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Institution of Civil Engineers

Civil engineering insights into nuclear new build in the UK

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Overview

A growing population, economic uncertainty and an imperative to reduce carbon emissions to a net value of zero by 2050 will place heavy demands on the UK's energy sector in the coming decades. In particular, the electrification of heat and transport and the growth of digital technologies could result in a near doubling of electricity consumption.[1] Overall, the UK continues to face an energy 'trilemma': the need to ensure a secure supply of energy, make that supply affordable for consumers and ensure that emissions targets are met.

There has been some success in addressing the trilemma. Coal's share of generation has fallen from 47.5% in 2006 to just 0.69% by the end of 2019.[2] However, fossil fuels were responsible for 42.2% of UK generation at the end of 2019, with renewables making up 37.4%. Nuclear capacity has stalled, then fallen, in the last few decades, and provided 18% of energy generation, the lowest proportion since 2008.[3]

Electricity generation will become even more important in future as demand profiles across other infrastructure sectors evolve and digital technologies are widely embedded in the design of assets and networks. As a consequence, generation methods that are reliable and resilient, providing security of supply, will be highly prized. Yet, as renewables become ever more affordable, policymakers need to examine what place new nuclear has, and how it should be supported.

Purpose of this paper

This paper provides insight into the potential costs and benefits of the UK's proposed nuclear new-build programme, alongside an analysis of possible alternatives. It draws on lessons from existing projects and has been developed through discussions with ICE Fellows, senior sector stakeholders and available published evidence.

About nuclear generation and new-build aspirations

The UK was the first nation to establish a civil nuclear programme, with Calder Hall connecting to the grid in 1956.[4] Despite this pioneering history, the UK has not built a nuclear power plant since 1995 when Sizewell B began generating electricity.

Nuclear power operates through much the same process as a carbon-fuelled power plant. It generates heat to transform a water supply to steam and power a turbine.[5] Nuclear has certain advantages over coal, oil and gas as it does not need to be continuously refuelled, will continue to provide power throughout its reaction and does not produce carbon emissions.[6]

[1] ICE (2016) National Needs Assessment – ITRC modelling undertaken for ICE's 2016 *National Needs Assessment* demonstrates that electrification of heat and transport could result in a near doubling of electricity consumption by 2050
[2] Ofgem (2020) Electricity Generation Mix by Quarter and Fuel Source (GB)
[3] Department for Business, Energy and Industrial Strategy (2020) Energy Trends: UK Electricity
[4] Radioactive Waste Management (2018) The UK's Nuclear History
[5] World Nuclear Association (2020) How Does a Nuclear Reactor Work?

The present generation of nuclear plants under development around the world is third generation and represents an evolution in fuel efficiency, safety and generation potential.

In the UK there are plans to build EPR Pressurised Water Reactors (PWRs) at Hinkley Point C and Sizewell C. Advanced Boiling Water Reactors (ABWRs) have been planned for deployment at Wylfa Newydd, in Anglesey, Wales, and at Oldbury, in Gloucestershire. However, development on both projects has been suspended following a failure to reach an agreement on financing and commercial arrangements.[7]

The government considers nuclear power to be an important part of a diverse energy mix. The technology provides consistent, reliable and decarbonised 'baseload' power and has a high load factor. This means that nuclear power can be relied upon to ensure minimum levels of power are met at any one time. This is important given the intermittent nature of renewables, the lack of storage capacity and the potential for price fluctuations for carbon-based fuels. It also means that nuclear has high availability. In 2016, nuclear's load factor, the total generated electricity as a proportion of potential generation, was 77%, compared to 46% for gas, 37% for offshore wind, 24% for onshore wind, 22% for coal and 11% for solar.[8]

Government policy on nuclear new build

In order to address the energy trilemma, the government has set out a policy of nuclear new build. This policy is guided by the 2011 National Policy Statement (NPS) for Nuclear Power Generation,[9] which was updated in 2018 following a 2017 consultation,[10] and the Nuclear Sector Deal (NSD).[11] A new NPS is due in 2020 which will update the list of sites available for new nuclear development.[12]

New capacity by 2025

The NPS set out that there is a need for substantial new nuclear capacity before the end of 2025. This was driven by a policy desire to avoid a situation where the UK might be locked into a higher-carbon energy mix. To expedite deployment, the NPS outlines eight sites which are already developed for existing or decommissioned nuclear sites.

Third-Generation Nuclear Technologies

Nuclear power plants use a sustained nuclear reactor to generate heat, which is then used to transform reserves of water to steam to drive turbines.

The current generation represents an evolution in fuel efficiency, safety and generation potential. There are two main types of reactor design:

Pressurised Water Reactors (PWRs)

The European Pressurised Reactor or Evolutionary Power Reactor (EPR) and the Chinese Hualong HPR1000 are examples of PWR designs. The EPR was first successfully deployed in Taishan, China, in 2018[1] and an EPR power plant is currently under construction at Hinkley Point C in the UK. The HPR1000 is currently under licensing review.[2]

Advanced Boiling Water Reactors (ABWRs)

ABWRs were first operated in Japan in 1996[3] and were accepted for use in the UK in 2017.

Hitachi had plans to build a reactor of this type at Wylfa Newydd, in Anglesey, Wales, and at Oldbury, in Gloucestershire.

1 EDF (2019) The Second EPR Reactor at China's Taishan Nuclear Power Plant about to Enter into Commercial Operation

2 Office for Nuclear Regulation and the Environment Agency (2019) Our Approach to Public and Stakeholder Engagement for the Generic Design Assessment (GDA) of the UK HPR1000 Nuclear Power Station

3 Hitachi (2020) ABWR Nuclear Power Plant

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6 World Nuclear Association (2017) The Nuclear Fuel Cycle
7 Horizon Nuclear Power (2019) Horizon Suspends UK Nuclear New Build Activities
8 Department for Business, Energy and Industrial Strategy (2017) Special Feature – Nuclear Capacity in the UK
9 Department of Energy and Climate Change (2011) National Policy Statement for Nuclear Power Generation (EN-6) Volume I of II; Department of Energy and Climate Change (2011) National Policy Statement for Nuclear Power Generation (EN-6) Volume II of II
10 Department for Business, Energy and Industrial Strategy (2018) Government Response: Consultation on the Siting Criteria and Process for a New National Policy Statement for Nuclear Power with Single Reactor Capacity Over 1 Gigawatt Beyond 2025
11 HM Government (2018) Industrial Strategy: Nuclear Sector Deal
12 Department for Business, Energy and Industrial Strategy (2018) Government Response: Consultation on the Siting Criteria and Process for a New National Policy Statement for Nuclear Power with Single Reactor Capacity Over 1 Gigawatt Beyond 2025

The cost challenge of nuclear new build

The Nuclear Sector Deal seeks to address cost concerns which have arisen since the National Policy Statement was published. It contains a target of reducing the costs of new nuclear plants by 30%, with an emphasis on advanced construction and manufacturing techniques. Beyond this, it considers how to reduce the costs of decommissioning and how best to support research, innovation and skills.

The nuclear industry believes the cost of new nuclear can be reduced through the upskilling of the workforce, improvements to supply chain management and through successive projects using a repeated design. This would reduce construction risks through replication of process. A new financing framework is also deemed necessary, with capital representing up to two-thirds of the cost of a nuclear project.[13]

Finance and funding

The government initially chose to directly negotiate a price with nuclear providers, agreeing a strike price with EDF and CGN of £92.5 per megawatt hour (MWh) at 2012 prices for Hinkley Point C. This is a Contract for Difference (CfD) index-linked to CPI inflation for 35 years.[14]

The contract does remove some uncertainty for the bill payer, with any overrun and decommissioning costs being borne by the developers. Nonetheless, the agreed strike price factored in some risk protection for EDF and has drawn criticism from the Committee of Public Accounts, which found that 'no one was protecting the interests of energy consumers in doing the deal', with an assessment on the impact to household bills which only 'went up to 2030' despite the 35-year length of the CfD.[15]

The subsequent reaction to this agreement may have complicated negotiations for other projects, most notably Wylfa Newydd, which suspended work after a failure to reach an agreement on financing and commercial arrangements.[16]

Developing the nuclear sector

The government set out an ambition to generate domestic jobs, improve earning power, support innovative design and construction and develop placemaking in the Nuclear Sector Deal. This includes provisions to make the nuclear sector in the UK more competitive. To pursue this, the NSD set out enhanced support for skills leadership, investment in nuclear research, the establishment of a national supply chain and productivity improvement programme, and support for UK companies to maximise contract wins in the nuclear sector.[17]

How successful has the nuclear new-build policy been?

New capacity by 2025

The government is not likely to meet its target for new nuclear capacity by 2025. Only one site of the eight outlined in the National Policy Statement, Hinkley Point C, has reached the construction phase.

[13] Nuclear Industry Association (2020) Forty by '50: The Nuclear Roadmap
[14] National Audit Office (2017) Hinkley Point C
[15] Committee of Public Accounts (2017) Hinkley Point C
[16] Horizon Nuclear Power (2020) Wylfa Newydd – About our Site
[17] HM Government (2018) Industrial Strategy: Nuclear Sector Deal

The cost challenge of nuclear new build

Hinkley Point C has seen substantial cost inflation, with an initial estimate of £16 billion[18] revised to between £21.5 billion and £22.5 billion in 2019. In September 2019 EDF also reported an increased risk of a delay of 15 months for the opening of the first reactor.[19] The subsequent impact of Covid-19 is likely to increase the risk to project costs and schedules further.

The National Infrastructure Commission has advised the government that there should be no more than one agreement to provide support for new nuclear (in addition to Hinkley Point C before 2025). The Commission emphasised that a highly renewable generation mix is a low-cost option for the energy system 'comparable to building further nuclear power plants'.[20]

Finance and funding

The CfD for Hinkley Point C compares poorly to an average wholesale cost of electricity of around £45/MWh since 2010,[21] and a renewables strike price of £39.65/MWh in 2012 prices in the most recent CfD round.[22] However, it should be considered that when this was drawn up there was uncertainty surrounding future carbon fuel costs and when renewable costs themselves were at a price point of around £90/MWh.[23]

The picture is also more complicated than a direct comparison on strike price. Hinkley Point C's strike price is fixed for 35 years but the plant has an operational life of 60 years, at which point electricity generated will likely be sold at market price. Renewable generation costs have continued to fall, but these generators have a shorter operating life, and costs will increasingly need to factor in capacity support or storage to balance out intermittent generation.

The government has consulted on adopting the Regulated Asset Base model for new nuclear,[24] a proposal which ICE believes is credible if detailed mechanisms can be developed for apportionment of risk, overruns on construction costs and schedules, regulation of approvals and payment sequencing and protections for consumers, who may be unfairly burdened with risk.[25]

Developing the nuclear sector

In developing Hinkley Point C, the government has met some of its Nuclear Sector Deal targets. Up to 64% of the construction costs of Hinkley Point C are being spent with UK companies and the project has created 25,000 domestic employment opportunities. In addition, 1,000 apprentice places are being funded and the project is providing £1.5 billion to the regional economy during the construction phase.[26] The development of skills and expertise in the nuclear field, for the first time since 1995, is of transferable benefit to nuclear research and potential future civil nuclear development.

Lessons from international nuclear projects

Given that there has been a significant gap in the building of new nuclear capacity in the UK, most developments in new nuclear have occurred abroad.

[18] EDF (2013) Building our Industrial Future
[19] EDF (2019) Update on Hinkley Point C Project
[20] National Infrastructure Commission (2018) National Infrastructure Assessment
[21] Ibid
[22] Department for Business, Energy and Industrial Strategy (2019) Contracts for Difference Allocation Round 3 Results
[23] Hansard (2016) Hinkley Point C
[24] Department for Business, Energy and Industrial Strategy (2019) Regulated Asset Base (RAB) Model for Nuclear
[25] ICE (2019) ICE Response to BEIS Consultation on a Regulated Asset Base (RAB) Model for New Nuclear
[26] Department for Business, Energy and Industrial Strategy (2018) Hinkley Point C Wider Benefits Realisation Plan

Most nuclear projects around the world have seen delays and cost increases. Taishan EPR, which became fully operational in September 2019[27] and is the first EPR design to complete, is notable for becoming operational before similar designs in Finland and France, despite commencing construction some years later. Those projects, Olkiluoto 3 and Flamanville, have seen initial costs of around €3 billion increase to €10.5 billion and €12.4 billion respectively.[28]

Taishan EPR is a similar design to Hinkley Point C; however, the design in the UK differs to meet separate standards. Nonetheless, lessons learnt in the construction of Taishan EPR are transferable to Hinkley Point C, with the experience of commissioning the first reactor at Taishan EPR enabling a three-month reduction in the activation of the second.[29] This culture of learning from experience is demonstrable at Hinkley Point C as well, with knowledge gained about the sequence of works from the completion of the first reactor's foundations in June 2019 applied to the second reactor.[30]

A report undertaken by the Energy Technologies Institute argues that 'first in class' projects – such as when a nation is trying to restart a nuclear industry, including building supply chains, training people and rediscovering regulatory mechanisms – have necessarily higher costs, and that this applies to the new generation of nuclear designs in particular.[31] The Institute attributes these higher costs to issues such as a lack of completed design before construction starts and a long schedule thereafter. It also notes that nuclear projects and programmes that have achieved low costs have built multiple units on a single site, enabling lessons to be learnt and therefore costs to be reduced. One such example is Barakah 1-4 in the United Arab Emirates, which utilised shared site infrastructure, bulk purchasing and a continued pipeline which avoided stop/start mobilisation of equipment and labour.

Price competitiveness is an increasing risk for nuclear projects, particularly when competing in markets where renewables and oil and gas are not heavily taxed, are given additional subsidy or are otherwise highly developed. The South Texas Project 3 and 4 in the United States is a withdrawn project based on ABWR technology similar to that planned for Wylfa Newydd. The project was abandoned in 2011 and officially cancelled in 2018.[32] Toshiba, which led the project, outlined that development was no longer financially viable, citing significant decreases in electricity rates due to the availability of shale gas and increased costs of regulation in the aftermath of the incident at Fukushima Daiichi, following the tsunami in 2011.

The only other nuclear development ongoing in the United States is the project at Vogtle 3 and 4 in Georgia. This is based on the Westinghouse AP1000 PWR model but has encountered numerous setbacks, which has increased the construction cost from $6,400 per kilowatt of installed capacity to $11,950.[33]

Where repeatable design and supply chains are established, there should be an expectation that the costs of additional nuclear plants can be reduced, which provides some reassurance that projects like Sizewell C will be able to benefit from the experience of Hinkley Point C. There is a need to avoid the mistakes of projects like Flamanville 3 EPR in France, however. A report written for the French Government described Flamanville 3 EPR as 'a failure for EDF', with a need for deep upgrading of industrial and skills capabilities in France's nuclear sector and more stringent quality controls needed at all levels. The report did, however, concede that the operation of the Taishan reactors demonstrates the relevance of the concept and design of the EPR.[34]

[27] EDF (2019) The Second EPR Reactor at China's Taishan Nuclear Power Plant about to Enter into Commercial Operation
[28] ICE Publishing (2017) Economy, Safety and Applicability of Small Modular Reactors
[29] EDF (2019) The Second EPR Reactor at China's Taishan Nuclear Power Plant about to Enter into Commercial Operation
[30] EDF (2020) J0 Milestone Achievement
[31] Energy Technologies Institute (2018) The ETI Nuclear Cost Drivers Project: Summary Report
[32] Toshiba Corporation (2018) Notice on Withdrawal from South Texas Project by Toshiba's Overseas Consolidated Subsidiary
[33] Energy Technologies Institute (2018) The ETI Nuclear Cost Drivers Project: Summary Report
[34] Jean-Martin Folz – Rapport au Président Directeur Général d'EDF (2019) La Construction de l'EPR de Flamanville

Public sentiment around nuclear power generation

ICE's public engagement work for *State of the Nation 2018: Infrastructure Investment* found that security of supply and climate change are key energy concerns for the public.[35] This does not, however, necessarily translate into support for nuclear power. According to YouGov, only a third of UK adults (33%) have a favourable view of nuclear energy, making it less popular than gas (40% favourability). Of those favourable, less than half (44%) want to see greater use of nuclear power, while 42% of all UK adults believe nuclear use should be reduced.[36]

Polling by the Nuclear Industry Association suggests that 72% of people support nuclear as part of a low-carbon mix. Some 35% also agree that it is the most secure form of reliable generation, compared to 16% for solar and 13% for gas and offshore wind.[37]

There is general acceptance of the need for additional investment in energy generation, although there is little appetite for higher bills that are not tied to improvements in energy efficiency and carbon reduction. The public are also resistant to new large-scale nuclear infrastructure programmes, with a preference for investment in renewables.[38] According to ICM, more than eight in ten people support electricity production from renewable energy sources.[39] The same ICM poll does, however, demonstrate that there is little understanding of nuclear power and its potential benefits, particularly among younger people. Only 26% of people aged 18 to 24 understand that nuclear power is a low-carbon energy source, although this rises to 61% of those aged 65 to 74 years old.[40]

Lessons to take forward from Covid-19

The global Covid-19 pandemic has impacted on every aspect of life and the economy. The nuclear sector, and energy producers more broadly, have had to adapt to changed working practices, and supply chain resilience has been tested.

Hinkley Point C has continued work on site by reducing the number of staff by roughly half, adopting social distancing measures, introducing temperature screening at the entrance, banning visitors and moving workers to campus facilities with an emphasis on protecting local communities.[41] Some administrative and design staff on the project, including those working on 'complex technical tasks… with quality maintained through rigorous checking and assurance',[42] have been successfully transferred to home working, although the scope for this is limited by the need for some staff to access the accredited network for sensitive work. These steps have not hindered the project thus far, with Hinkley Point C managing to maintain its schedule, including its 'J0' milestone set four years ago for June 2020.[43]

Staff safety is and should be paramount. Other nuclear sites, such as Sellafield, which manages nuclear reprocessing, waste and decommissioning, took the decision to pause all construction except for essential work on nuclear safety, judging that this would maximise social distancing.[44]

While electricity demand has dropped slightly during lockdown, due to lower industrial requirements for power, it has reduced by only around 10%.[45] The pandemic may continue for some time and both National Grid and energy producers have contingency plans in place for further reductions in staffing levels, including placing teams in reserve to cover

[35] ICE (2018) State of the Nation 2018: Infrastructure Investment
[36] YouGov (2019) Shale Gas is Even Less Popular in UK than Coal
[37] Nuclear Industry Association (2019) Nuclear Industry Association Publishes 2018 Public Polling
[38] ICE (2018) State of the Nation 2018: Infrastructure Investment
[39] Institution of Mechanical Engineers (2020) Public Perceptions: Nuclear Power
[40] Ibid
[41] EDF Energy (2020) Coronavirus – What we are Doing to Keep the Site and Community Safe
[42] Somerset Live (2020) Coronavirus: Five Hinkley Point C Workers have Tested Positive for COVID-19, EDF Energy Confirms
[43] EDF (2020) Hinkley Point C Project Achieves Latest Major Milestone on Schedule
[44] Sellafield Ltd (2020) Staff News and Information
[45] National Grid ESO (2020) What Does Lockdown Mean for Electricity in Great Britain

sicknesses.[46] Nuclear has an advantage in not requiring daily resupply, providing greater resistance to supply-side shocks, and major infrastructure projects will contribute to the economic recovery.

Alternative approaches

Next-generation nuclear

The government is investing some £460 million into nuclear research and innovation, aiming to improve the efficiency of nuclear power as a generating source, particularly focusing on fuel, safety, design and construction.[47] Fourth-generation Fast Neutron Reactors, which could reprocess spent fuel from traditional nuclear power plants, and research into fusion, which could promise limitless power, are prominent research avenues. These technologies can also yield transferable benefits, through advancements in robotics, advanced materials and computing models.[48]

Small Modular Reactors

Small Modular Reactors (SMRs) are a new generation of low-energy-output, low-hazard, compact and modular nuclear reactors. With the integration of inherent and passive safety measures, off-site construction and higher fuel burn-up rates, they promise a safer, lower-waste and reduced-risk venture, with earlier returns for investors.[49] SMRs are supported within the Nuclear Sector Deal. Several domestic consortiums, including one led by Rolls-Royce, which manufactures reactors for the UK's nuclear submarines, have the technology and expertise to build reactors.

SMRs could have certain advantages over large-scale third-generation nuclear plants, with some designs small enough to be built in factories and transported by road or rail.[50] This could allow for earlier adoption of standardised design, and economies of scale which could lead to reduced manufacturing times. Reactors could also be installed on location, significantly reducing construction times.[51] Rolls-Royce argues that an SMR reactor could provide 440 megawatts of electricity, enough to power a city the size of Leeds, and that a production line would be more affordable than a one-off bespoke major project.[52]

Multiple smaller reactors could be deployed more flexibly and the impact of shutdowns for maintenance would be reduced if rotated between multiple smaller generators. This is especially important if the need for a model that can provide baseload power is disrupted by innovations being undertaken by National Grid's Electricity System Operator (ESO), which manages electricity distribution for the grid. Multiple smaller nuclear reactors could more flexibly respond to energy demand, given that the ramp-up times for a reactor to adjust output are measured in days. Alternatively, a network of SMRs could divert continuous energy production to convertible or energy-intensive industrial tasks, such as the production of hydrogen, energy storage or desalination plants, which are likely to become increasingly important.

SMRs do have potential drawbacks, however. Strategically sited large-scale nuclear plants would likely be easier to protect from security threats than multiple sites. SMRs could also have potentially higher operating costs as larger power plants generally reduce the cost per megawatt of electricity produced.[53]

[46] Nuclear Industry Association (2020) Dependable Power Supplies in Challenging Times
[47] Department for Business, Energy and Industrial Strategy (2020) Funding for Nuclear Innovation
[48] Ibid
[49] ICE Publishing (2017) Economy, Safety and Applicability of Small Modular Reactors
[50] International Atomic Energy Agency (2020) Small Modular Reactor (SMR) Regulators' Forum
[51] SMR Regulators' Forum/IAEA (2019) Report on Key Regulatory Interventions during a Small Modular Reactor Lifecycle
[52] Rolls-Royce (2018) UK SMR: A National Endeavour
[53] Atkins (2015) Our Nuclear Future?

Renewable power and evolution of the national grid

Renewables today offer affordable electricity, contribute substantially to the energy mix and, apart from carbon emissions in construction and transmission of power, can produce zero-carbon electricity. With the exception of hydropower and tidal power, however, they have relatively short operating lives and provide intermittent generation, with generation outputs fluctuating depending on weather conditions.

While it is true that nuclear is adept at providing reliable and continuous baseload power, National Grid's Electricity System Operator has set out that the need for baseload is unlikely to be an issue after 2025.[54] Battery storage projects are coming onstream, with some 500 megawatts of storage capacity installed within the last year.[55] There are also large-scale plans for increased capacity from offshore wind and solar in the near future.

Additionally, by 2025 National Grid expects to have 'all of the tools, processes and services in place such that we can operate the grid at zero carbon, to the extent that that generation mix is available at the time'.[56] At present a combination of coal, gas and nuclear generation is needed to provide grid inertia and stable voltage. Renewables cannot provide these services.

Changing the grid model to one which doesn't require high levels of synchronous power should allow for a much larger proportion of generation at any one time to come from low-carbon and renewable sources than at present, which will particularly affect the need for coal and gas generation.

A grid which can be more flexible about the source and location of electricity generation would pave the way for a 'Community Renewables' pathway, one potential scenario outlined by the ESO in its work on future energy scenarios.[57] In this scenario, by 2050 up to 58% of total generation capacity is decentralised and not provided by the main transmission grid. There would be high rates of storage capacity, particularly in homes, which would balance out peaks and troughs in renewables production and decrease demand for nuclear capacity. However, in other scenarios, notably the 'Two Degrees' scenario, which relies on a centralised grid, there would be more nuclear demand.[58]

There will be a need for a diverse energy mix. Renewable generation is heavily weather dependent and a reliable mix of storage, green gas or nuclear is likely to be needed to ensure a secure supply of energy across the UK.

About ICE

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[54] Business, Energy and Industrial Strategy Committee (2020) Oral Evidence: The Impact of Coronavirus on Business and Workers, HC 219
[55] National Grid ESO (2019) Future Energy Scenarios
[56] Ibid
[57] Ibid
[58] Ibid