CRACKS IN THE SYSTEM

How the UK’s nuclear energy gap could be larger than thought.
EXECUTIVE SUMMARY

Britain may be facing a greater shortfall in low-carbon electricity generation than has previously been suggested. Not only are a number of proposed new nuclear power stations in doubt, but some of the UK’s oldest reactors have seen technical problems in the last few years that could see them having to close ahead of time.

The UK’s fleet of Advanced Gas-Cooled Reactors (AGRs) have been reliable providers of low-cost, low-carbon electricity for decades. However, they are now nearing the end of their operational lives. As they do so, safety concerns with an issue known as keyway root cracking have forced shutdowns at the Hunterston B and Hinckley Point B power stations. It is possible that one or both of the Hunterston reactors may not return to action, and that cracking in other AGRs may also prove terminal ahead of currently-scheduled closure dates.¹

In recent years, Government has progressively reduced its forecasts of the amount of new nuclear capacity coming online, as the cost of renewables has fallen faster than anticipated and backers have pulled away from projects such as Moorside in Cumbria. Reviews by bodies such as the National Infrastructure Commission (NIC) have shown that the UK power system needs fewer new nuclear stations than Government has historically believed. However, none of these assessments has so far taken into account the potential for early closure of AGRs.

This report considers the impacts that would occur if all AGRs closed three years ahead of schedule. This scenario would seem to be a real possibility given that Hunterston B, scheduled for closure in 2023, was found to have potentially terminal cracking in 2018 and, at the time of writing, remains closed.

This is just one indicative scenario. Should the UK’s nuclear regulator find that cracks are worse than thought, it is feasible that it could order all affected plants to close at once, or they could close on a different timescale. Either way, it should not be taken as a given that they will continue to operate to historical levels during the 2020s.

A three-year-early closure across the AGR fleet would lead to a reduction in nuclear capacity (below Government forecasts) reaching 4.5 gigawatts (GW) in 2023-4. For comparison, this is about one and a half times the capacity of the new nuclear power station being built at Hinckley Point C.

This would be unlikely to provoke a shortage in the nation’s electricity supply, as – in the absence of new policies – more power could be sourced from gas-fired units (and from coal, until 2025), and some gas-fired power stations scheduled for closure in the mid-2020s might remain open for a few years longer. Alternatively, more power could be imported along the burgeoning network of undersea cables connecting the UK with other European nations.

¹ By ‘scheduled closure dates’ we mean here the dates at which closure is currently set. Most of the AGRs have had their scheduled lifetimes extended, as discussed later in this report.
However, the premature reduction in carbon-free electricity from the AGRs would make it more difficult to achieve climate change targets without new policies to incentivise investment in additional generation capacity, energy efficiency or demand-side response.

The UK is already off-track to meeting the Fourth and Fifth Carbon Budgets, covering the periods 2023-27 and 2028-32 respectively. Further, the Clean Growth Strategy requires gas generation to decline by about two percentage points per year. And Government is expected soon to sign into law a target of reaching net zero emissions around mid-century, a commitment that will mean it becomes economically pragmatic to accelerate decarbonisation in the near-term rather than seeing it retarded.

This report examines four potential ways of replacing the potentially lost generation:

1. Increasing development of offshore wind
2. A mix of onshore and offshore wind and solar
3. Natural gas
4. Alternative nuclear technology, namely small modular reactors (SMRs).

The peak AGR deficit, if it occurs on the timeline described herein, would happen before the coal phase-out cutoff of 2025 – therefore, an extension of the coal phase-out was not considered here as a policy response. In any case, we consider it vanishingly unlikely that ministers would contemplate an extension given the government’s commitment to climate change targets, agreed generation limitations under the Industrial Emissions Directive, its leadership of the Powering Past Coal Alliance, and growing public concern about both climate change and air pollution.

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2. Published in 2017, the Clean Growth Strategy (https://www.gov.uk/government/publications/clean-growth-strategy) is Government’s plan for delivering carbon reductions across the economy. By 2032, it envisages gas generation providing a maximum 15% of UK electricity (compared with about 40% now).
This report cites evidence showing that SMRs, which currently do not exist in commercial form, are very unlikely to be ready in time to play a role. It also shows that increased use of natural gas would put severe pressure on carbon budgets, and that both of the renewables-based strategies are feasible, contributing the ‘missing’ volumes of low-carbon electricity without compromising climate change commitments.

Importantly, both the renewables-based options – especially Option 2 – come in cheaper than allowing gas generation to fill the gap.

Increasing the amount of renewables capacity on the timescale indicated would require new policies – an expansion of the existing support mechanism for offshore wind (Contracts for Difference, CfDs) and/or a new mechanism that would effectively re-boot onshore wind and solar power. For onshore wind and, increasingly, for solar, this would not amount to a subsidy, as prices for new build are below the wholesale electricity price, but would involve providing a guaranteed, predictable return.

Accelerating renewables build in this way would appear to be a no-regrets option. If it transpires that the AGRs do all operate successfully until their scheduled retirement dates, the only consequence of accelerating renewables deployment would be a sharper fall in carbon emissions from the power sector as new renewables further displace coal (until 2025) and gas generation. As the Committee on Climate Change has repeatedly advised government – and as government admits in the Clean Growth Strategy – additional low-carbon policies are in any case needed to hit carbon budget targets. In addition, the extra renewables capacity in place would then act as a hedge against non-delivery of in-doubt new nuclear facilities post-2025.

A rollout of more variable renewables could also bring with it an increase in flexible technologies that ensure supply always meets demand. Boosting capacity of storage, interconnection and demand-side measures could cut energy bills by £8 billion per year, according to the National Infrastructure Committee, and is generally seen as a no (or very low) regrets option.

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Nuclear power has been a mainstay of the UK’s electricity mix for decades. Since the world’s first commercial-scale power station opened at Calder Hall in 1956, a vast amount of nuclear-generated electricity has flowed into British homes and businesses. During the past several years, around one-fifth of British electricity has been generated in nuclear power stations, helping to push the proportion of low carbon electricity in the national system to more than half in both 2017 and 2018.

However, the UK’s nuclear fleet is now ageing quickly; two of the oldest operational reactors in Europe are both located on British soil.

The oldest of the seven power stations that make up the UK’s fleet of Advanced Gas-cooled Reactors (AGRs) have been in operation since 1976. They are all currently expected to retire by 2030, leaving just one existing nuclear plant, the Sizewell B Pressurised Water Reactor (PWR) in Essex, in operation.

<table>
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<th>Nuclear power station</th>
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<th>Operational Capacity (GW)</th>
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<tbody>
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<td>Hunterston B</td>
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<td>1.0</td>
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<tr>
<td>Sizewell B (PWR)</td>
<td>2035</td>
<td>1.2</td>
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</table>

Table 1: Planned closure dates and capacities of the UK’s nuclear fleet. Source: EDF

The AGRs are all now close to reaching, or operating beyond, their original expected retirement dates. The lifetimes of the two oldest plants – Hunterston B and Hinkley B – have been extended twice, first to 2016 then to 2023, lengthening their operational lives by 12

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4 http://www.bbc.co.uk/cumbria/content/articles/2006/10/16/sellafield_50years_feature.shtml
6 Hinkley B and Hunterston B have both been in operation for 43 years. The oldest nuclear plant in Europe is Beznau in Switzerland, which has been in operation since 1969.
7 Only one plant from the current fleet, EDF plans to have both reactors at Hinkley Point C running by this date.
8 https://www.edfenergy.com/energy
years. For Hunterston B, which was originally set to close in 2011, this is an extension of more than 25% of the previous expected lifetime.

In 2016, EDF applied for regulator approval to again extend the lifetimes of more of the AGR fleet, pushing back the retirement of Heysham 1 and Hartlepool by five years to 2024, and Heysham 2 and Torness by seven years to 2030 (Table 1).  

EDF has also stated that it plans to extend the life of the UK’s nuclear fleet as long as possible, therefore these dates are not set in stone. Running each plant for five more years has been shown to be one of the best ways of reducing gas burn during the 2020s.  

Ministers and policymakers appear to have assumed that these lifetime extensions will occur unhindered, and that the UK’s fleet of nuclear power stations will continue to meet 10-15% of national power demand during the 2020s.  

This is slightly lower than current levels due to assumptions of declining load factors. Nonetheless, it remains a significant contribution to the British electricity supply.

As such, official projections and forecasts include power from these power stations until the end of the next decade.

However, issues related to long-term radiation exposure of reactor components have raised concerns that not all of the UK’s AGR fleet will be able to continue operating as expected.

Over years of use, the material properties of graphite bricks in the reactor cores are affected by neutrons produced during the fission process and from oxidation by the coolants used as part of safe operation. This results in a phenomenon known as keyway root cracking, in which tension between inner and outer layers of the brick leads to fractures.

It is not possible to remove and repair these components, therefore engineers expect cracking to ultimately cause the closure of AGR units. EDF, owners of the UK’s nuclear fleet, said in May 2018 that “[keyway root cracking] would probably limit the lifetime for the current generation of AGRs.”  

Issues affecting the graphite reactor cores have started to blight the two oldest plants, Hunterston B in Scotland and Hinkley Point B in Somerset, raising concerns that the rest of the fleet could begin to be affected. Cracks in bricks at Heysham 1 and Hartlepool were also found in 2014, although less severe than those at Hunterston B.

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10 https://sandbag.org.uk/project/coal-to-clean/
12 https://www.bbc.co.uk/news/uk-scotland-glasgow-west-46290475
13 http://www.onr.org.uk/civil-nuclear-reactors/graphite-core-ageing.htm
15 https://www.bbc.co.uk/news/uk-england-lancashire-29672953
British AGR power stations are the only units in the world that are affected by this issue, therefore there are uncertainties over the best course of action.16 Without precedent in dealing with the issue of keyway root cracking, there is little information available on the scale of the issue or how long plants can operate safely once defects are detected.

The UK’s Office for Nuclear Regulation imposes some of the world’s highest standards on nuclear safety, therefore any plants that are at risk of operating below these are at risk of being closed, either temporarily or permanently.

Should generation from the AGR fleet fall short of expectations over the coming decade, there is risk of a clean power gap forming, unless new low-carbon capacity is built to fill the hole.

This gap would comprise the time between the decommissioning of the existing fleet and the currently-delayed construction of the next generation of nuclear power stations. The expectation that a decarbonised and expanded electricity system will be increasingly used to cut emissions from other sectors – such as transportation or heating – renders this concerning.

Only one nuclear power station is currently under construction in the UK, EDF’s 3.2 GW Hinkley Point C project in Somerset. It appears likely that this power station will progress to completion, with switch-on scheduled for 2025-26. However, EDF is facing significant financial difficulties and with other European Pressurised Reactor (EPR) projects blighted by long delays, it cannot yet be considered to be a certainty that the plant will be commissioned on time.

16 http://www.onr.org.uk/civil-nuclear-reactors/graphite-core-of-agrs.htm
Attempts by the government to persuade investors to back other plants have faltered. Developers have walked away from proposed reactors at Moorside, Wylfa Newydd and Oldbury, while plans for new power stations at Sizewell and Bradwell remain at an embryonic and uncertain stage.

Politicians have expressed concerns that if these projects do not materialise, the UK could face a clean power gap. Little scrutiny, however, has been placed on the notion that the UK’s current fleet of nuclear power stations may not continue operating until the end of their extended lives.

This report will examine the risk posed by the UK’s existing fleet closing earlier than planned, before showing representative scenarios of how the output from AGR power stations could be replaced.

17 https://www.bbc.co.uk/news/business-46122255
IMMEDIATE EFFECT

In recent decades the UK’s nuclear fleet has been one of the most dependable components of the electricity supply system, with plants reliably operating at around 90% of their maximum capacity. The remainder of time is usually taken up with planned maintenance and refuelling, which require the reactors to be powered down.

Recently, though, this high dependability has started to falter. The two reactors at EDF’s Hunterston B nuclear power station have been closed since March and October 2018 due to safety concerns owing to fractures in graphite bricks that make up the reactor cores.\(^\text{20}\) There is a crack in around one in every ten bricks in the core at Hunterston B.\(^\text{21}\) In May 2018 analysts calculated that loss of output resulting from the six month closure of Hunterston B was set to cost owner EDF £120 million.\(^\text{22}\)

![Quarterly nuclear generation (TWh)](image)

**Figure 1:** Quarterly UK nuclear generation (TWh). Source: BEIS

Historical output from the UK’s nuclear fleet was largely stable from 2010 to 2017 (Figure 1). Assuming that a 90% load factor is the maximum realistic operational limit of the fleet, the 71 terawatt hours (TWh) generated in 2017 was just 1% shy of this ceiling. In fact, the average annual generation from 2012 to 2017 inclusive was 69.5 TWh, or 98% of maximum expectations.

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21 https://www.bbc.co.uk/news/uk-scotland-47485321
However, 2018 nuclear output fell to 65 TWh, or 91% of the realistic output limit. Cracks in reactor cores can be blamed for the vast majority of this decline.

Data from the World Nuclear Association lobby group shows how ageing AGR plants are becoming increasingly susceptible to outages. Problems at Dungeness B during 2017 pushed down the load factor of one of its units to 51%, while problems at Hunterston B have reduced its output to zero during 2019 to date.

The long-term outages at Hunterston B have reduced the UK’s operational nuclear capacity by 965 MW, or 11%. The combined expected annual output of this power station is more than 7.5 TWh, around a third of that expected from EDF’s Hinkley Point project.

In May 2018, EDF forecast that the 2019 output of Hunterston B would be 3 TWh lower than planned, assuming that the unit returns to action shortly. However, there is a very real possibility that the Office for Nuclear Regulation (ONR) will not authorise the plant to resume operations, leaving an immediate 7.6 TWh/year hole in the UK’s low carbon electricity supply.

Replacing this output with electricity generated from fossil fuels would have a clear impact on the UK’s carbon emissions. Were natural gas to fill the gap, electricity sector CO₂ emissions would be approximately 2.9 million tonnes (Mt) higher. Coal stepping in to fill the output from Hunterston B would lead to the emission of around 6.5 million tonnes of CO₂.

For comparison, the UK’s power sector produced 72 Mt of CO₂ in 2018. Were Hunterston B to remain offline all year, with output replaced by fossil fuel generation, this alone could increase emissions from the power sector by 4-9% in 2019.

Considering that the majority of the UK’s progress in cutting carbon to date has been driven by the power sector, which itself is mainly a result of reducing coal combustion, fossil fuels stepping in to fill the low carbon power gap left by early nuclear retirements would likely cause concern among policymakers.

24 http://www.world-nuclear.org/country/default.aspx/United%20Kingdom
27 Based on CCGT carbon intensity of 375g/kwh
28 Based on coal carbon intensity of 850g/kwh. Limits on coal plant running hours under the Industrial Emissions Directive, and commercial decisions around when these hours can be best ‘used’ may prevent it from fully filling the gap.
CAPACITY GAP

To date, scrutiny of the government’s energy plans has focussed on the possibility of new plants not coming to pass, rather than the existing fleet being forced to retire earlier than planned. Issues currently facing the fleet suggest this may be short-sighted.

After life extensions were announced by EDF, electricity generation by the UK’s AGR fleet well into the 2020s began to be included in government energy projections. The latest iteration of these, released in April 2019,\(^2\) shows UK nuclear capacity reaching a low of 4.6 GW in 2024, before increasing to 13.5 GW as a new fleet of power stations come online (Figure 2).

This ‘dip and rebound’ in nuclear capacity is mirrored in output expectations, which falls from 59 TWh in 2020 to less than 36 TWh in 2024. Government projections see the connection of several new power stations to the grid increasing nuclear generation to more than 100 TWh by the mid-2030s.

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\(^2\) https://www.gov.uk/government/collections/energy-and-emissions-projections
These projections assume that new nuclear power stations will begin to be commissioned from 2025, and do not account for recent decisions by Toshiba and Hitachi to cancel or suspend work on three new power stations.\textsuperscript{30}

Government data also assumes that lifetime extensions across the UK’s nuclear fleet will ensure that there is overlap between generation from the existing AGR fleet and the start of power generation by the new fleet. This assumption forms a vital plank of the government’s plans to ensure that power sector carbon targets are met, while retiring many gas, coal and nuclear power stations that are currently in operation.

Similar assumptions for extended lifetimes of the UK’s AGR fleet also feature in the Committee on Climate Change (CCC)’s forecasts of planned retirements of electricity-generating assets.\textsuperscript{31}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{planned_closures.png}
\caption{Planned retirements of UK electricity generating capacity by technology type. Chart shows remainder of existing capacity once planned closures taken into account. Addition of new capacity not shown.}
\label{fig:planned_closures}
\end{figure}

\begin{verbatim}
Figure 3: Planned retirements of UK electricity generating capacity by technology type. Chart shows remainder of existing capacity once planned closures taken into account. Addition of new capacity not shown.
Source: BEIS, ECIU Calculations
\end{verbatim}

\textsuperscript{30} BEIS documents explain that power system modelling took place in September 2018, before announcements that Toshiba and Hitachi were not proceeding with planned nuclear power stations.

\textsuperscript{31} Slight differences between CCC and BEIS forecasts can be explained by CCC figures being released before BEIS latest set of data.
Neither BEIS or CCC forecasts consider the possibility that the nuclear fleet will be forced to retire before EDF’s re-extended dates. The remainder of this section will analyse the effects of the UK’s AGR power stations being forced to close earlier than planned, most likely due to keyway root cracking in graphite cores.

If all of the AGR fleet had to retire three years early, this would see the first power stations removed from the grid next year. This closure schedule represents an indicative scenario for the UK’s oldest AGR units, and can therefore be applied across the fleet, as plants can expect to face similar problems after comparable years of operation. Should the issues affecting the oldest plants be sufficiently serious to damage the entire fleet, however, there is a chance that the ONR could order the immediate closure of all UK AGR capacity.

Hunterston B and Hinkley B are the oldest units in the fleet – with the former currently offline and most blighted by graphite core issues – and are therefore the most likely to close first, with the rest of the AGRs following. The PWR at Sizewell B is not affected, therefore its retirement date remains unchanged.

<table>
<thead>
<tr>
<th>Nuclear power station</th>
<th>Planned closure</th>
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</tr>
<tr>
<td>Sizewell B (PWR)</td>
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</table>

Table 2: Comparison of current nuclear closure dates and those in the accelerated closure scenario.

Should issues with reactor cores force plants to close three years before planned, more than half of the AGR fleet (5 GW) would be retired by the end of 2021, with the remainder shut down by 2027 (Figure 4).
Looking at closures of the current plants in isolation does not account for new nuclear stations that are expected to be commissioned over the next 15 years. Although proposals to build new units at Moorside, Wylfa Newydd and Oldbury appear to have faltered, EDF and its Chinese partners remain confident that new capacity at Sizewell C and Bradwell B can be delivered in the early 2030s.32

Construction at Hinkley Point C is underway, with reactors expected to begin generating in 2025 and 2026. Delays at other plants using the same technology, however, mean these dates are not definite. As such, a scenario where Hinkley Point C is delayed by more than a decade is considered.

The National Infrastructure Commission (NIC) has stated that the UK’s power sector does not need any more nuclear power stations beyond Hinkley Point C.33 The NIC sees renewables – backed by flexible technologies such as storage and interconnection – as the cheapest way of providing the bulk of British electricity. This recommendation, coupled with difficulties financing new nuclear power stations, pours some doubt over the likelihood that these projects will be realised.

32  https://www.thetimes.co.uk/article/sizewell-c-nuclear-power-to-come-on-stream-in-2031-35nw6wwsv
There are therefore three scenarios that could come to pass, should the UK’s AGR fleet be forced into early retirement, in which either three (Hinkley C, Sizewell C, Bradwell B), one (Hinkley C), or no new nuclear power stations start generating before 2035 (Figure 5). In each case, there is a gap in both capacity and generation compared with BEIS projections.

In either of the scenarios where new nuclear power stations do come online, there will still be an immediate shortfall on BEIS projections should the existing fleet close three years early. After closing in 2024, the gap reappears as the remainder of the AGR fleet comes offline early. This highlights the potential of early closure to derail government plans to ensure that nuclear power remains a key part of the UK’s electricity mix in coming decades.

In the ‘worst-case scenario’, in which the UK’s AGR fleet is forced to retire early and Hinkley Point C is either cancelled or delayed by more than five years, there could be a 6 GW shortfall of nuclear capacity compared with government projections by 2030. This would double to 12 GW by 2035.

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34 Forecasts assume that the first reactor at Hinkley Point C will be online in 2025 and the second in 2026, that Sizewell C will be fully operational in 2031 and that Bradwell B will begin generating in 2033/34.
GENERATION GAP

The inevitable result of reduced generation capacity is a fall in the amount of low-carbon electricity produced annually. In the short term, the AGR fleet retiring early would cause an annual 17 TWh deficit on the BEIS forecast for nuclear output arising as soon as 2021. This soars to more than 100 TWh – or close to one third of current annual UK power demand – by 2035 in the worst case scenario, where no new nuclear power stations begin generating before 2035 (Figure 6).

In scenarios where either one or three new nuclear power stations are commissioned, a shortfall on BEIS projections remains, with the gap much smaller if Hinkley C, Sizewell C and Bradwell B all begin generating on schedule. The annual generation shortfall for each scenario is shows in Table 3, with the cumulative power gap in Table 4.

Figure 6: Future UK nuclear generation scenarios.\textsuperscript{35}

\textsuperscript{35} Load factors for existing plants assumed to be 80%, based on BEIS energy and emissions projections. Load factor of 90% assumed for Hinkley C, Sizewell C and Bradwell B.
Cracks in the system

<table>
<thead>
<tr>
<th>Year</th>
<th>Shortfall (TWh): Accelerated closure with Hinkley C, Sizewell C and Bradwell B</th>
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Table 3: Annual nuclear power generation shortfall for three early retirement scenarios compared with BEIS 2019 projections (TWh).36

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<tr>
<th></th>
<th>Cumulative shortfall: Accelerated closure with Hinkley C, Sizewell C and Bradwell B</th>
<th>Cumulative shortfall: Accelerated closure with Hinkley C</th>
<th>Cumulative shortfall: Accelerated Closure, no new plants</th>
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<td>Cumulative low-carbon power shortfall to 2035</td>
<td>337.2 TWh</td>
<td>501.9 TWh</td>
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Table 4: Cumulative power gap to 2035 for three early retirement scenarios compared with BEIS 2019 projections.

The potential cumulative shortfall to 2035 of 337–767 TWh is a significant amount of energy, roughly equal to 1–2 years of current national electricity demand. Replacing this output at low cost, without increasing sectoral carbon emissions and while maintaining the gold standard of reliability that British homes and businesses are used to, could be challenging.

36 Forecasts assume that the first reactor at Hinkley Point C will be online in 2025 and the second in 2026, that Sizewell C will be fully operational in 2031 and that Bradwell B will begin generating in 2033/34.
FILLING THE GAP

This section will evaluate four possible ways of ensuring that the UK retains sufficient electricity supply in the years to 2035. Four options are presented, each corresponding to different avenues that the government could pursue. In each case, the additional capacity referred to will be needed on top of that already planned or under development:

- Maintain current policy focussed on supporting offshore wind
- Fill the gap with a mixture of offshore wind, onshore wind and solar PV
- Build more natural gas fired power stations, running the risk of compromising decarbonisation targets and increasing reliance on fuel imports
- Incentivise new nuclear technologies to fill the gap.

1. 100% Offshore wind

Although it hasn’t explicitly banned onshore wind or solar PV, current government policy to hold auctions in which they cannot compete has left offshore wind as the dominant option for developers looking to build large-scale renewable capacity. There is currently 8 GW of offshore wind in operation in British waters, with the government aiming to increase this to at least 30 GW by 2030.37

Growing output from planned offshore wind projects is anticipated to displace high carbon electricity (that generated from gas or coal) from the electricity system. It is not expected to fill a gap caused by a shortfall in nuclear generation. To step in and fill this gap, more generating capacity would be needed on top of that already planned.

Table 5 shows the cumulative new offshore wind capacity that would need to be commissioned each five years to 2035 to ensure that early retirement of the AGR fleet does not result in a generation shortfall. As much as 2.9 GW of extra capacity could be needed as soon as 2025.\(^{38}\) This additional capacity would be on top of that set to be built on current policy.

This is roughly in line with current government expectations of how much will be awarded contracts in the May 2019 CfD auction;\(^{39}\) filling the gap left by an accelerated closure of the AGR fleet would therefore require this target capacity to be doubled.

Increasing the budget and raising the 6 GW ceiling for this auction may ensure that offshore wind would cover an AGR energy gap. This has already been proposed by NGOs and industry figures.\(^{40}\)

Even if Hinkley Point C starts generating in 2025, more power would be needed to replace the output from Hunterston B and Hinkley B in the event that their closure dates are accelerated.

<table>
<thead>
<tr>
<th>Year</th>
<th>Accelerated closure with Hinkley C, Sizewell C and Bradwell B</th>
<th>Accelerated closure with Hinkley C</th>
<th>Accelerated Closure, no new plants</th>
</tr>
</thead>
<tbody>
<tr>
<td>2020</td>
<td>21</td>
<td>21</td>
<td>21</td>
</tr>
<tr>
<td>2025</td>
<td>0.5</td>
<td>0.5</td>
<td>2.9</td>
</tr>
<tr>
<td>2030</td>
<td>6.3</td>
<td>6.3</td>
<td>11.1</td>
</tr>
<tr>
<td>2035</td>
<td>6.8</td>
<td>15.1</td>
<td>19.9</td>
</tr>
</tbody>
</table>

Table 5: Additional cumulative offshore wind capacity needed to meet generation shortfall in AGR early retirement scenarios. Source: ECIU Calculations.

Out to 2035, however, much more offshore capacity would be needed. Even if EDF and its Chinese partners deliver all three of their planned power stations (Hinkley C, Sizewell C and Bradwell B) on schedule, an additional 6.8 GW of offshore wind capacity would be needed to offset the generation loss from new nuclear plants currently included in BEIS forecasts that developers have decided not to proceed with.

This figure nearly triples to 19.9 GW if none of the next generation of nuclear power station has begun generating by 2035. This upper end is nearly 70% more than the expected offshore wind capacity detailed in the offshore wind sector deal (to 2030), suggesting a much faster rollout would be needed.

\(^{38}\) Assuming 60% load factor for new offshore wind installations.  
\(^{39}\) Based on figures in BEIS latest Energy and Emissions projections.  
**2. Mixture of offshore and onshore wind, and solar PV**

Ministers and officials are well aware of the pitfalls of relying on a single source of power, and although offshore wind produces a higher and more constant output than its onshore cousin, there may be concerns if all of the output gap is replaced by turbines fixed to the seabed.

Different renewable technologies have different generating characteristics; therefore, a mix of renewables would be expected to provide a more consistent supply. This would help to minimise balancing costs and reduce upward pressure on energy bills. Table 6 shows the capacities of different technologies needed should the nuclear output gap be filled with a representative 40:40:20 mixture of onshore wind, offshore wind and solar PV.\(^41\)

The lower load factors of onshore wind and solar PV compared with offshore wind mean that a more balanced mixture of renewable generating technologies requires greater overall capacity. However, due to the lower cost of installing turbines on land than at sea, this option is likely to be more financially attractive. The costs of each scenario will be analysed later in this chapter.

Assuming that Hinkley Point C begins generating on time, a combined 8.7 GW of new renewable capacity will be needed by 2030. If EDF’s project is delayed, however, this jumps to 15 GW.

In the worst-case scenario, in which no new nuclear is online by 2035, an additional 27 GW of (combined) renewable generating capacity could be required, compared with BEIS forecasts. This falls to 9.2 GW if EDF and its Chinese partner delivers its trio of new power stations on schedule.

<table>
<thead>
<tr>
<th>Year</th>
<th>Accelerated closure with Hinkley C, Sizewell C and Bradwell B</th>
<th>Accelerated closure with Hinkley C</th>
<th>Accelerated Closure</th>
</tr>
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<tbody>
<tr>
<td>2020</td>
<td>1.1</td>
<td>1.1</td>
<td>0.6</td>
</tr>
<tr>
<td>2025</td>
<td>0.3</td>
<td>0.3</td>
<td>0.2</td>
</tr>
<tr>
<td>2030</td>
<td>3.4</td>
<td>3.4</td>
<td>19</td>
</tr>
<tr>
<td>2035</td>
<td>3.7</td>
<td>3.7</td>
<td>18</td>
</tr>
</tbody>
</table>

Table 6: Additional cumulative renewable generation capacities needed to meet generation shortfall in AGR early retirement scenarios. Source: ECIU Calculations.\(^42\)

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\(^{41}\) 40:40:20 mixture by capacity, rather than output. Load factors of offshore wind, onshore wind and solar PV assumed as 60%, 40% and 12%, respectively.

\(^{42}\) Figures refer to renewable capacity alone. Additional balancing capacity and/or DSR not specified, although costs are included in calculations in a later section of this report.
The lack of policy support for onshore wind or solar PV represents a barrier to expanding capacity in the UK. While some projects may be viable on a merchant basis, it is unlikely that the quantity needed to fill in for nuclear power stations that have either closed early or not been delivered on time would be achieved without support through the Contracts for Difference (CfD) scheme or a different mechanism.

Rapid falls in the cost of low-carbon electricity – with onshore wind and solar PV the cheapest – means that contracts signed with the government would not involve a subsidy payment to developers. It would, instead, guarantee a constant price for power output, reducing project risk and allowing access to cheaper capital, which brings costs down further.

As with the offshore wind scenario, the need for a large amount of low-carbon capacity to be constructed within the next decade would require changes to policy in the short term to bring new projects through the pipeline.

Both this scenario and that based on offshore wind alone would require an increase in the flexible technology required to balance an increasingly variable supply.

A recent ‘smart systems and flexibility plan’ co-published by BEIS and Ofgem details the steps needed to bring about a power system that is sufficiently responsive to incorporate high levels of renewable and other low carbon energy sources while keeping bills low and maintaining high standards of reliability.43

However, some recent policy decisions are somewhat counteractive to this goal of realising a smart and flexible power system. The detrimental treatment of demand side response in the capacity market, Ofgem’s targeted charging review and slow progress from network owners to upgrade systems are, among others, moves that are widely expected to slow the transition.

3. Natural gas

The government has announced that all unabated coal-fired generation will be off the UK’s power system by 2025, leaving only natural gas as a fossil-fuel option to fill a nuclear capacity gap.

Natural gas, however, is not a low-carbon fuel. Replacing low-carbon nuclear output with a high-carbon alternative would impact the UK’s progress towards meeting climate targets, which, to date, have been largely driven by the power sector.\(^{44}\)

With the potential to run at very high load factors if required, the amount of natural gas capacity needed to fill the gap in each scenario would be lower than the amount of wind and solar. Based on an 85% load factor, as little as 4.5 GW of new gas capacity could be needed by 2030 (Table 7).

In the shorter term, assuming that Hinkley C is delivered on time, less than 500 MW extra could be needed by 2025, although more capacity (or, more likely, higher output from currently under-utilised plants) would be needed in the early 2020s to cover the first wave of AGR retirements. The worst case scenario sees an additional 7.8 GW of new CCGT capacity connected to the system by 2030, and more than 14 GW by 2035.

<table>
<thead>
<tr>
<th>Year</th>
<th>Accelerated closure with Hinkley C, Sizewell C and Bradwell B (GW)</th>
<th>Accelerated closure with Hinkley C (GW)</th>
<th>Accelerated Closure, no new nuclear plants (GW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2020</td>
<td>15</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>2025</td>
<td>0.4</td>
<td>0.4</td>
<td>21</td>
</tr>
<tr>
<td>2030</td>
<td>4.5</td>
<td>4.5</td>
<td>7.8</td>
</tr>
<tr>
<td>2035</td>
<td>4.8</td>
<td>10.7</td>
<td>141</td>
</tr>
</tbody>
</table>

Table 7: Additional cumulative natural gas CCGT capacity needed to meet generation shortfall in AGR early retirement scenarios. Source: ECIU Calculations.

While the capacity of gas power stations needed to fill the gap may be lower, doing so would lead to an increase in carbon emissions, as low-carbon nuclear output is replaced by high-carbon natural gas. Filling the nuclear gap with power from CCGT units could lead to an extra 20 MtCO\(_2\) emissions in the UK power sector by 2030 (Figure 7).\(^{45}\)

Much less visible than the complete closure of the coal fleet, but as significant, is the requirement for gas-fuelled generation to fall from its current level of about 40% down to at most 15% by 2032, as outlined in the Clean Growth Strategy. This means gas generation falling by around two percentage points per year over the next 13 years. Rising output from natural gas power stations would not be compatible with this target.


\(^{45}\) Based on CCGT emissions intensity of 350g/kWh.
This increase in emissions would reverse the trend of cutting carbon emissions from the UK’s electricity supply (Figure 8). As early as 2024, this scenario would see the power sector switch from emissions falling year-on-year, to emissions increasing in earnest (following a brief blip in 2021 when Hunterston B and Hinkley B come offline). This would virtually guarantee the missing of carbon targets to which future governments are legally bound.

Considering the expected trend for increased electricity use in transport, heating, industry and other sectors, an increase in the carbon intensity of the power sector would effectively neuter emissions reductions expected in, for example, transport and heating via electrification.

By 2030 power sector emissions could be 37% higher than in forecasts in the latest BEIS scenario. This would leave the sector – and the country – off track to meet goals set out in the 2008 Climate Change Act, and in the 2015 Paris Agreement. It would also miss the goal set in the 2017 Clean Growth Strategy to have no more than 15% of power from natural gas by 2032.46

Even in the best case, where three new nuclear power stations come online, early closure of the AGR fleet and replacement of output with natural gas would see annual power sector emissions stop decreasing in 2026, with 2035 emissions 28% higher than in BEIS forecasts.

![Graph showing change in annual power sector emissions projections with increased gas output.](source)

The considerable cumulative power gap out to 2035 means replacing the missing 337–767 TWh (Table 4) with CCGT-derived power, which would have a substantial impact on national emissions. Even utilising the most modern and efficient power stations, cumulative emissions could be as much as 268 MtCO$_2$ higher (Table 8). This surge in output would severely impact the ability of the UK to meet emissions targets set out in the fourth and fifth carbon budgets.

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47 Based on emission intensity of 350gCO2/kWh.
<table>
<thead>
<tr>
<th>Accelerated closure with Hinkley C, Sizewell C and Bradwell B</th>
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<th>Accelerated Closure, no new plants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cumulative additional carbon emissions to 2035</td>
<td>118 MtCO$_2$</td>
<td>176 MtCO$_2$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>268 MtCO$_2$</td>
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</tbody>
</table>

Table 8: Cumulative additional carbon dioxide emissions to 2035 for each gas-replacement scenario

The extra emissions associated with fossil fuel combustion show that an increase in electricity from natural gas power stations is not a viable solution should the current nuclear fleet be forced into early retirement, or should the next generation of nuclear power stations be cancelled or delayed, or both.
4. Other nuclear technologies

A gap left by the early closure of the UK’s AGR fleet and the delayed or incomplete rollout of the next generation of reactors leaves space, in theory, for alternative nuclear technologies. The most advanced, and with strong backing from the nuclear industry, are small modular reactors (SMRs).

SMRs are small (typically sub-300 MW) reactors, which can be connected in parallel to provide the same capacity as traditional, larger reactors. Proponents of SMRs point to the potential to construct reactors on a production line rather than in bespoke mega-projects, as a way of keeping costs down. By standardising module design and assembling on-site, backers of SMR technology argue that cost falls comparable to those seen in the offshore wind sector could be achieved.

Assembling a large capacity power station out of a number of identical modules may avoid delays and cost overruns that have blighted the construction of large scale bespoke projects in the UK, Finland and France.

However, no commercial, safety approved SMRs exist. Any design would be required to complete a stringent ONR design assessment to guarantee its safety, just as other reactor types must do to gain a licence to operate in the UK. The National Infrastructure Commission

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48 Rolls-Royce, for example, is a strong proponent of SMRs.
estimates that the end-to-end deployment process for the first SMRs will take 12-14 years, a delay that would prove problematic considering the potentially increasing urgency of the UK’s nuclear capacity gap.

The government is currently taking preliminary actions to support SMRs, also known as ‘Advanced Nuclear Technologies’. Having run a competition to incentivise companies to put forward prospective designs, it is now encouraging new designs to register for safety and operational assessments. It is expected to announce an alternative funding mechanism for new nuclear projects in the upcoming Energy Bill. This is expected to reduce financing costs by reducing risk faced by developers, thereby achieving lower overall project costs.

SMRs (along with larger nuclear reactors) are also not suited to varying output in response to fluctuations in demand. A recent Policy Exchange report that supported SMR technology argued that nuclear reactors should run at constant output, with surplus energy stored for use at a later time. This inflexibility incurs a cost – analogous to the system cost of renewables – which is likely to be considered in investment cases.

Ultimately, until the technology is more advanced, SMRs do not appear to be a realistic option for large-scale power generation in the timescale in question. They will therefore not be considered during the rest of this report.

52 https://www.ft.com/content/3f0df14d0-7548-11e8-aa31-31da4279a601
In addition to greenhouse gas emissions, it is vital to consider the costs of technologies that may fill the gap. Having been constructed by the state and fully amortised over decades of use, the cost of generating power by the UK’s AGR fleet is among the lowest on the system. Therefore, replacing this power will likely impose an additional cost.

Developments in technology and policies to reduce financing costs have seen the price of power from renewable sources drop rapidly in recent years. In the November 2017 Contracts for Difference auction, two offshore wind farms secured fixed-price contracts at £57.50/MWh, around half the cost of contracts granted to offshore wind farms in an auction held just two years prior.\(^{54}\)

Without the added complication of constructing at sea, onshore wind is cheaper still. Indicative figures from the industry suggest that private-wire deals (fixed price contracts with firms rather than with the government) have been agreed at close to £40/MWh, significantly below the cost of any other form of new capacity. Solar PV lies somewhere between the two.

Natural gas power stations, on the other hand, are not getting cheaper. Whereas the cost of renewable generation is weighted heavily towards CAPEX costs, which have fallen as the sector has become less risky to invest in, a large component of the cost of generating power at a natural gas power station is dependent on operational costs; of which the lion’s share is fuel and carbon costs.

Table 9 shows the cumulative costs of replacing the aggregate power output to 2035 with electricity from 100% offshore wind; capacity in the mixed renewables scenario; or with natural gas output from CCGT power stations.\(^{55}\) An additional cost is added to the renewable scenarios to account for the cost of balancing variable outputs. These calculations only include the cost of power to fill the gap, not the cost of power generated by the proposed new nuclear fleet.\(^{56}\)

In all circumstances, the cost of filling the gap with fossil fuel power is higher than would be the case for expanding renewable capacity, even if a conservative £20/MWh balancing cost is added on top of the generating cost for intermittent/variable capacity.

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\(^{54}\) In line with Government policy, all costs referred to are in 2012£.

\(^{55}\) Costs include those incurred by early closure of the AGR fleet and filling the gap left by next generation nuclear projects that are not currently going ahead.

\(^{56}\) No new nuclear cost counterfactual is included as, aside from Hinkley Point C there is no cost data for the next wave of power plants. Considering the recent falls in cost of electricity from renewable sources, it would be expected that scenarios with a higher proportion of wind and solar would be cheaper. Nuclear costs, however, could be reduced should plants be supported under the Regulated Asset Base model, which is expected to reduce financing costs as the Government takes a greater stake in the project.
Balancing costs are imposed on the system by nature of the variable nature of wind and solar generation technologies; other apparatus is needed to ensure that fluctuations in output do not lead to non-continuous supply. This generally refers to four ‘flexibility mechanisms’ – storage, such as batteries or pumped hydro; interconnectors to allow trade of power with neighbouring countries; demand shifting, in which peak loads are lessened by incentivising power use at off-peak times; and flexible peaking plants, to fill in the final gaps. These are explained in detail in a recent ECIU report.\textsuperscript{57}

<table>
<thead>
<tr>
<th>Accelerated closure with Hinkley C, Sizewell C and Bradwell B (GW)</th>
<th>Accelerated closure with Hinkley C (GW)</th>
<th>Accelerated Closure, no new nuclear plants (GW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cumulative clean power shortfall to 2035 (TWh)</td>
<td>337 TWh</td>
<td>502 TWh</td>
</tr>
<tr>
<td>Cost of replacing output with 100% offshore wind</td>
<td>£22-25bn</td>
<td>£33-38bn</td>
</tr>
<tr>
<td>Cost of replacing output with renewable mix</td>
<td>£20-23bn</td>
<td>£29-38bn</td>
</tr>
<tr>
<td>Cost of replacing output with natural gas CCGT</td>
<td>£27bn</td>
<td>£41bn</td>
</tr>
</tbody>
</table>

Table 9: Costs of filling the cumulative power gap to 2035. Source: ECIU calculations.\textsuperscript{58}

The difference in cumulative costs to 2035 could be as high as £18 billion should the natural gas scenario be chosen over the mixed renewables option, even including additional system costs associated with weather-driven output.

Therefore, should ministers be faced with this decision, opting for a new era of natural gas power stations would be the least cost-effective and least environmentally friendly option.

\textsuperscript{57} https://eciu.net/reports/2018/gb-power-transition-get-smart

\textsuperscript{58} Calculations based on offshore wind LCOE of £55/MWh, onshore wind £40/MWh, solar PV £45/MWh, CCGT H-class £82/MWh. Balancing costs of £10-20/MWh added to renewable generation costs. Renewables costings based on recent auction results or modelling of expected costs, CCGT costings based on BEIS forecasts for 2025 commission date.
CONCLUSIONS

Despite the increasing occurrence of cracks in AGR reactor cores, the notion that British nuclear power stations will not continue to operate reliably to the end of their extended lifetimes is not considered in official projections.

Meanwhile, there has been intense media and political focus on the problems associated with bringing the next generation of nuclear power plants online – and the risk of a capacity gap opening. This report finds that problems could arise sooner than expected should the AGR fleet be forced to retire early.

The current retirement schedule will see the UK’s seven AGR reactors closed by 2030, by which point some units will have been operating for 25% longer than originally planned. Should these plants be forced to close just three years before the current schedule, with the final plants closing in 2027, gaps in generation capacity and output will grow during the 2020s.

If current outages are not resolved rapidly, the UK will face a clean power gap of up to 7.6 TWh per year. Were fossil fuels, coal or gas, used to fill this gap, annual power sector CO₂ emissions could be up to 6.5 million tonnes higher, just short of 10% of total power sector emissions during 2018.

It is also not certain that the government’s plans to see several new nuclear power stations commissioned will come to fruition. Scenarios outlined in this report show that, in a worst case scenario – where AGR plants close early and the next generation of nuclear reactors falters – the UK electricity system could be caught short by more than 100 TWh by 2035, equivalent to around one third of current annual demand.
Analysis of a number of ways of filling the gap show that a mixture of renewable generation technologies – onshore wind, offshore wind and solar PV – would be the lowest cost option, with cumulative savings to 2035 up to £18 billion compared with natural gas-fired power stations.

Should natural gas, a high carbon fuel, step in to fill the low carbon power gap, there will be a resultant increase in British carbon emissions. This report finds, that in the worst case scenario, an additional 268 million tonnes of carbon dioxide could be produced by 2035, equivalent to around 75% of total annual (2018) national emissions; this would clearly put the UK’s progress towards either current or future carbon targets in grave danger.

Current policies to boost low carbon power sources fall short of what is needed to meet targets, even without issues that could see current nuclear power stations close early or planned units commission later. Therefore, should the government wish to ensure that progress in decarbonising the power sector, which has been the main driver of cutting emissions in the UK, does not stall, it would be wise to support more technologies than at present and ensure that power flowing into British homes and businesses in coming decades is as low cost and as low carbon as possible.