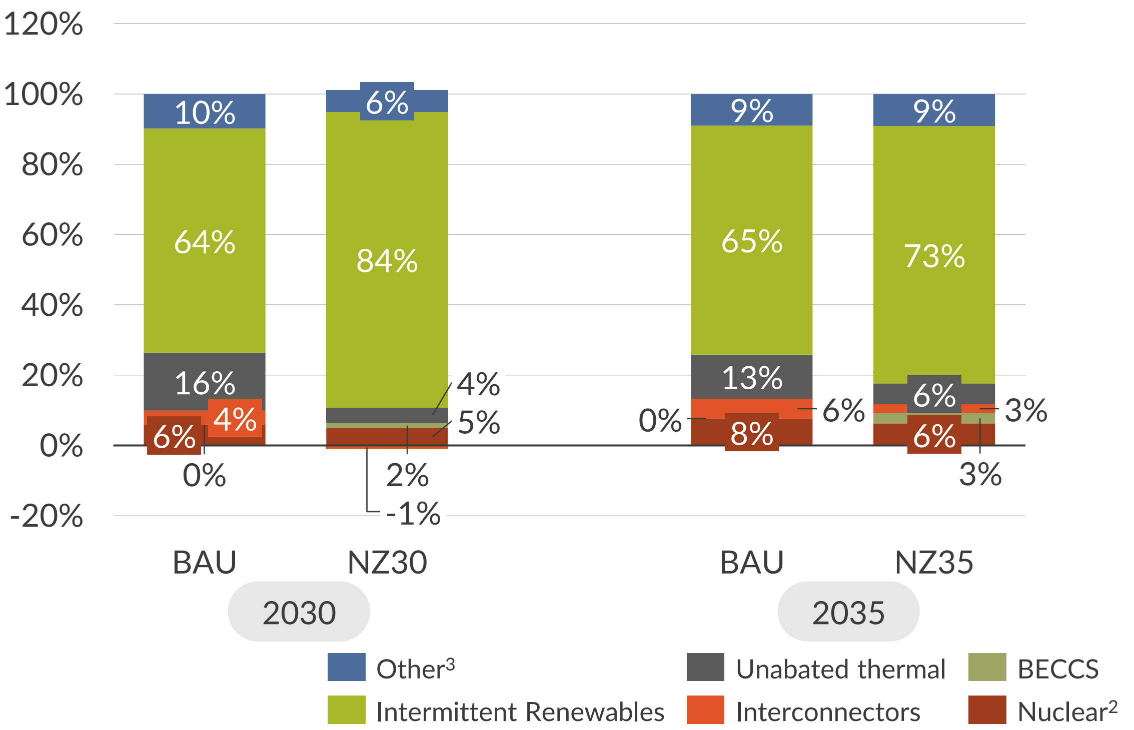
Power Sector Carbon Emissions[1] **Total 2024–2050**



To reach Net Zero, intermittent renewable generation increases to over 70% of the total, with unabated thermal generation comprising under 10%

- To reach Net Zero in 2035, renewables, nuclear and imports reach 82% of total generation, with 6% of unabated thermal offset by BECCS
- The shorter timeline to 2030 gives less generation available from nuclear, CCS and BECCS, and therefore renewables must increase to 77% of generation

Generation and net imports, %



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Source(s): Aurora Energy Research

Contents

A wide mix of technologies are required to meet the Net Zero targets which face specific barriers which must be overcome

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1 Accelerated renewable deployment

Solar
Planning delays have resulted in long lead times for solar developments

Onshore wind
A de-facto ban in England and Wales has stalled onshore wind growth

Offshore wind
Development timelines could delay delivery even with the recent boost in Administrative Strike Price

2 Low-carbon baseload power

Nuclear
High upfront costs and construction complexities have led to long Delays and large cost overruns

3 Flexible capacity

Interconnectors
Government backing of a cap-and-floor mechanism for interconnectors has aided their deployment

Long duration energy storage
A pipeline of LDES projects exists, but large-scale capital deployment to enable their construction will rely on secure revenue streams

Battery storage
A large pipeline of short duration assets is present, but must gain access to revenue opportunities to come online

4 Carbon removal technologies

BECCS
Net Zero is heavily dependent on negative emissions technology, However, there is no current regulatory framework to ensure standards

Gas CCS
Gas CCS technology is not currently in operation in GB and has limited
suitable locations for storage limit deployment

Source(s): Aurora Energy Research

Offshore wind has been deployed at scale in GB but is now experiencing headwinds from higher costs and market uncertainty

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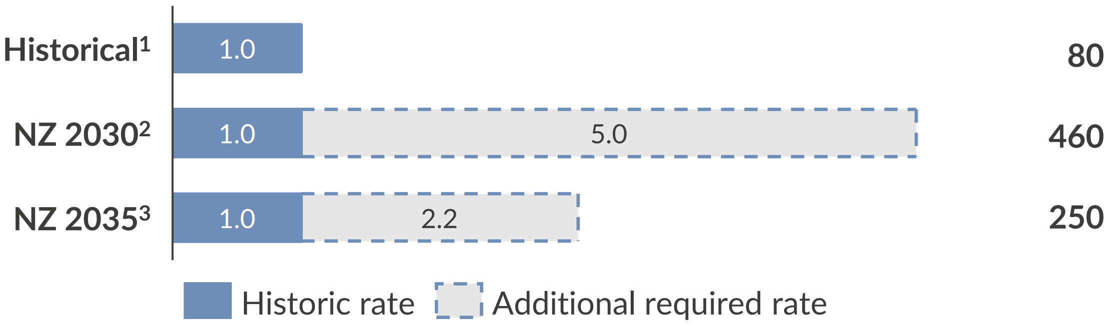
Offshore Wind

Yearly average increase in capacity GW/year

Turbines/year[4]

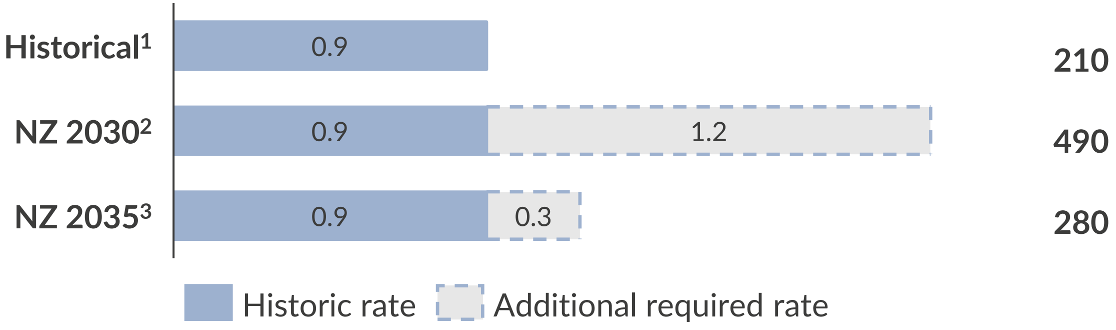


- Development timelines and supply chain constraints could delay delivery even with the increased budgets in future auction rounds
- GB has been a pioneer in developing large scale offshore wind, however, to reach decarbonisation goals a further acceleration is required
- A complex early-stage process of environmental impact assessments, planning and OFTO can account for up to 2/3 of the development timeline
- The REMA consultation is increasing the uncertainty around expected revenues for offshore wind, further hindering investment

Onshore Wind

Yearly average increase in capacity GW/year

Turbines/year[5]



- As with solar capacity, onshore wind capacity growth has stalled significantly in recent years
- This is due to the de-facto onshore wind ban in England, and a period of no CfD availability
- To reach Net Zero the process for planning and development must be significantly accelerated to a rate of 2.1GW/year, above the previous build rate of 0.9W/year

1) Average annual increase calculated from 2013 to 2023; 2) Average annual increase calculated from 2025 to 2035; 3) Average annual increase calculated from 2025 to 2030; 4) Based on 13MW turbine; 5) Based on 4.3MW turbine.

Source(s): Aurora Energy Research

Solar developments, particularly in England and Wales, have been restricted by planning and grid connection difficulties

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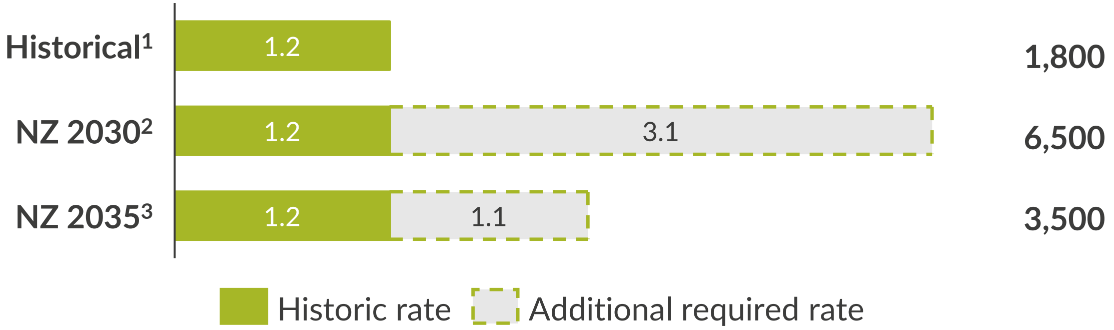
Solar

Yearly average increase in capacity
GW/year

Yearly land area[4]
football pitches/year



- Growth in solar capacity has stalled in recent years due to planning hurdles and grid connection issues for larger plants, particularly in England and Wales
- In order to reach Net Zero targets, massively accelerated growth is required
- The rate of growth required exceeds the historic rate of 1.2GW/year, with an increase on top of this of 1.1GW/year required to reach Net Zero in 2035, and 3.1GW/year further to reach Net Zero 2030

Nuclear

- No acceleration in nuclear deployment is considered, as given recent delays to Sizewell C and the 19-year development timelines for large plants it is infeasible for any new capacity to be delivered by 2030 or 2035
- Delays in planning permission and bottlenecks in approval of reactor designs contribute to this long timeline
- A shortage of skilled workers restricts any concurrent plant construction
- The complex, high capex projects require government support, and have financial constraints, with a limited pool of already stretched funders

Interconnectors

- Interconnector deployment has been supported by government backed cap and floor mechanisms, and are one technology where the rate of deployment doesn't need further acceleration in the Net Zero scenarios
- Although total levels of imports are reduced in many years of the Net Zero scenarios, interconnection is still vital for security of supply
- The potential for carbon leakage where interconnect imports are utilised is possible, however imports are often from low-carbon, cheaper generation sources and should not represent a significant shift in emissions profile

1) Average annual increase calculated from 2013 to 2023; 2) Average annual increase calculated from 2025 to 2035; 3) Average annual increase calculated from 2025 to 2030; 4) Based on 3 acres/MW, 2 acres/pitch.

Source(s): Aurora Energy Research

Flexible generation will be critical to enable renewables deployment, but require market reform to remain economic

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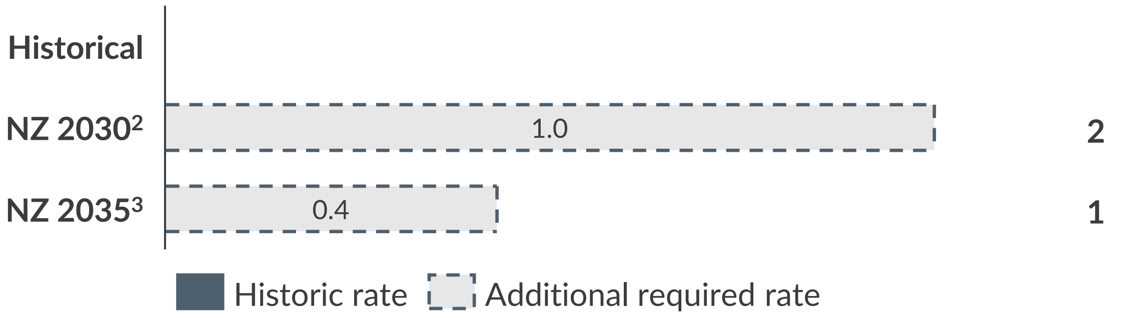
Long duration energy storage (LDES)

Yearly average increase in capacity — Plants/year[4]

GW/year

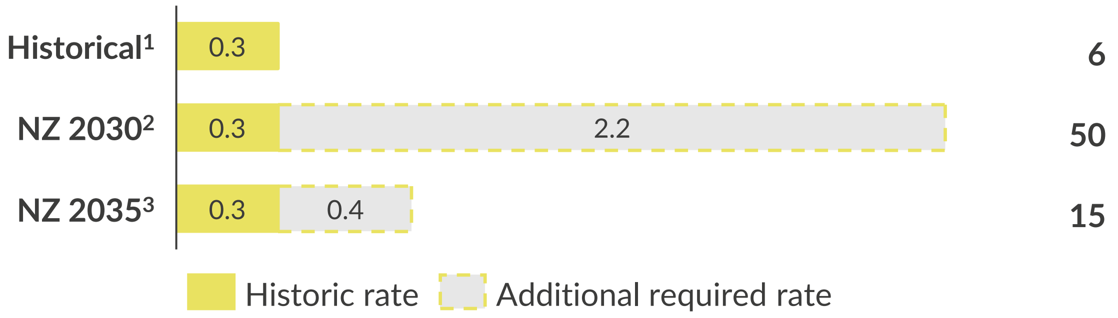


- Long duration storage is need to shift excess RES generation to times of high demand, with a total of up to 9GW of additional projects required by 2035
- Commissioning of new plants for some LDES technologies, such as pumped-storage hydro, is not possible by 2030 due to long construction times
- Consultation on a cap and floor mechanism for LDES is underway, which will be necessary to give long term revenue security to allow financing for the large-scale capital deployment necessary

Battery storage

Yearly average increase in capacity — Assets/year[5]

GW/year



- Battery levels reach 20GW in the Net Zero 2030 scenario, far above BAU, but below the full available pipeline of 43GW[6]
- The required overall rate for Net Zero power in 2030 of 2.5GW per annum could be achievable if action of grid connection timings is successful
- The Net Zero 2030 scenario requires an increase in BESS capacity to replace unabated thermal peaking capacity
- Existing capacity market support for BESS assets is limited, given the low derating factors, with Balancing Mechanism participation also an issue

1) Average annual increase calculated from 2018 to 2023; 2) Average annual increase calculated from 2025 to 2035; 3) Average annual increase calculated from 2025 to 2030; 4) Based on Cruachan pumped storage at 440MW; 5) Based on 50MW capacity; 6) Pipeline of potential assets in REPD database, December 2023.

Source(s): Aurora Energy Research

Other enabling technologies required for the energy transition also have development risks

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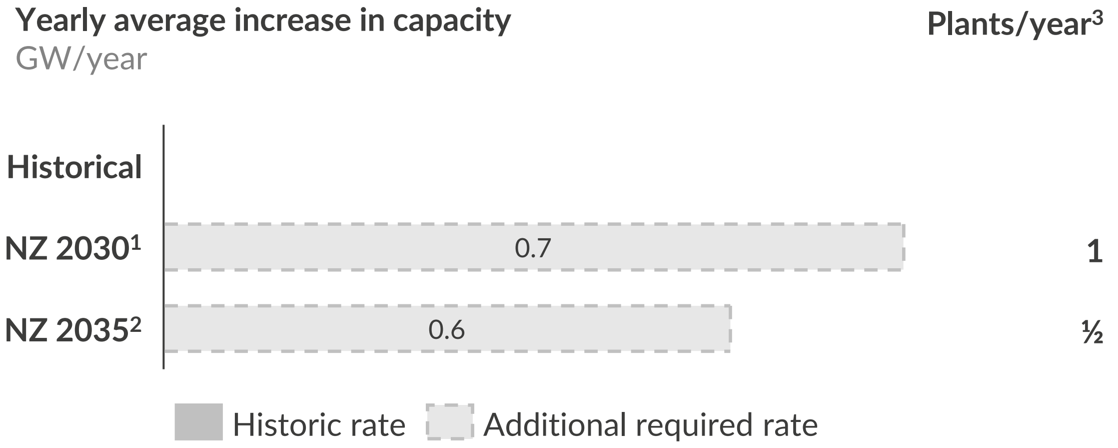
Gas CCS

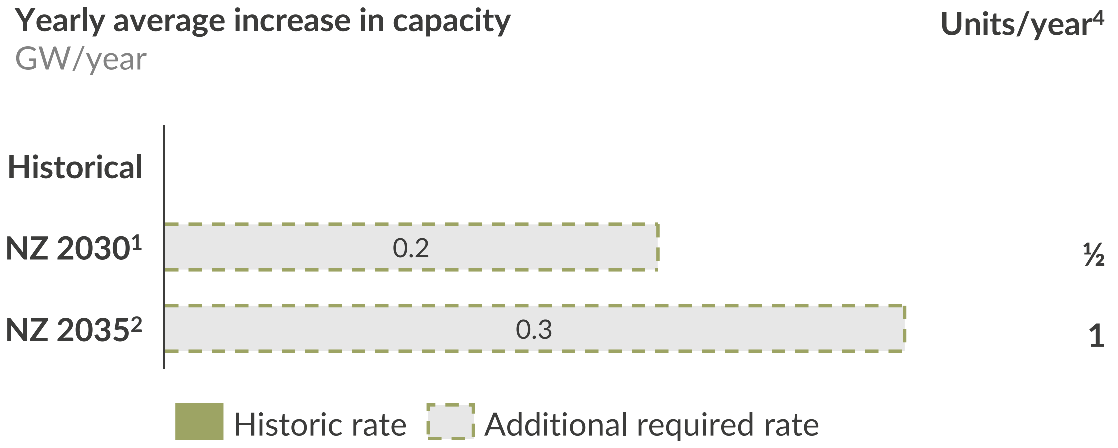
Yearly average increase in capacity
GW/year



- Increased CCS is required to ensure security of supply with dispatchable gas generation however relies on technology unproven at scale
- Significant support schemes, such as the CCS clusters, have been announced and will be needed to bring the technology to market
- CCS is a greater component for Net Zero in 2035, as timelines to 2030 are too short for mass deployment of the nascent technology

BECCS

Yearly average increase in capacity
GW/year



- BECCS is required to offset the unabated gas generation, however policy intervention will be required to standardise negative emissions treatment
- Currently there is no international standard on the level of negative emissions that can be allocated, the classification of feedstocks or conformation to such standards, which could lead to mistreatment of BECCS emissions reductions
- We have assumed a level of -941gCO_2/kWh for BECCS[5]. The level of negative emissions from BECCS is highly contested and a lower rate of negative emissions would make it even harder to reach Net Zero power

1) Average annual increase calculated from 2025 to 2035; 2) Average annual increase calculated from 2025 to 2030; 3) Based on 860MW Net Zero Teeside Power capacity; 4) Based on Drax unit converted capacity of 460MW; 5) Taken as a mid-point estimate of -647 and -1137 kg/MWh in: García-Freites, S., Gough, C., & Röder, M. (2021). The greenhouse gas removal potential of bioenergy with carbon capture and storage (BECCS) to support the UK's net-zero emission target. Biomass and Bioenergy, 151, 106164.

Source(s): Aurora Energy Research, Biomass and Bioenergy, Drax

Urgent policy reforms, including new measures and extending existing ones, are needed to overcome these barriers to Net Zero

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	Policy measures required
Net Zero 2035	▪ **Resolve Grid Hurdles:** Prioritise addressing technical and planning barriers that restrict grid build-out (e.g., connection queue management). ▪ **Reform Network Charging:** Finalise reform to the network charging structure (TNUoS) for remote renewable resources to avoid prohibitive costs. ▪ **Expand & Update CfD Scheme:** Drastically increase the budget for Contracts for Difference (CfD) and ensure parameters are set to not prioritise competition over securing necessary renewables capacities ▪ **Enable BM Market Participation:** Rapidly fully implement market reforms like the Open Balancing Platform to allow technologies like grid-scale batteries to fully participate in balancing mechanisms, ensuring revenue and grid stability. ▪ **Streamline Planning for Solar & Onshore Wind:** Reform planning processes in England and Wales to unlock untapped growth potential ▪ **LDES Financing:** Finalizing the cap-and-floor mechanism for long-duration energy storage (LDES) will attract investment in major projects like pumped-storage hydro. ▪ **Emerging Tech Support:** Expand support for essential technologies like Carbon Capture & Storage (CCS), hydrogen, and BECCS (Bioenergy with CCS) for secure supply and negative emissions (along with promptly ensuring governance around international accounting of negative emissions)
Net Zero 2030	**Measures required include all those for NZ35, and further measures:** ▪ **Desperate Acceleration:** NZ30 would require an impossibly rapid ramp-up of support schemes and planning reforms, far beyond what's feasible. ▪ **LDES Reliance:** Significantly more Long Duration Energy Storage (LDES) would be needed if Carbon Capture & Storage (CCS) deployment is slowed by the 2030 timeline. ▪ **Industrial Transformation:** Back major industrial support for electrification or fuel switching, since many industries would have to abandon Combined Heat & Power (CHP) production. ▪ **Carbon Price Intervention:** Forcefully increase carbon pricing to levels that drive unabated gas generation off the system, potentially causing disruptions. **Key Takeaway:** Given lead times, skills shortages, and supply chain constraints, the interventions needed for NZ30 are likely impossible by 2030.

Source(s): Aurora Energy Research

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Reaching Net Zero Power by 2030 would require a more radical overhaul of the electricity system at an infeasible rate

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Business-as-usual (BAU)

Business-as-usual assumes a trajectory based on the current economic and policy landscape.

- There is no explicit target for Net Zero within this scenario and it reaches this milestone in 2051

Net Zero 2035 (NZ35)

To reach Net Zero in 2035, there are several deviations from BAU.

This scenario could potentially be achieved if coherent policy action, market design and financial support is enacted at a large scale and high speed

Net Zero 2030 (NZ30)

Further accelerating Net Zero in the power sector to 2030 requires more extreme policy action and is likely to be out of reach.

- To reach Net Zero in 2030, even more intervention is required further to the 2035 case
- Key scenario changes over the Net Zero 2035 case are as follows:
  - Renewables buildout must be accelerated forward, reaching 118GW by 2030
  - Grid buildout is accelerated to match
  - Active measures are taken to remove unabated gas, including higher carbon prices and the removal of CHP plants
- CHP must be replaced or converted to biomass, with alternate low-carbon heating provision
- BECCS is key to this scenario and must run at baseload due to the limited availability of alternatives to unabated thermal generation

This scenario requires a massive acceleration in deployment which is considered infeasible

Source(s): Aurora Energy Research

The Net Zero power in 2030 scenario reaches 118GW of renewables capacity, which is infeasible with planning, grid and supply chain barriers

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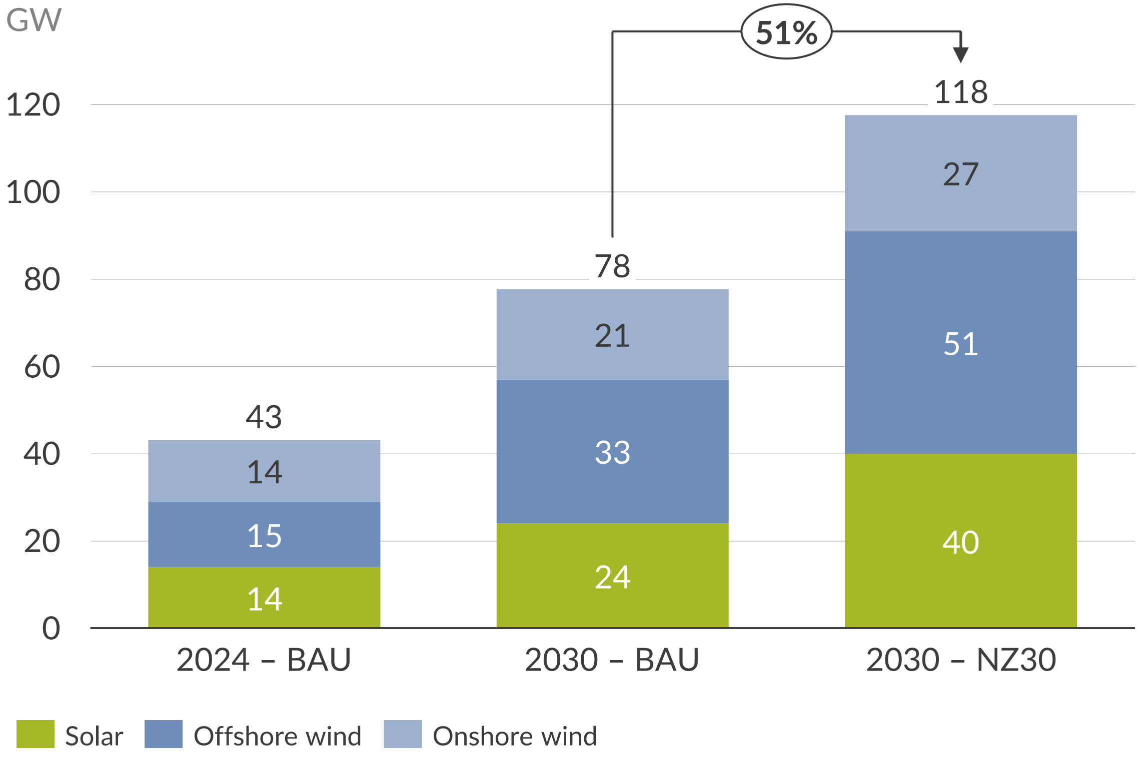
NZ30

Large scale renewables deployment is required to reach Net Zero, however must be accompanied by additional systemic change

- Renewable capacities increase by 51% to reach Net Zero in 2030, relative to the Base scenario
- This must be accompanied by a doubling of flexible technologies, and tripling of key B6 boundary capacity to ensure the generation is effective

Installed renewables capacity

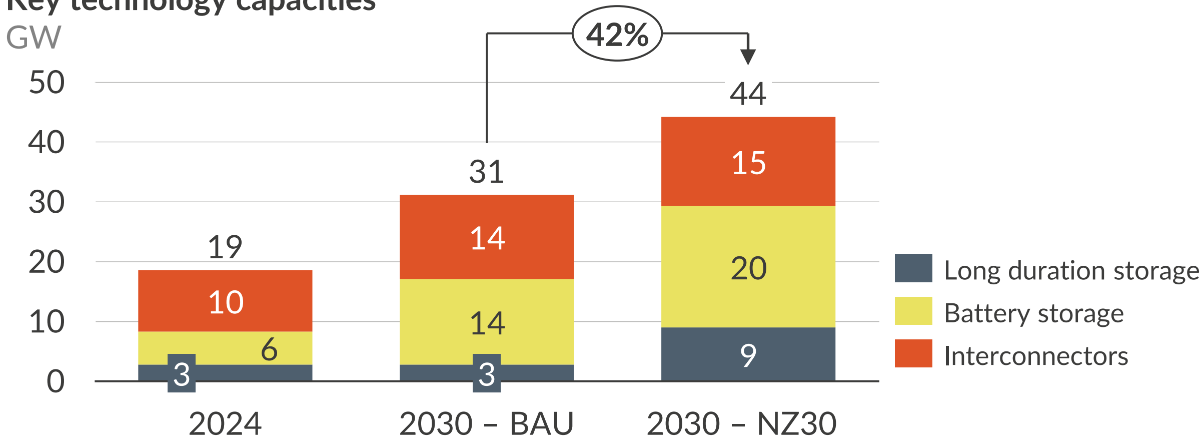
GW



However, the RES deployment must be accompanied by other technologies and infrastructure build

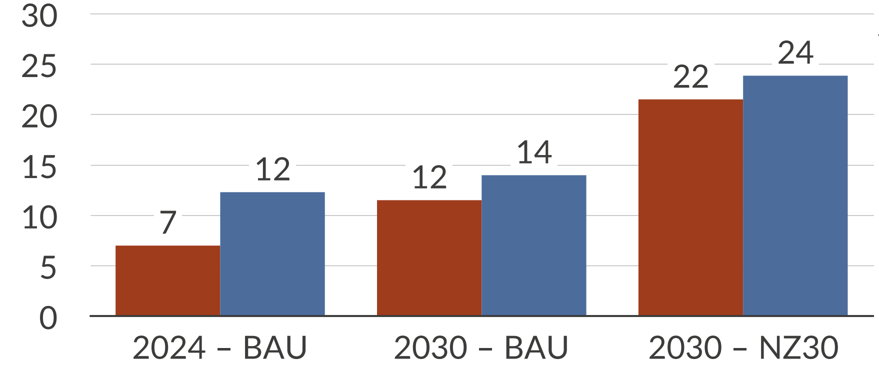
Key technology capacities

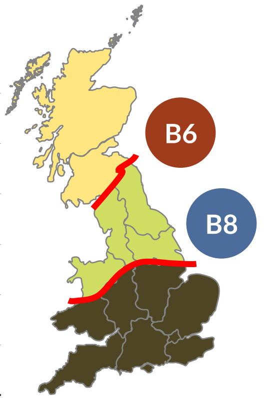
GW



Boundary capacity

GW





Despite rapid growth in renewable generation unabated gas maintains a residual role in ensuring security of supply

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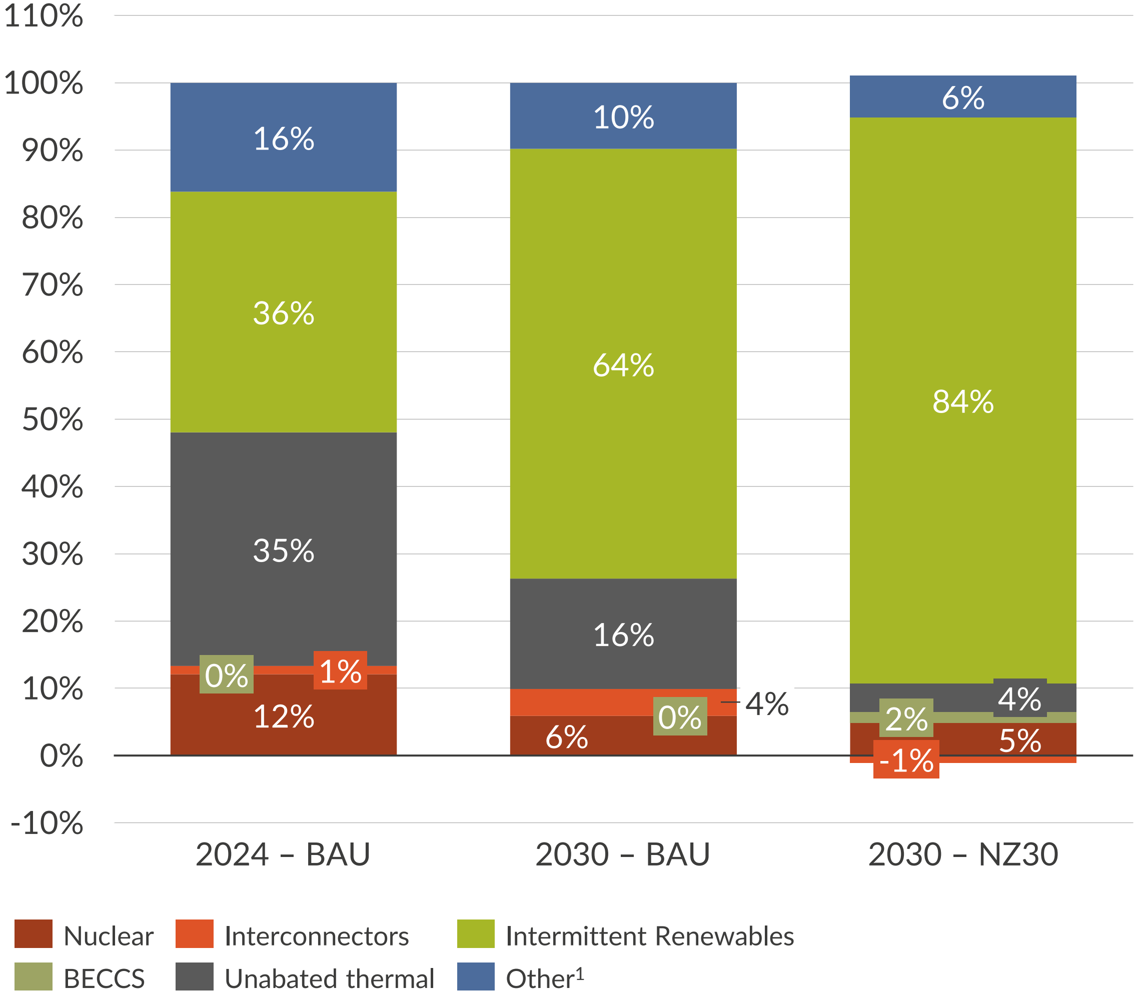
NZ30

Proportion of total generation by technology category

%



Despite massive growth in renewables, unabated gas fired generation is still required for security of supply, even when Net Zero is reached

- Direct renewable generation reaches 84% of total generation in 2030 when Net Zero is reached
- This is an 20% increase over BAU, where renewable buildout is significantly lower
- Even with Net Zero reached, unabated gas generation is still required to ensure system security at 4% of total generation
- However, this generation is four times lower than the 16% of unabated thermal generation in BAU in 2030
- In the Net Zero scenario, the gas emissions are offset but BECCS, which would require significant acceleration to reach this timeline.

Despite this scenario reaching Net Zero on paper, the required deployment of renewables, flexible generation and abated technologies alongside the removal of gas-fired CHP, mean this is not a feasible timeline for decarbonisation of the power sector.

1) Includes generation from storage, demand-side response (DSR), hydrogen peaking plants, hydrogen CCGTs, BECCS, biomass and gas CCS.

Source(s): Aurora Energy Research

To accelerate power sector decarbonisation the rate of deployment reaches extreme levels, which are extremely unlikely to materialise

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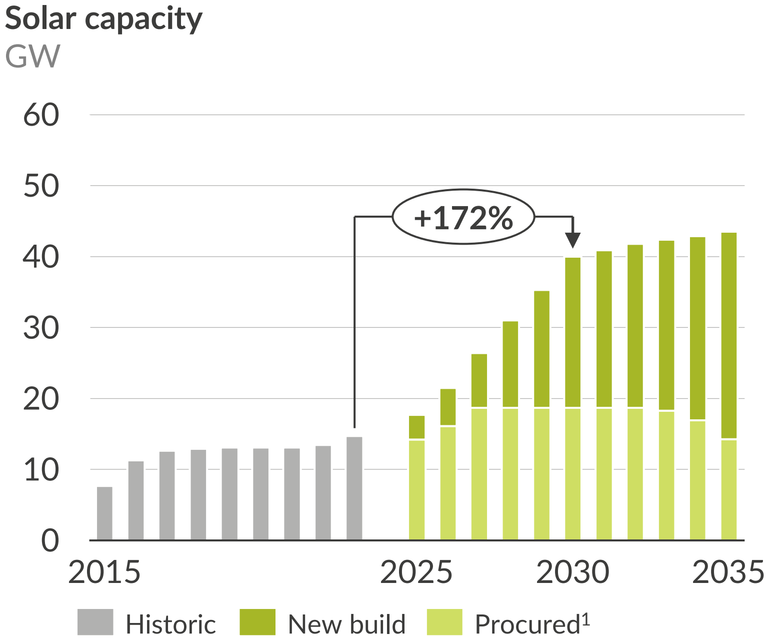
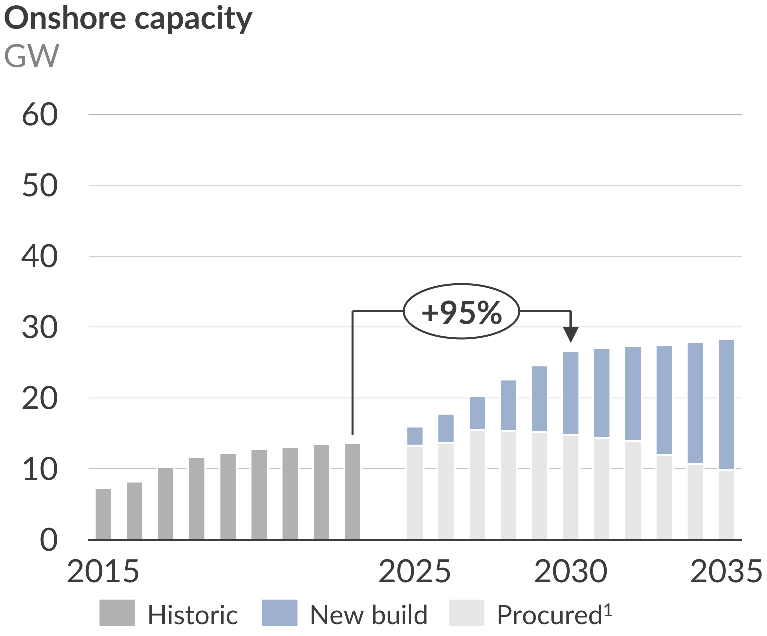
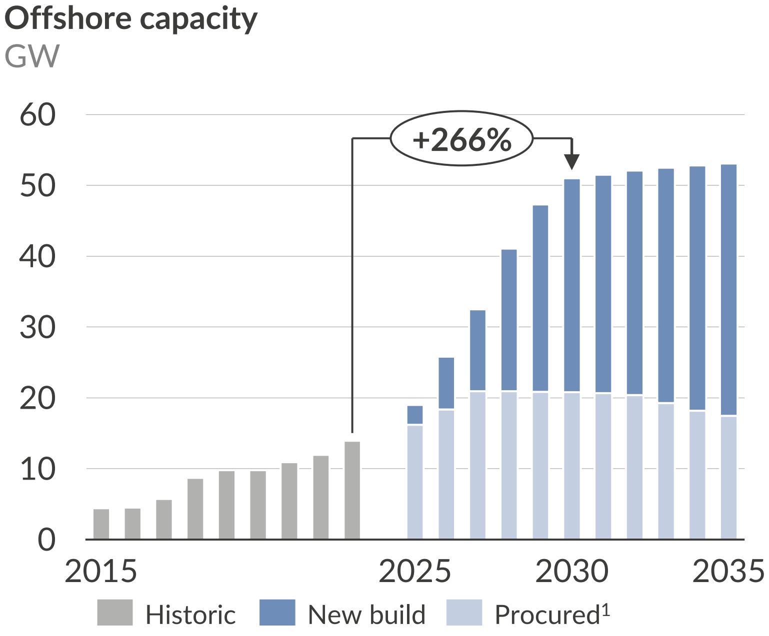
NZ30







- To reach Net Zero in 2030, solar capacity must increase by over 25GW in 5 years, which is infeasible given current planning and development times
- Onshore wind buildout must be accelerated from recent stagnating growth to almost doubt in capacity by 2030
- Offshore wind projects have a length planning and permitting procedure and supply chain constraints, and as such the required increased to 2030 is infeasible

Investment capex cost required for new-build renewable capacity to reach Net Zero power by 2030

2025–2030	£1.8bn/yr	£2.2bn/yr	£11.6bn/yr	=	£15.6bn/yr | £93.5bn
2031–2035	£0.7bn/yr	£1.4bn/yr	£2.3bn/yr	=	£4.4bn/yr | £22.5bn
2025–2035	£1.3bn/yr	£1.9bn/yr	£7.4bn/yr	=	£10.6bn/yr | £116.0bn

1) Procured in ROCs, FiT and CfD up to AR5.

Source(s): Aurora Energy Research

Finance, planning times, skills and supply chains will be the key barriers to delivering a Net Zero power sector by 2030

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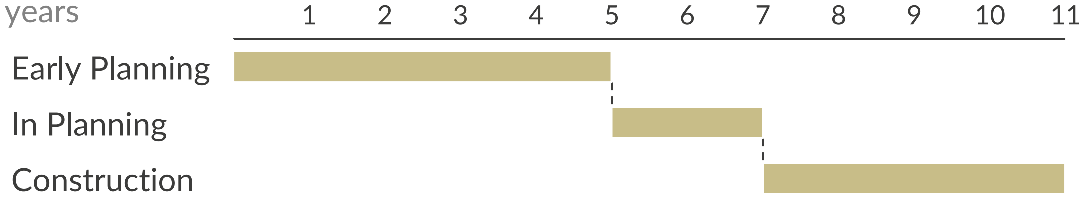
1 Financing: Public vs. Private

- High CAPEX technologies like pumped storage and nuclear require bespoke risk mitigation for financing
- Difficulty in raising debt and equity due to high risks
- Global competition makes attracting capital more difficult
- An acceleration of renewable technologies will likely lead to a suppression in capture prices and a higher dependency on subsidy spending

2 Planning and consenting: just a matter of political will?

- Includes environmental assessments and the granting of planning consent
- Uncertainty around market design, grid connection queues and a competitive global landscape with competing subsidy schemes e.g. EU's Clean Energy Package may hinder GB's ability to attract investment for renewable capacity

Illustrative expected development timeline for offshore wind projects

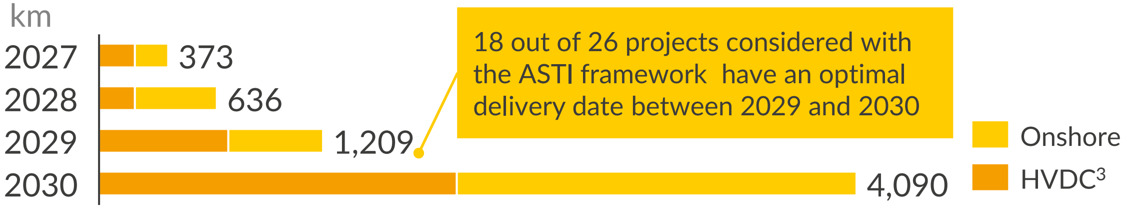


- Due to a tight delivery timeline, a NZ30 scenario will incur potentially insurmountable challenges, to build out its ambitious renewable pipeline

3 Supply chains and skills: is the UK competitive at a global level?

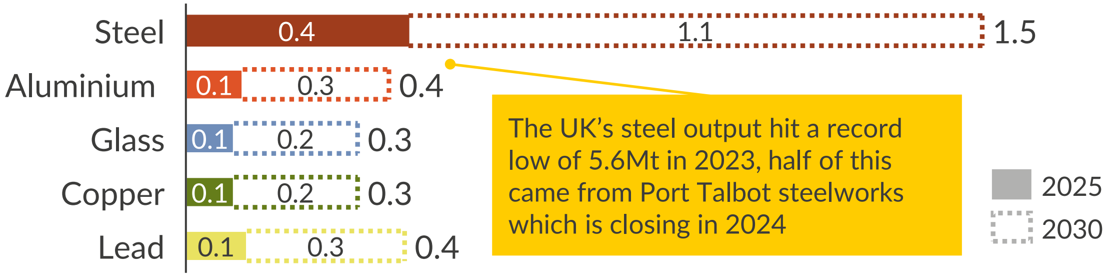
- Key transmission upgrades and new lines under ASTI[1] aim to be deployed by 2030 to support the current 50GW offshore wind target, including offshore HVDC links from Scotland to England

Cumulative new build and upgraded line length in under ASTI by delivery year[2]



- Supply chains will need to scale up 250–400% to deliver this deployment of transmission capacity
- By further accelerating expected grid build requirements relative to ASTI, under the NZ30 scenario presented, total material demand is expected to proliferate significantly beyond that of ASTI's requirements illustrated below

Total material demand for line build and upgrade under ASTI[4, 5]



1) Accelerated Strategic Transmission Investment framework; 2) Entry year is taken to be the "optimal start date" as defined under ASTI; 3) HVDC: High Voltage Direct Current cable; 4) Considers material demand for line build; 5) Assumes an average cable weight of 0.067t/km-MVA for underground cables and 0.023t/km-MVA for overground cables.

Source(s): Aurora Energy Research, LME, US DOE, Institute of Energy Economics, AEMO, TransnetBW, RTE

Reaching Net Zero by 2030 would require infeasible system transformation within the restrictive timeline

AURORA

NZ30

	Net Zero 2030	Feasibility assessment	
RES increase	Increase to 40GW solar, 27GW onshore wind and 51GW offshore wind by 2030	The increases in capacity necessary are at a far greater rate than any previous deployment of RES in GB. This is unfeasible in the required timeline, due to planning delays, grid connection waits and supply chain constraints	Infeasible
Flex buildout	Increase to 20GW BESS, 9GW LDES and 15GW interconnectors by 2030	The pipeline of BESS assets could reach the 20GW capacity in this timeline. However, reaching 9GW LDES by 2030 is not possible due to the planning, development and construction times for these systems	Infeasible
Grid buildout	Increase to 22GW B6 and 24GW B8 boundary capacity by 2030 as part of a wider transmission and distribution system upgrade	The required grid build to allow the renewables to be integrated onto the power system is infeasible by 2030, partly due to planning constraints, but also the long development and construction times for large infrastructure projects	Infeasible
Gas phase-out	Further increase of carbon price to 54% above BAU in 2030, and removal of CHP plants from the system	Although very high, the carbon price could be raised to the required levels, however the removal of gas-fired CHP is likely impossible, with industrial processes reliant on this unable to adapt to new fuelling in time	Infeasible
BECCS	1GW of capacity required by 2030, with requirement to run at baseload	The deployment of BECCS would require an accelerated timeline for the conversion of existing biomass plants to CCS, far ahead of the operator's plans[1]. Wider sustainability issues of BECCS must also be decisively managed	Change of trajectory

Current trajectory | Change of trajectory | Infeasible

1) 'The value of BECCS at Drax Power Station', January 2024.

Source(s): Aurora Energy Research

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Net Zero Power by 2035 could potentially be achieved by immediate, large-scale coherent policy action, market design and financial support

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Business-as-usual (BAU)

Business-as-usual assumes a trajectory based on the current economic and policy landscape.

- There is no explicit target for Net Zero within this scenario and it reaches this milestone in 2051

Net Zero 2035 (NZ35)

To reach Net Zero in 2035, there are a number of deviations from BAU.

- The target to reach Net Zero in 2035 is a designated outcome of this scenario, with input actively chosen to reach it
- Key scenario alterations to BAU include:
  - Increased demand, reflective of a wider Net Zero landscape
  - Increased renewables buildout
  - Higher carbon pricing
  - Reduction in generation for unabated thermal assets
  - Increased grid capacity to allow for effective integration of renewables
- Unabated gas is still required for security of supply, with the associated carbon emissions offset by BECCS

This scenario could potentially be achieved if coherent policy action, market design and financial support is enacted at a large scale and high speed

Net Zero 2030 (NZ30)

Further accelerating Net Zero to 2030 requires more extreme policy action.

This scenario requires a massive acceleration in deployment which is considered infeasible

Source(s): Aurora Energy Research

To reach Net Zero in 2035 a rapid deployment of renewable technologies is required onto a system modified to support them

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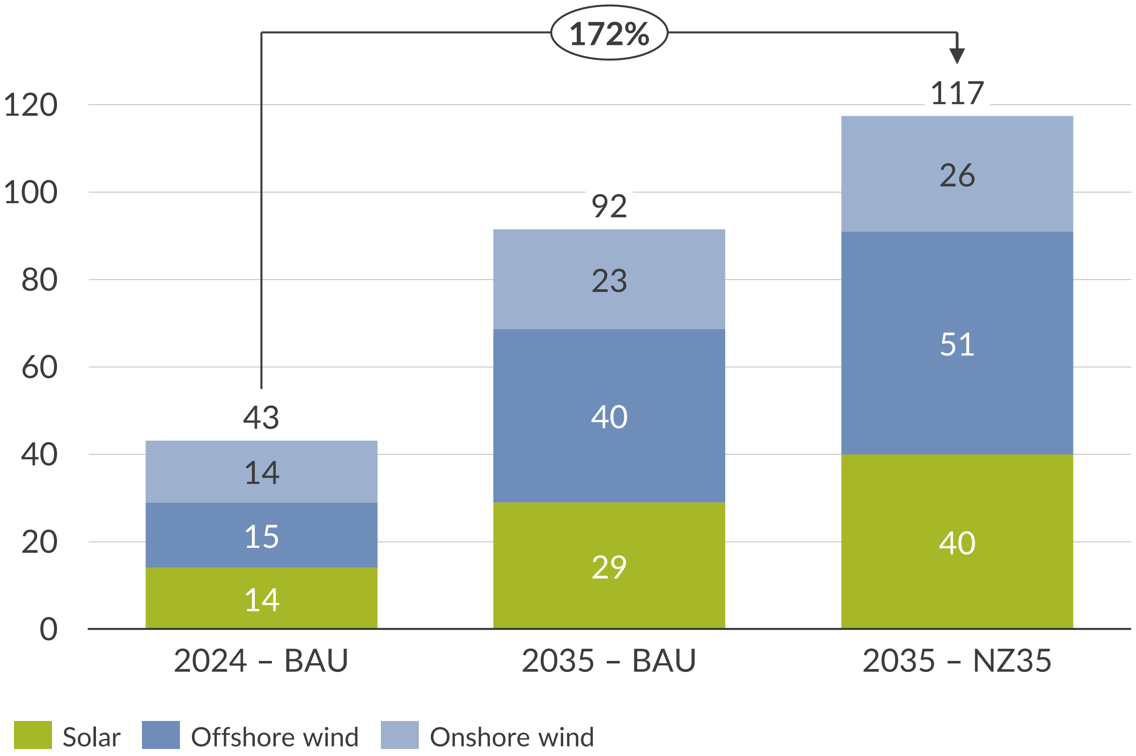
NZ35

Large scale renewables deployment is required to reach Net Zero, however must be accompanied by additional systemic change

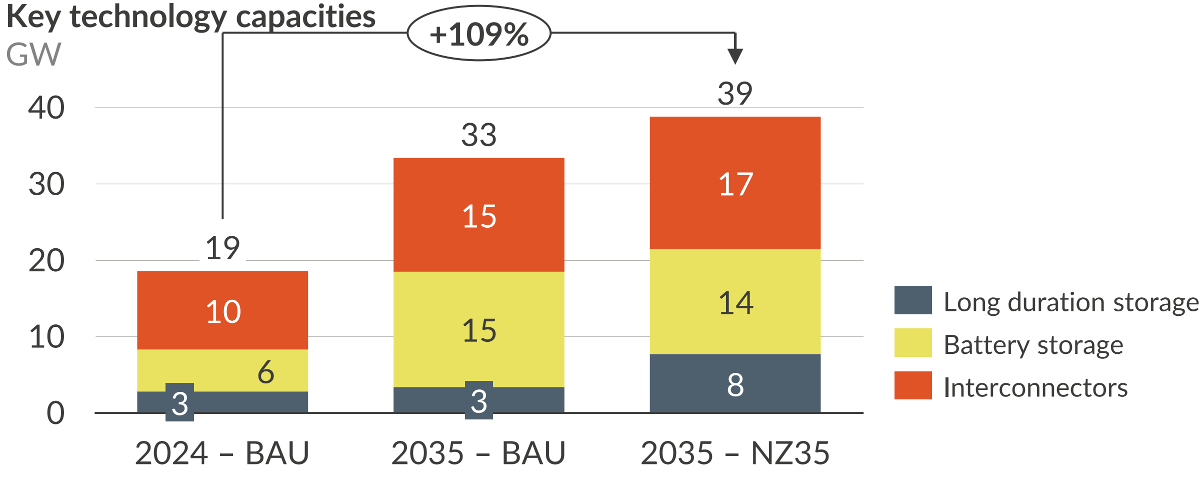
- Renewable capacities increase by 172% in order to reach Net Zero
- This must be accompanied by a doubling of flexible technologies, and tripling of key B6 boundary capacity to ensure the generation is effective

Installed renewables capacity
GW

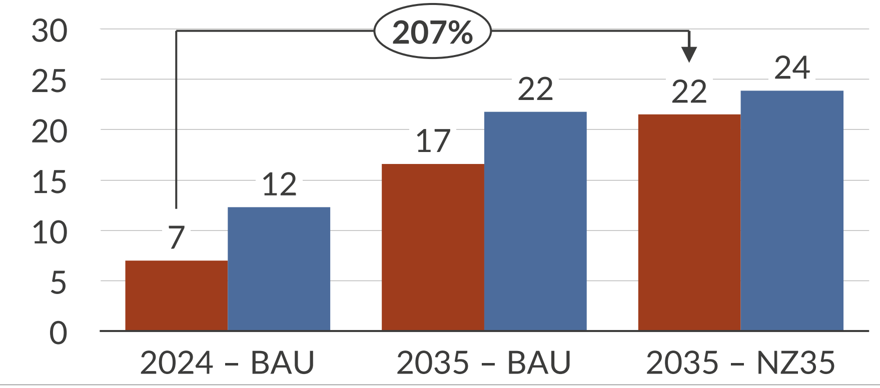


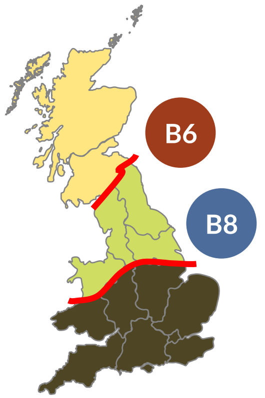
RES deployment must be accompanied by flexible technologies and infrastructure build

Key technology capacities
GW



Boundary capacity
GW



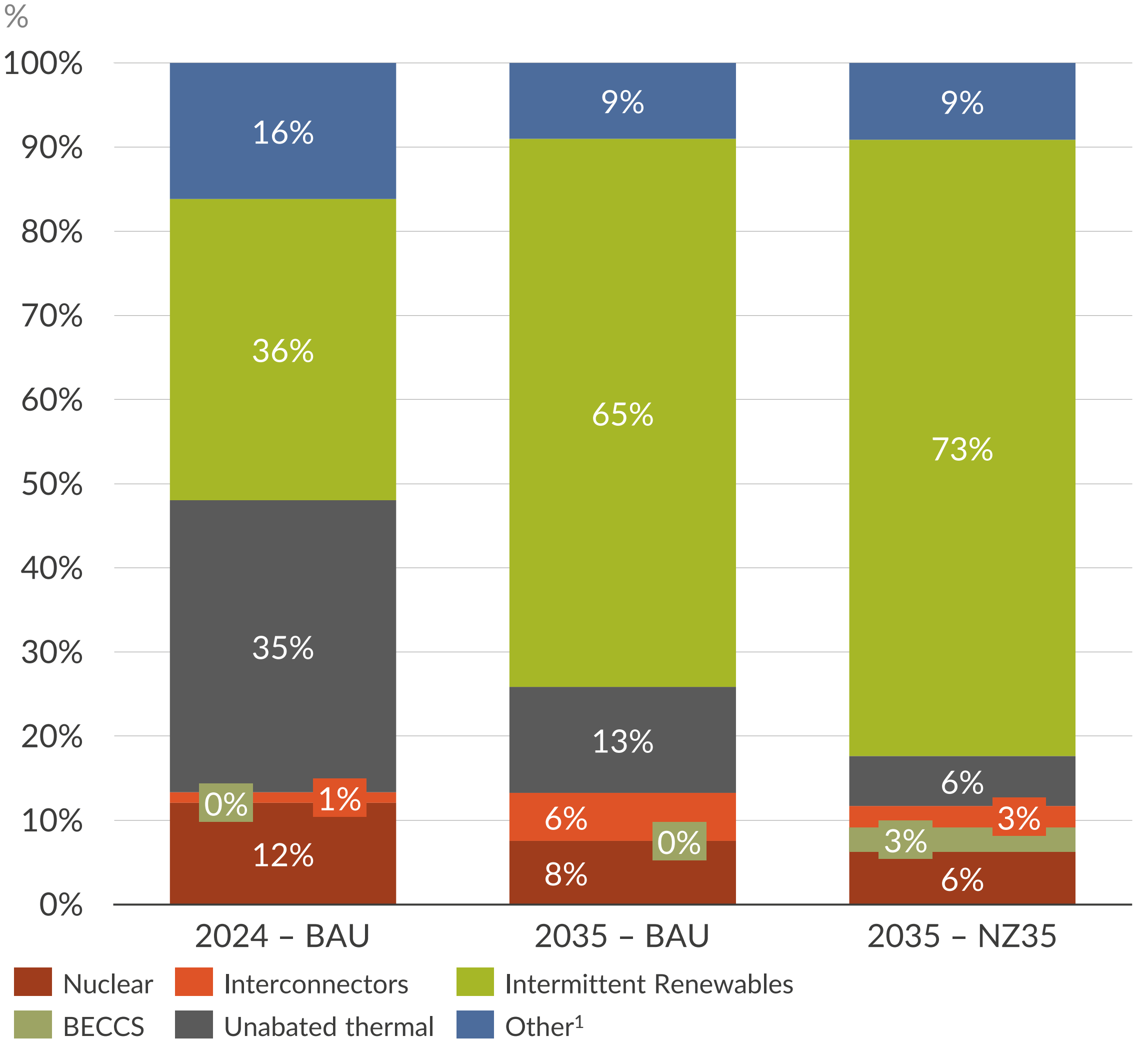


Source(s): Aurora Energy Research

Renewable generation reaches 73%, with the negative emissions technology required to offset gas peaking requirements

NZ35

Proportion of total generation by technology category



Despite massive growth in renewables, unabated gas fired generation is still required for security of supply, even when Net Zero is reached

- Direct renewable generation reaches 73% of total generation in 2035 when Net Zero is reached
- This is an 8% increase over BAU, where total power sector carbon emissions are still over 18MtCO_2e
- Even with Net Zero reached, unabated gas generation is still required to ensure system security at 6% of total generation
- These emissions are offset by the negative emissions of BECCS
- Net imports from interconnectors are reduced in 2035 in the Net Zero scenario by 3% compared to BAU, as greater inflexible renewable capacity is online
- Nuclear becomes a lower proportion of total generation in Net Zero, as no further nuclear capacity is able to operate on this timeline, and total demand is increased

1) Includes generation from storage, demand-side response (DSR), hydrogen peaking plants, hydrogen CCGTs, BECCS, biomass and gas CCS.

Source(s): Aurora Energy Research

The rapid deployment far outpaces the rate at which these technologies have been brought online to date

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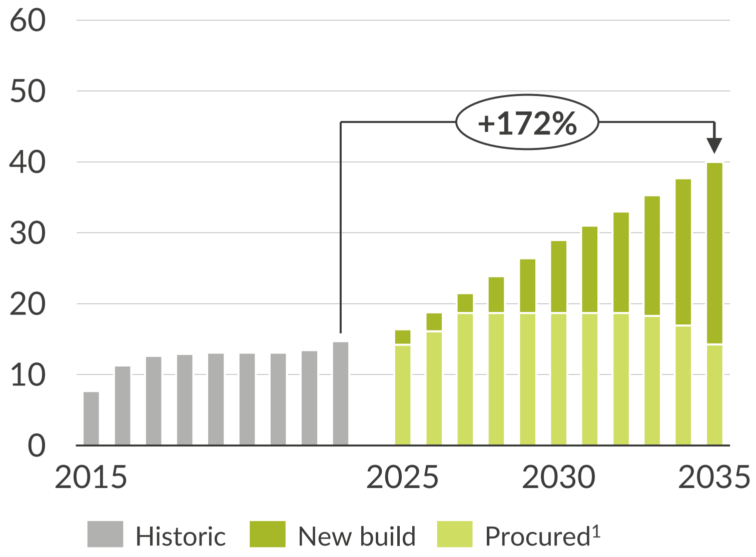
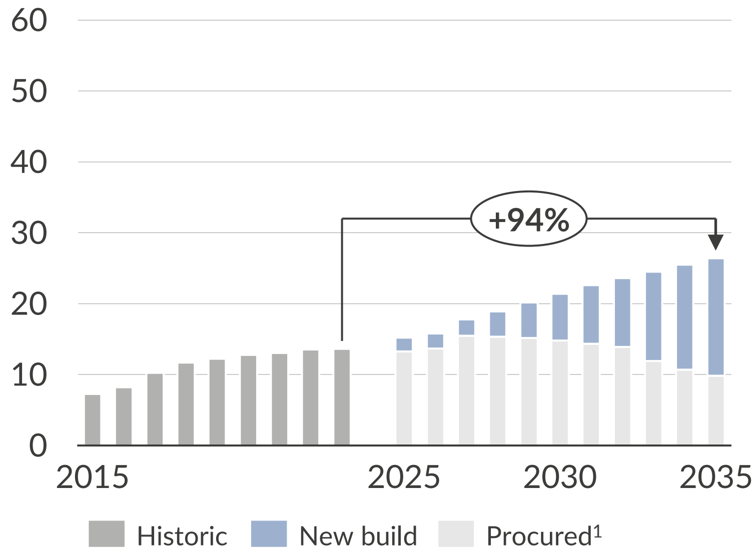
NZ35

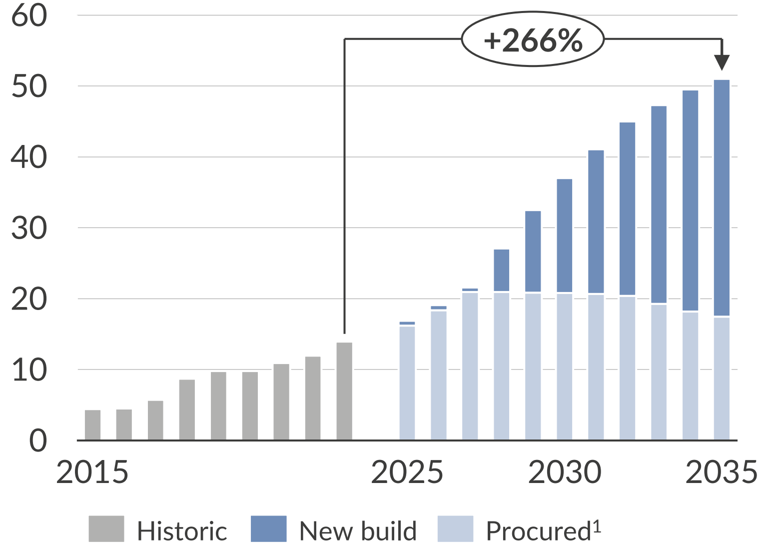
Solar capacity
GW



Onshore capacity
GW



Offshore capacity
GW



- Planning and connection delays have led to reduced growth in solar capacities, however the solar capacity must more than double in 10 years to reach Net Zero in 2035
- Planning constraints have also restricted onshore wind growth, however installed capacities must increase greatly to over 25GW in 2035
- Despite recent auction setbacks, offshore wind capacity has continued to rise, however the required capacity growth is the largest of all technologies, and must occur against a headwind of increasing cost and market reform uncertainty

Investment capex cost required for new-build renewable capacity to reach Net Zero power by 2035

2025–2030	£0.9bn/yr	£1.2bn/yr	£6.1bn/yr	=	£8.2bn/yr | £49.3bn
2031–2035	£1.4bn/yr	£2.2bn/yr	£7.5bn/yr	=	£11.1bn/yr | £55.3bn
2025–2035	£1.1bn/yr	£1.7bn/yr	£6.8bn/yr	=	£9.5bn/yr | £104.6bn

1) Procured in ROCs, FiT and CfD up to AR5.

Source(s): Aurora Energy Research

The required technology developments for Net Zero in 2035 are heavily dependent on policy that enables them

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NZ35

	Net Zero 2035	Feasibility assessment
RES increase	Increase to 40GW solar, 26GW onshore wind and 51GW offshore wind by 2035	The increases in capacity necessary are at a far greater rate than any previous deployment of RES in GB, which the current planning schemes and market setup are ill-equipped to support
Flex buildout	Increase to 14GW BESS, 8GW LDES and 17GW interconnectors by 2035	The current pipeline of assets could reach this capacity, however there are significant issues around grid connections, long timelines for large projects and lack of firm support for long duration energy storage
Grid buildout	Increase to 22GW B6 and 24GW B8 boundary capacity by 2035 as part of a wider transmission and distribution system upgrade	This is a greatly increased grid buildout compared to recent years, which would require large investment and planning reform, but is essential to reach Net Zero
Gas phase-out	Increase of carbon price, at a level of 27% above BAU in 2035	Carbon pricing could be used as a policy lever however would result in higher peak prices where gas unabated thermal plants are still required.
BECCS	3.3 GW of capacity by 2035	Reaching Net Zero requires negative emissions technologies to offset emissions from unabated thermal generation. The deployment of BECCS within the required timescales is unlikely given the lack of a developed framework and wider sustainability issues which must be decisively managed

Current trajectory   Change of trajectory   Infeasible

Source(s): Aurora Energy Research

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Significant additional ancillary services must be procured to maintain system operability and stability requirements

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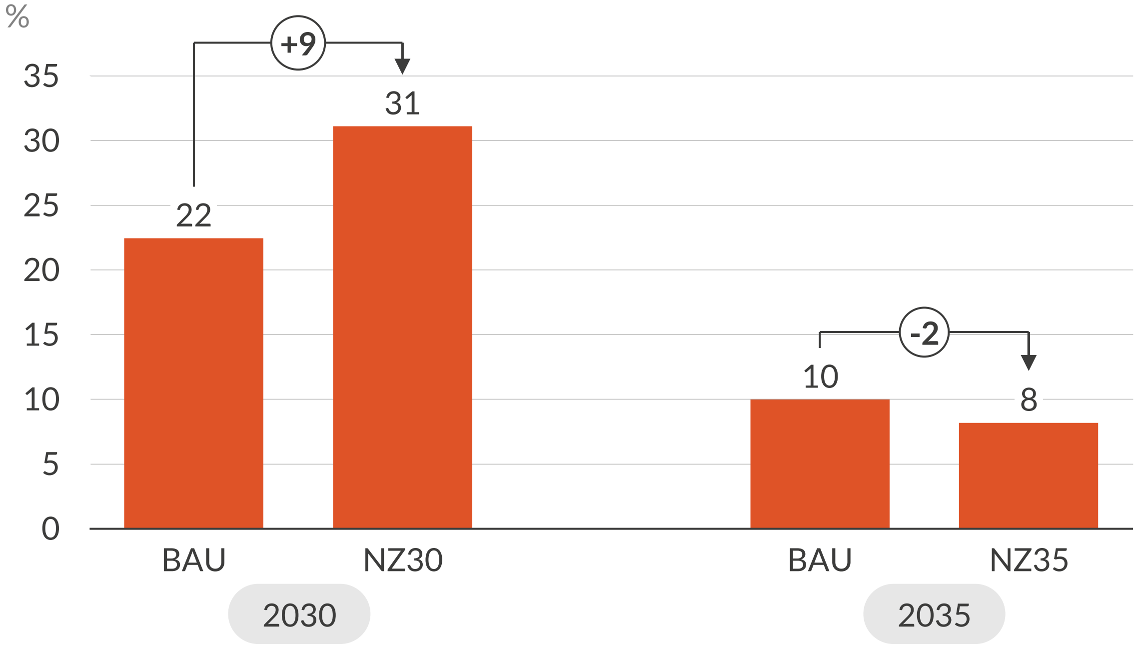
As the power system shifts to a renewables and flexible technology led system, system operability challenges must be addressed

- **Inertia and short circuit level**—Falling load factors for thermal plants will lead to reduced levels of inertia on the system, meaning that losses will lead to faster changes in frequency
- **Voltage (reactive power)**—Falling synchronous generation leads to increasing requirements for reactive power
- **Frequency response**—Increased variation in generation leads to faster and more frequent variations in frequency
- **Restoration**—Traditional providers of restoration services are large, transmission-connected thermal generators, which will reduce in capacity and load factor and must be replaced
- **Energy balancing**—Increasing volatility in supply, thanks to increasing intermittent generation in the form of wind and solar, are likely to result in larger Balancing Mechanism volumes, prices and costs

A number of responses have been announced to address these issues with larger procurement necessary alongside a faster Net Zero transition. These include:

- **Stability pathfinder auctions** (inertia)
- **Voltage pathfinder auctions** (reactive power)
- **Electricity system restoration tenders** (restoration)

Proportion of year where inertia is below the target limit



- With falling thermal generation and Hinkley Point C not yet online, 2030 represents a pinch-point in system inertia
- The Net Zero 2030 scenario has 39% more time where system inertia is below NGESO's 2025 limit of 96GVA.s
- Addressing this could results in additional turn-up of synchronous generation, particularly gas CCGTs, resulting in an increase emissions
- The Net Zero scenario has less time under the 2025 NGESO limit in 2035 at 8%, as higher demand and greater nuclear capacity contribute to system inertia

Source(s): Aurora Energy Research, National Grid ESO

Complimentary grid build is required to support the transportation of excess renewable generation from the North, to demand in the South

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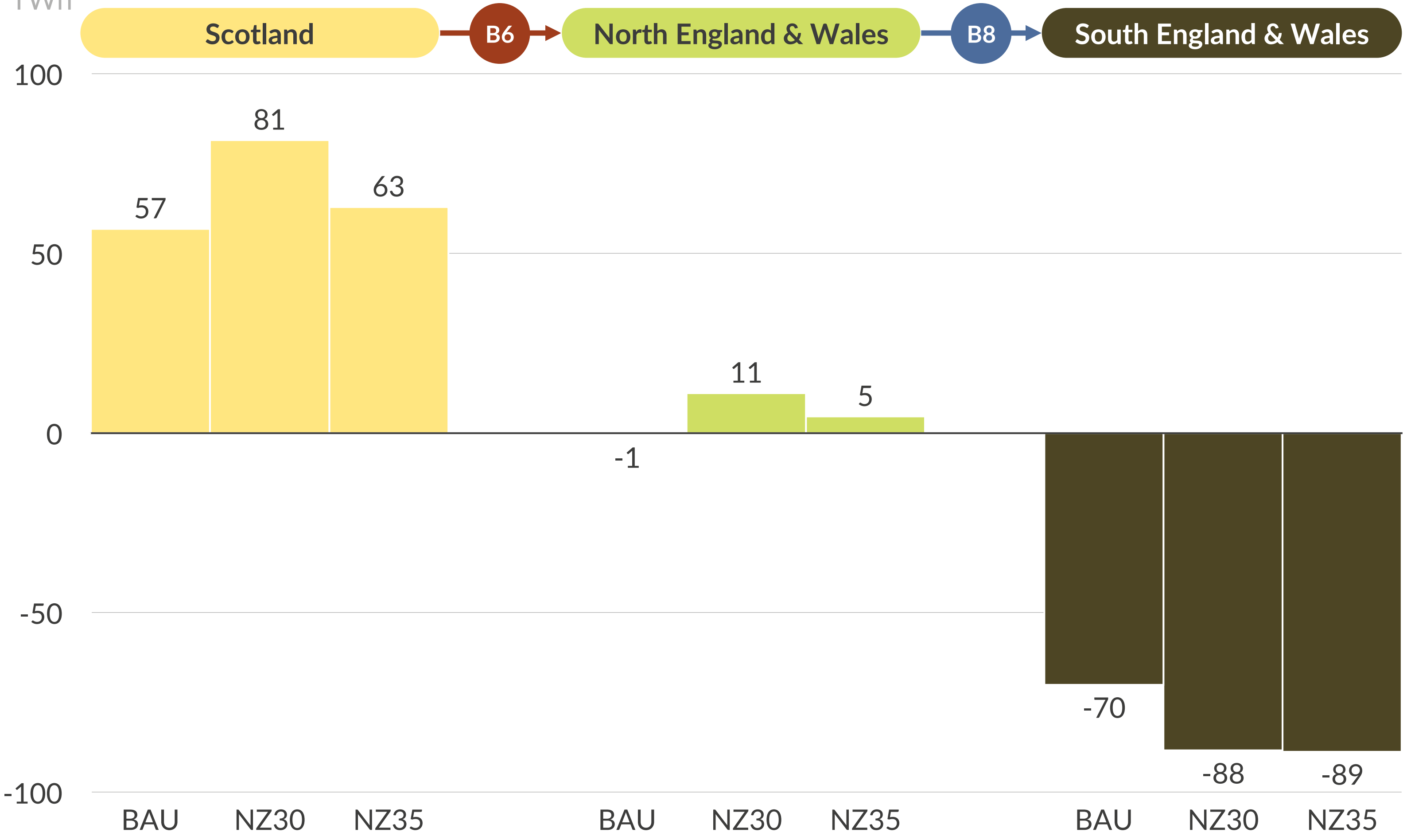
Excess zonal generation[1] in 2030
TWh



- Net Zero scenarios for 2030 and 2035 reveal a significant zonal imbalance between electricity generation in the north and demand in the south (170 TWh and 152 TWh respectively).
- This highlights the urgent need to accelerate grid build, enabling the transfer of excess generation in Scotland to high-demand areas in Southern England and Wales.
- Successfully accelerating grid build-out, especially across the B6 and B8 boundaries, will require major shifts in investment and policy priorities.
- Even with these shifts, implementation within a 10-year timeframe remains a significant challenge.

1) Excluding interconnector imports.

Source(s): Aurora Energy Research

To avoid excess curtailment, grid build must be accelerated to complement growth in renewables capacity

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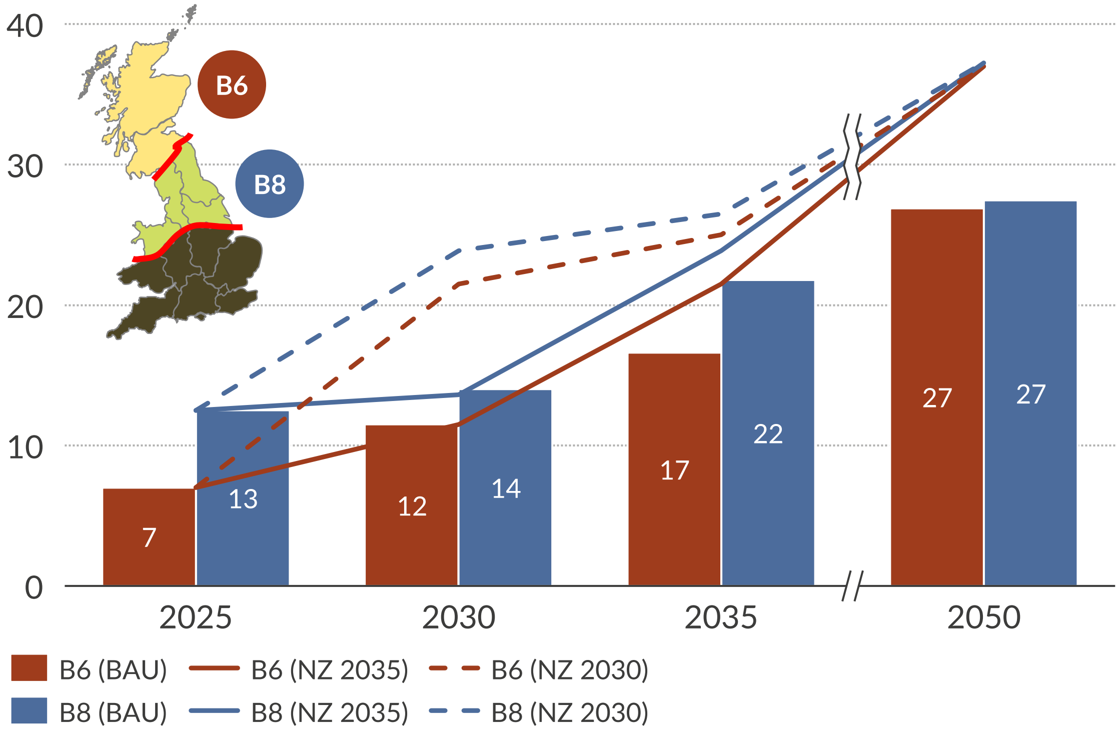
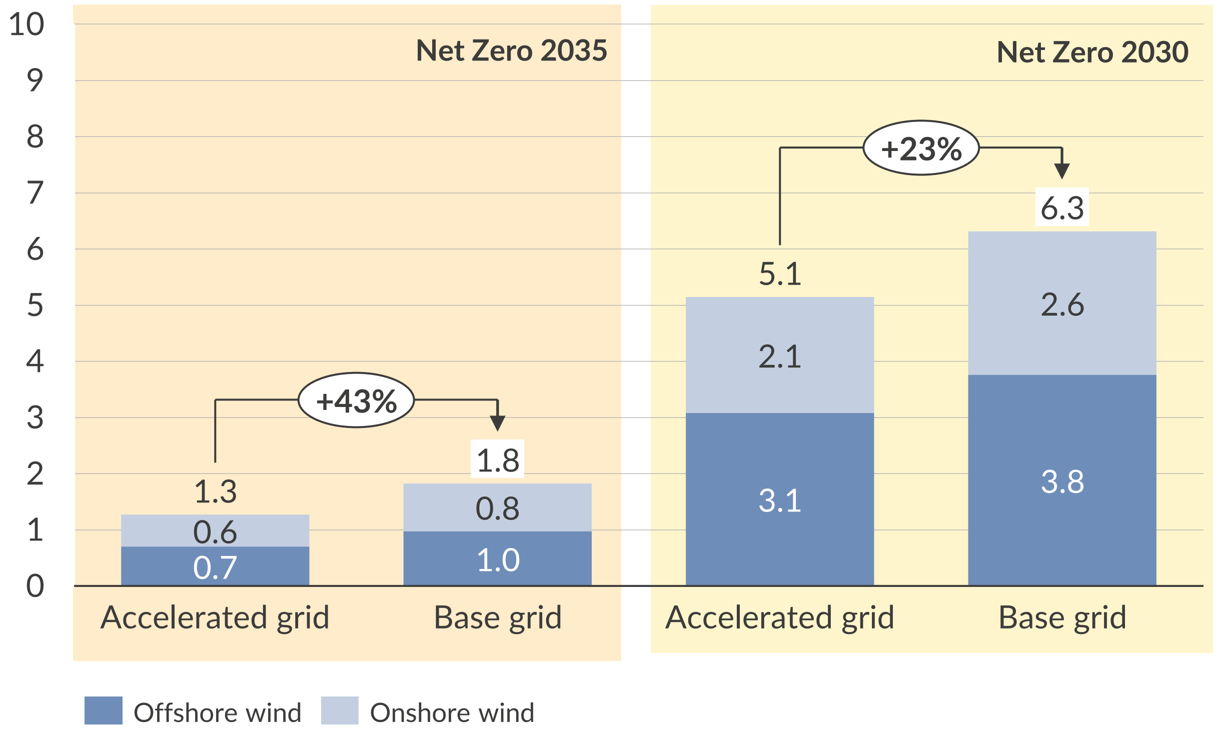
Network transfer capacity assumptions
GW - Nameplate



Yearly average curtailed wind volumes for 2025–2035
TWh



- The acceleration of grid capacity build across the key B6 and B8 transmission boundaries in the Net Zero scenarios will require a shift in investment and policy priorities, and even so will be challenging to implement within the 10-year time horizon

- Failure to adequately reinforce the grid, whilst continuing renewables deployment, will lead to excess curtailed volumes with an increase of 43% in the Net Zero 2035 scenario without grid trajectory modifications
- This generation will have to be replaced by turning up dispatchable power sources in the South, resulting in higher prices and carbon emissions

Source(s): Aurora Energy Research

Short term policy and investment decisions to reach Net Zero in the 2030s will have a lasting yet limited impact on GB's energy system

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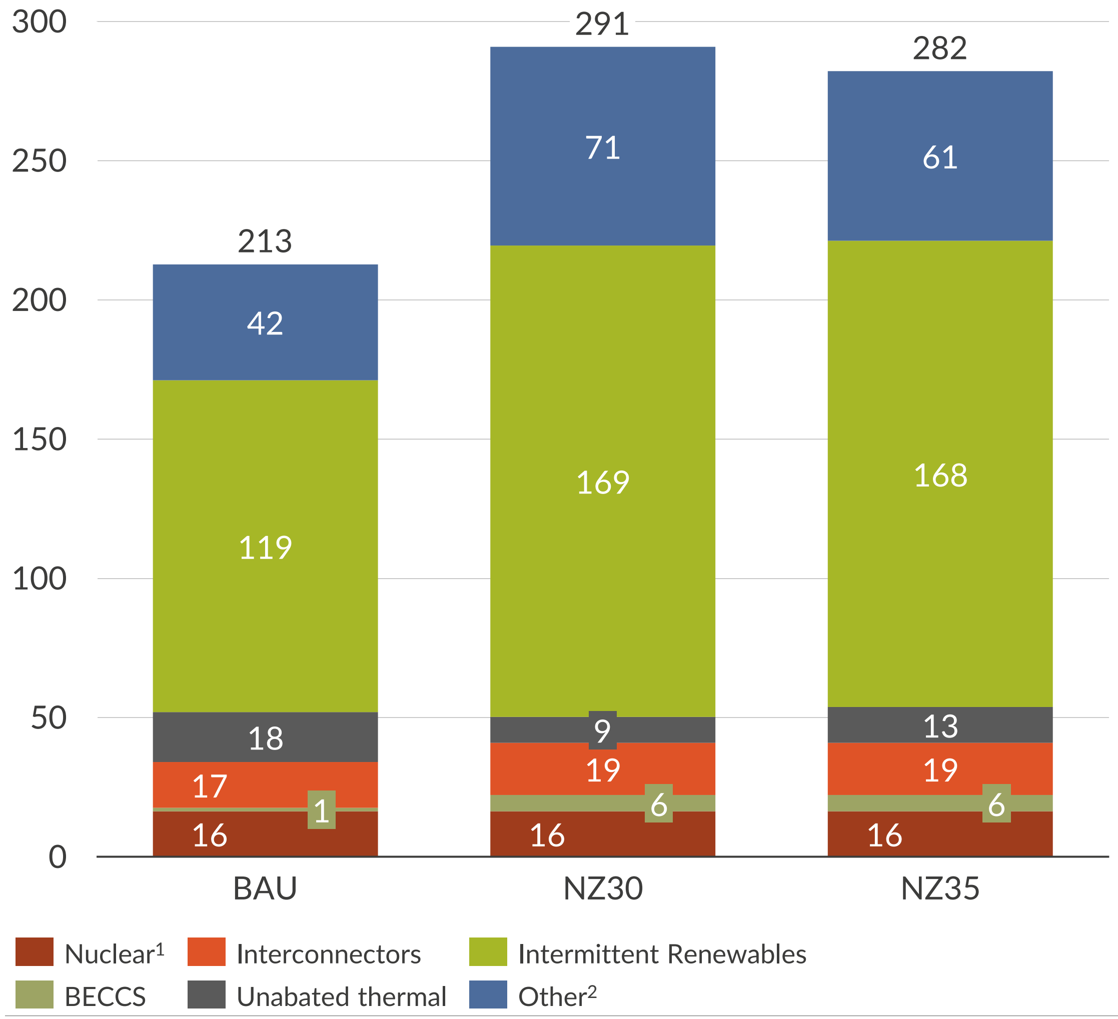
Installed Capacity in 2050

GW



A Net Zero system results in a greater capacity of low-cost renewable generation online in 2050, with a broadly similar overall composition

- Targeting Net Zero in an earlier year results in a greater proportion of renewables and flexible generation in these earlier years
- With Net Zero's expected higher demand, a larger power system results, reaching over 280GW of total capacity, compared to 213GW in BAU
- The resulting power system in 2050 for all scenarios has broad similarities:
  - High proportion of renewable capacity
  - Similar hydrogen and nuclear generation
  - Similar interconnection and short-duration flexible technologies
- However, the Net Zero scenarios do give lasting changes:
  - Increased CCS capacity
  - Greater long-duration storage capacity
  - Higher absolute levels of renewable capacity

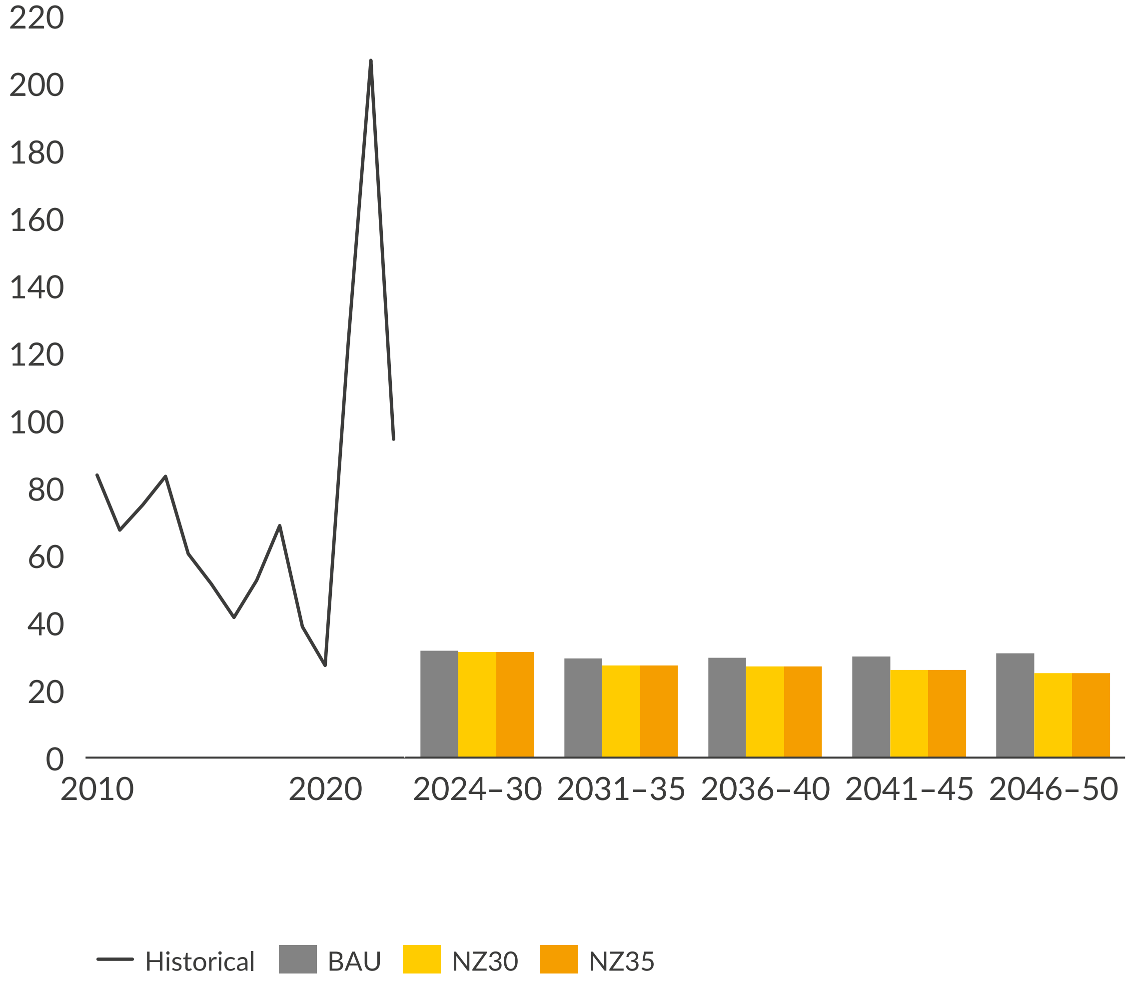
1) Assumes Hinkley Point C, Sizewell C and Bradwell B delays, with an upsizing of expected future capacity; 2) Includes generation from storage, demand-side response (DSR), hydrogen peaking plants, hydrogen CCGTs, biomass and gas CCS .

Source(s): Aurora Energy Research

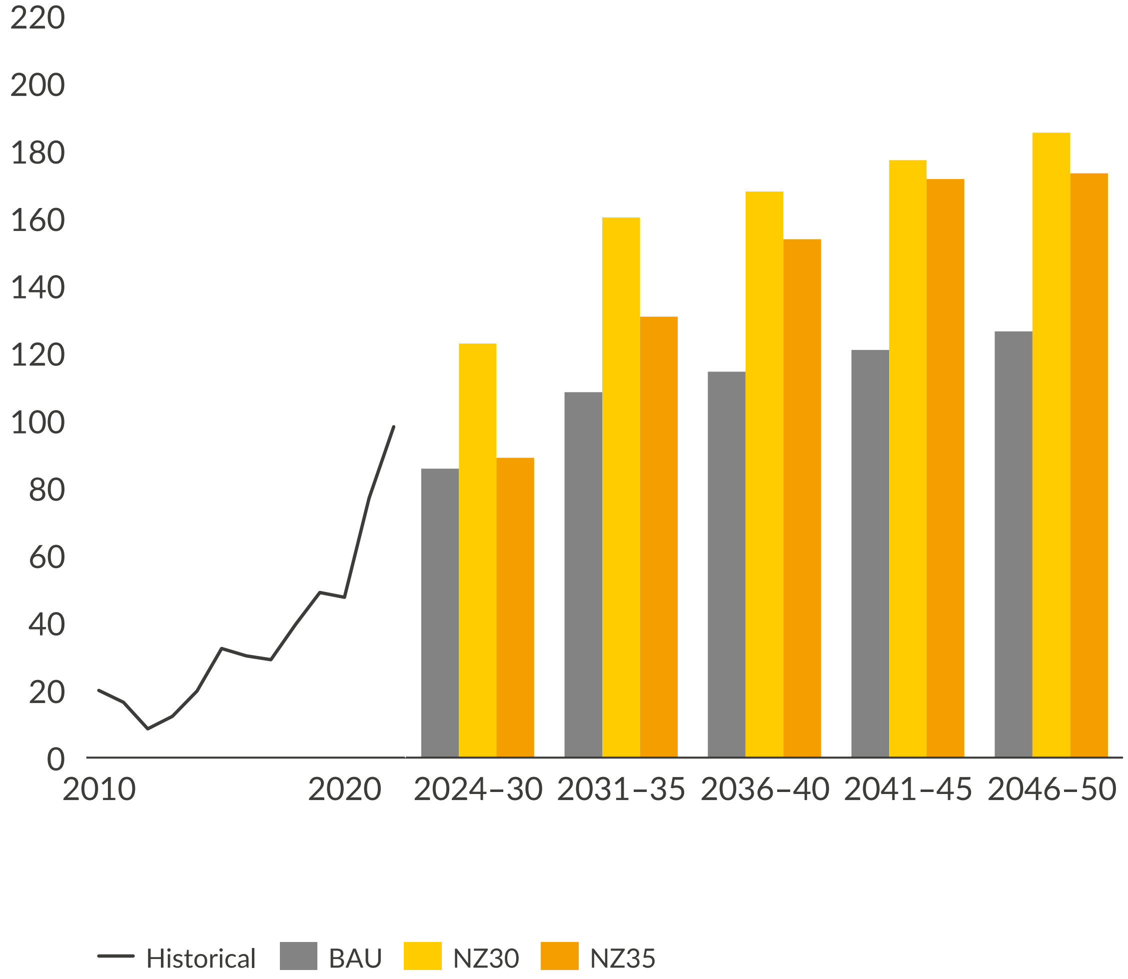
Contents

To reach Net Zero in 2030 carbon price mechanisms must be addressed to displace carbon intensive power sources

Natural gas prices
p/therm (real 2022)



Carbon prices (UK ETS + CPS)
£/tCO_2 (real 2022)

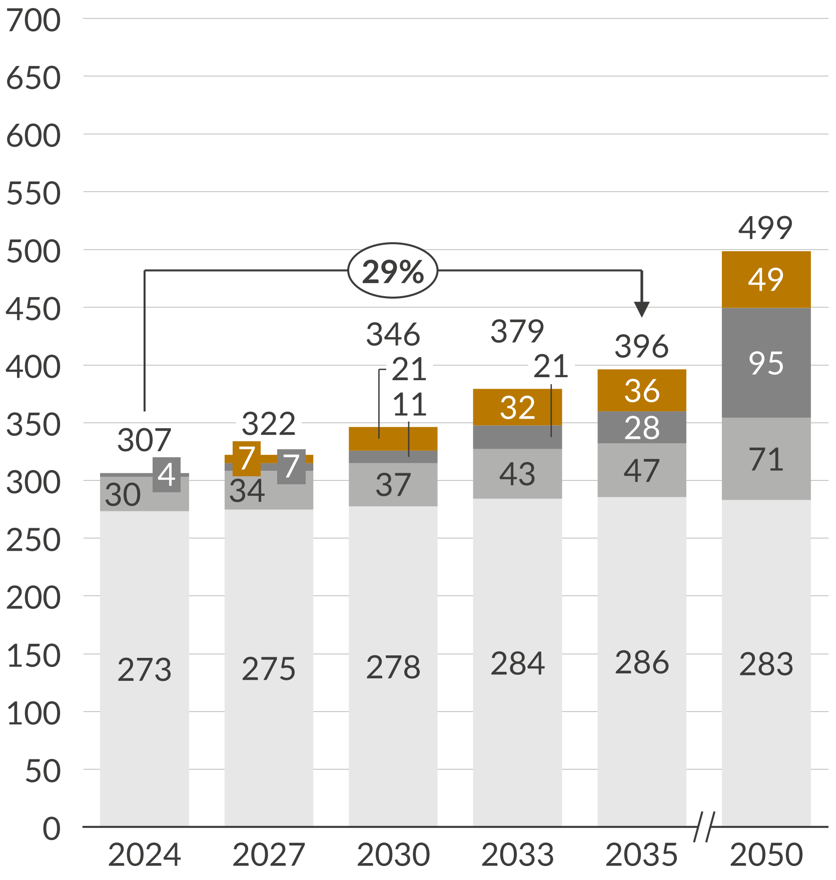


Source(s): Aurora Energy Research

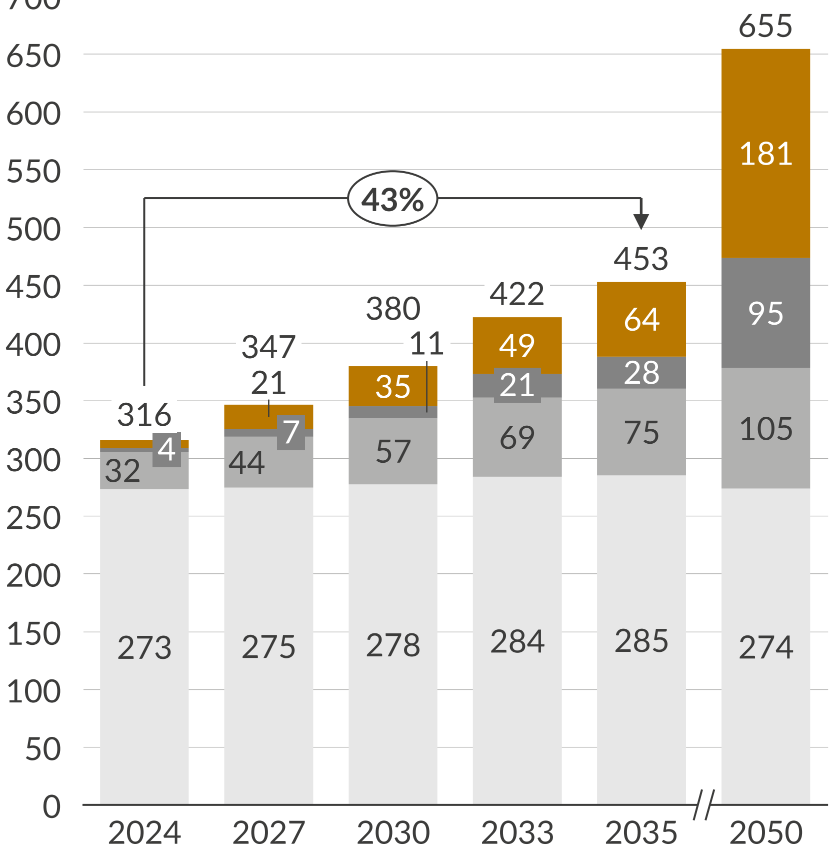
AURORA

Electrification of heat and transport supports a pathway to Net Zero while increasing total power demand in 2035 by 43% relative to 2024

Annual Power Demand – Aurora BAU
TWh



Annual Power Demand – Net Zero Scenarios
TWh



Base power demand[1] Heat pumps & P2H EVs Hydrogen[2]

- Annual power demand increases by 29% from 2024 to 2035 in the BAU cases
- The Net Zero scenarios demand increases further, with a 43% rise across the same time period
- This is driven by the assumption that wider and more stringent decarbonisation would accompany the drive to Net Zero in the power sector
- The increase in demand arises from assumed increases in heat pump and heat electrification power demand, and increased electrolysis to produce green hydrogen in the Net Zero scenarios
- For context, the CCC assumes a 50% increase in demand by 2035 from pre-covid levels[3]

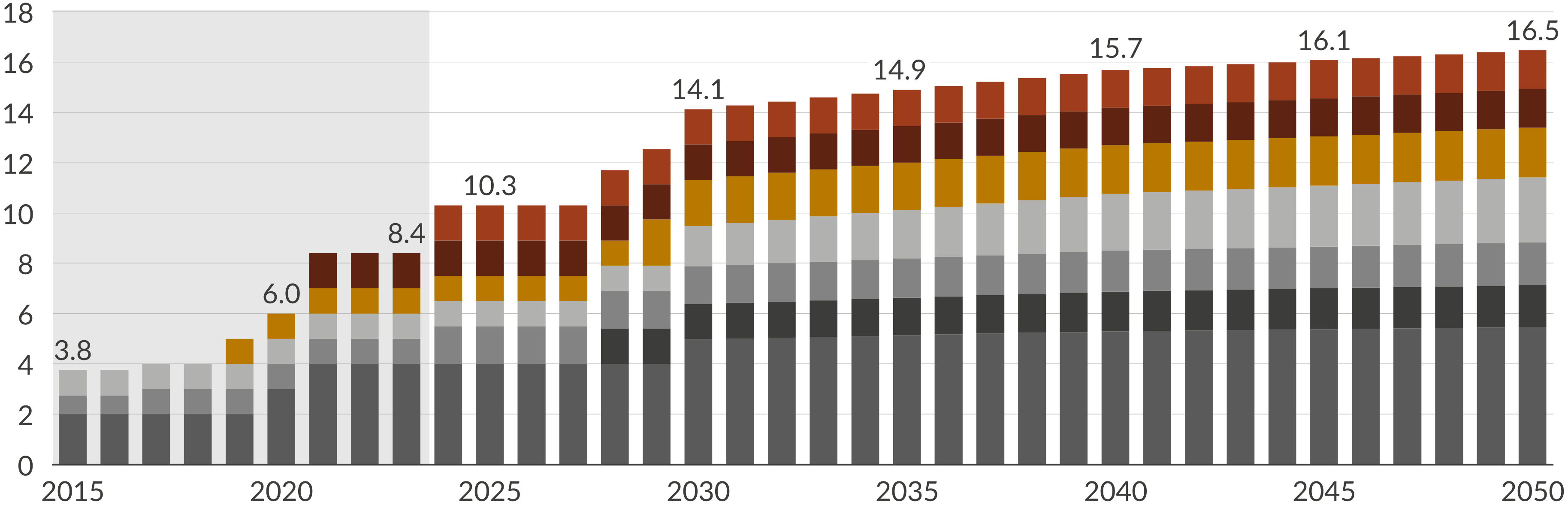
1) Underlying power demand excluding heat, hydrogen and transport; 2) Demand for Green hydrogen production from electrolysis; 3) CCC Report 'Delivering a reliable decarbonised power system' March 2023.
Source(s): Aurora Energy Research

AURORA

Given the high amount of uncertainty about interconnector deployment, we assume total capacity to reach 14.9GW by 2035

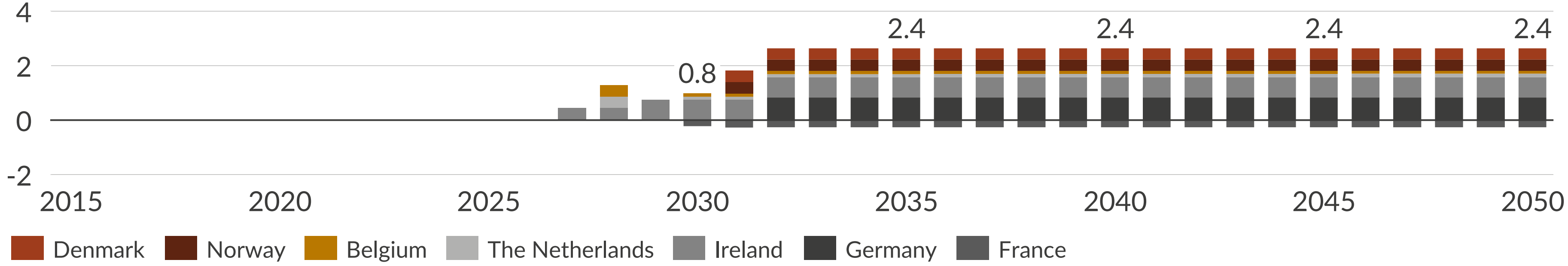
Installed interconnector capacity[1] – Aurora BAU

GW



Installed interconnector capacity delta[1] – Aurora Net Zero Scenarios

GW



- Given the uncertainty around interconnector deployment post-Brexit, we assume total capacity to reach 14.1 GW by 2030 and 16.9 GW by 2060
- Beyond the projects which have already started construction, we consider it possible for three more projects to deploy up to 2030[2]: one each to Belgium, the Netherlands and France
- After 2030 we anticipate further gradual capacity build-out, in line with expanding intermittent renewable capacities

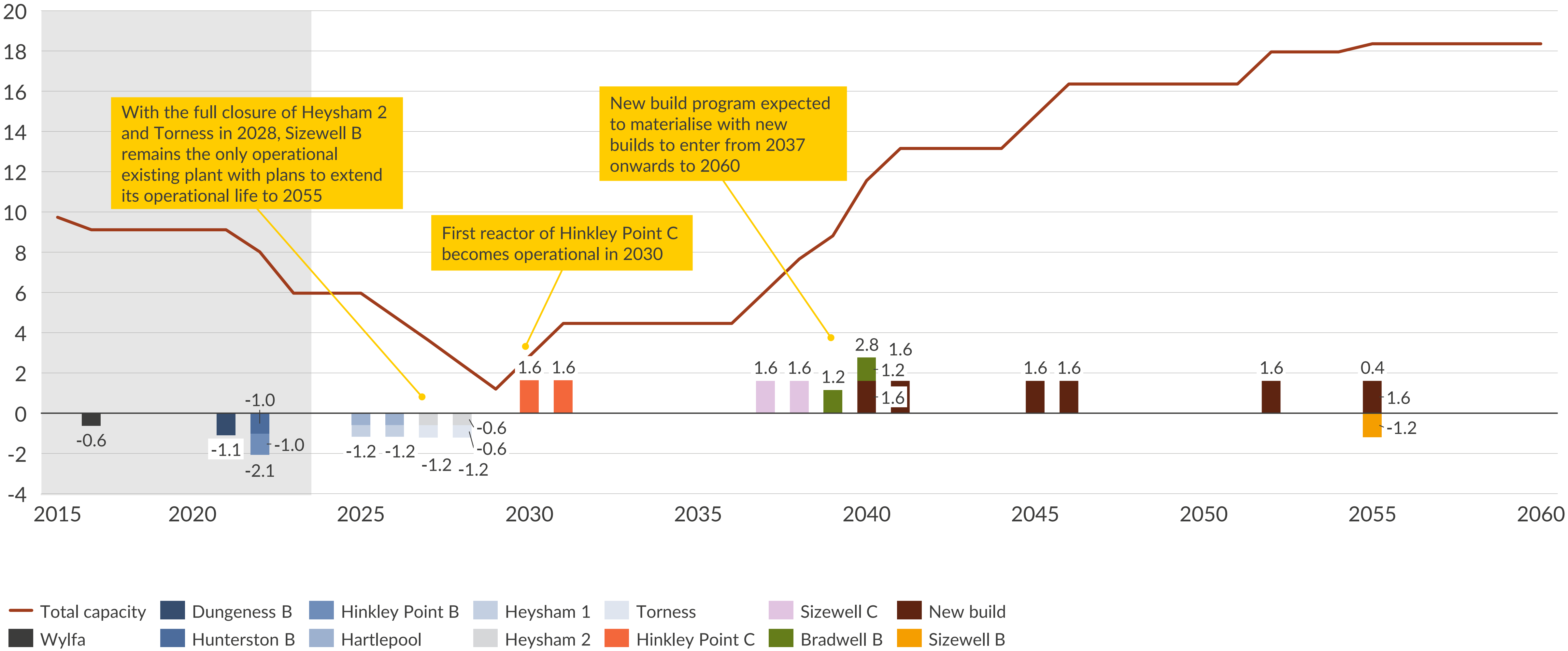
1) Based on end-of-year capacity; 2) The capacities of the three projects currently in development are de-rated in our scenario according to their development stage to reflect historic success rates.

Source(s): Aurora Energy Research, Ofgem, European Commission

In all scenarios Aurora assumes 5GW of existing nuclear will decommission by 2030, while 13.9GW of new builds deliver beyond Hinkley Point C

Installed nuclear capacity – All scenarios

GW



1) Line chart represents end-of-year capacity.

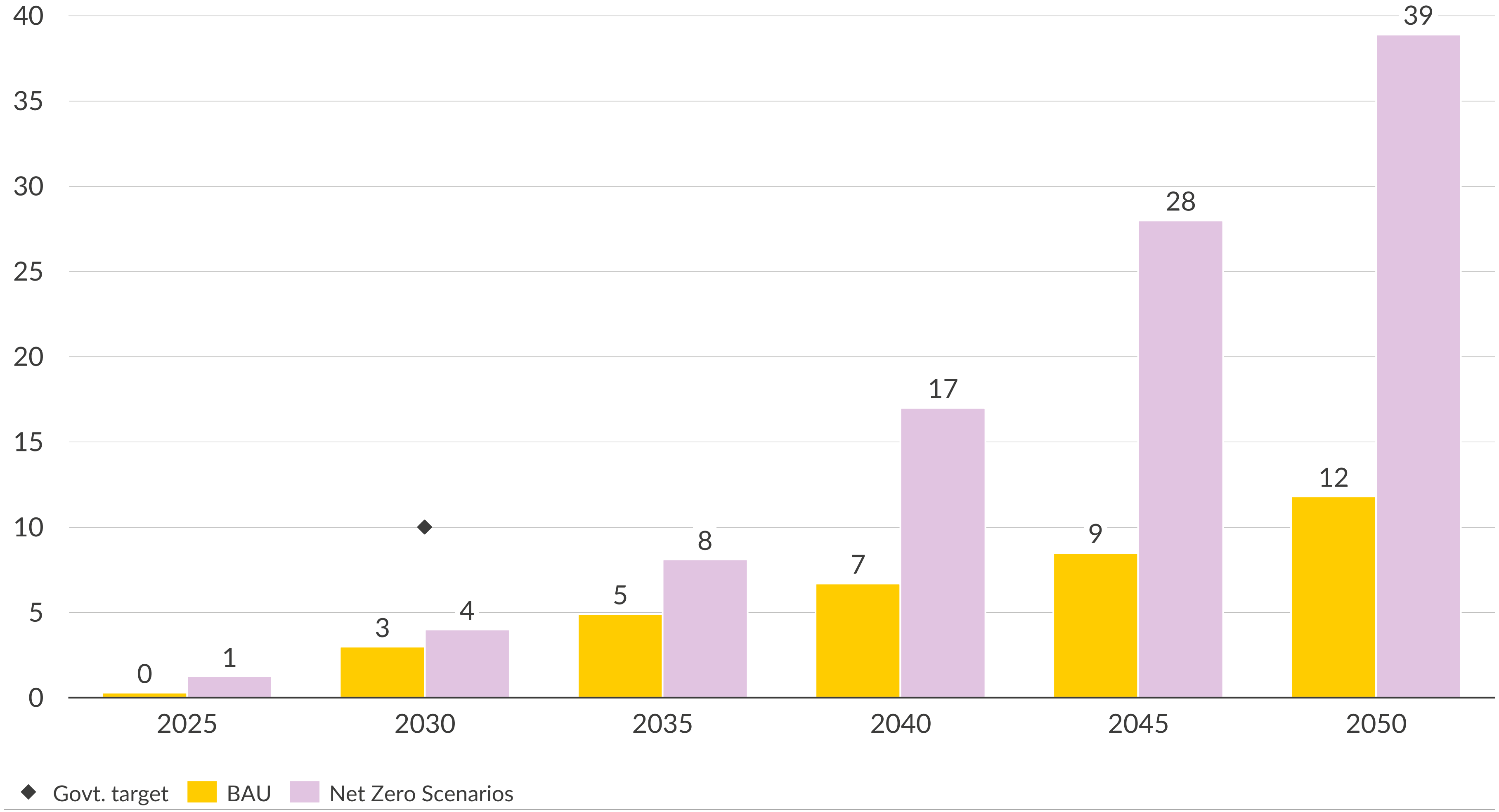
Source(s): Aurora Energy Research

AURORA

Government targets 10GW of low carbon hydrogen production by 2030, electrolyser capacity is expected to reach 12GW by 2050

Electrolyser capacity timeline

Installed capacity GW (H_2)



Source(s): Aurora Energy Research

- Aurora's BAU scenario assumes 3GW of low carbon hydrogen production by 2030 with a mix of electrolysis and gas reformation
- For green hydrogen production which directly impacts the power sector, we assume 5GW of large-scale alkaline electrolysers by 2035
- In the Net Zero scenarios, further electrolyser capacity is anticipated, reaching 8GW in 2035
- The Government's ambition is for up to 10GW of low carbon hydrogen capacity by 2030 as published in the 2022 British Energy Security Strategy (BESS) and the August 2022 Hydrogen Strategy Update

Contents

Unique, proprietary, in-house modelling capabilities underpin Aurora's superior analysis

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4 Integrated Models

Hydrogen (AER-HY)

Carbon (AER-ETS)

Power markets (AER-ES)

Global Commodities & Gas (AER-GLO/GAS)

INPUTS

- Technology
- Policy
- Demand
- Commodity prices[1]
- Weather patterns

Dispatch model

- ½ hourly or hourly
- Iterative modelling
- Dynamic dispatch of plant
- Endogenous interconnector flows

Continuous iteration until an equilibrium is reached

Investment decisions module

- Capacity market modelling
- Capacity build / exit / mothballing
- IRR / NPV driven
- Detailed technology assessments

OUTPUTS

- Capacity mix
- Generation mix
- Wholesale & imbalance prices
- Capacity market prices
- Profit / Loss and NPV
- Electric vehicle charging

1) Gas, coal, oil and carbon prices fundamentally modelled in-house with fully integrated commodities and gas market model

Source(s): Aurora Energy Research

Aurora's GB locational balancing model simulates power flows across key network boundaries to forecast system actions in the balancing mechanism

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Aurora's **locational balancing capabilities** simulate thermal constraints and associated system actions used to manage power flows across the B6 and B8 network boundaries. These additional features aim to capture the impact of thermal constraints on market prices which influence the capacity and generation mix in GB.

1 Inputs

Identify key constraints and assumptions for their future transfer capabilities

- **Identify B6 and B8 boundaries as key bottlenecks** in the GB transmission network
- **Plant Mapping -** allocating plants to specific balancing zones
- **Demand Mapping** – allocating demand to specific balancing zones

2 Balancing Module

Solve for system and energy balancing actions

- **Solve system balancing** by re-dispatching with boundary transfer (thermal) constraints, using unconstrained dispatch as starting point
- **Determine energy balancing** merit order stacks based on weather and demand uncertainty and wholesale market opportunity costs
- **Calculate system price** based on energy balancing actions

3 Balancing Market Outcomes

…to determine the balancing market volumes and prices at half-hourly granularity

- **Average accepted bids/offers** by balancing zone
- **Balancing Mechanism profits** by plant
- Stochastic system-wide **Balancing Mechanism price**
- System-wide **Gross Imbalance Volumes (**Net Imbalance and Bidirectional balancing)

4 Market-wide Outcomes

These are fed into the model's build decisions to determine asset-specific revenues

- **Capacity build decisions**

Source(s): Aurora Energy Research

Details and disclaimer

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