

THE FALSE ECONOMY OF ABANDONING NUCLEAR POWER

**Techno-Zealotry and
the Transition Fuel Narrative**



**THE NEW NUCLEAR
WATCH INSTITUTE**



FORWARD BY TIM YEO, CHAIRMAN, THE NEW NUCLEAR WATCH INSTITUTE

There is now near universal agreement that the electricity generation industry must be almost entirely decarbonised by 2050 to prevent the rise in average global temperature from exceeding 2°C. However, the way in which this goal should be reached continues to be vigorously debated.

Some campaigners claim that by mid-century Britain, and indeed other countries, will be able to meet all its energy needs from renewables. Pointing to the delays and cost overruns experienced recently in the construction of some new nuclear plants they argue that, despite its impeccable credentials as a reliable supplier of low carbon baseload electricity, nuclear power should now be phased out along with coal.

They suggest that gas can fill the capacity gap caused by the closure of coal plants until the massive (and so far, uncostered) electricity storage facilities, which will be needed as dependence on intermittent energy sources increases, are available. Substituting gas for coal will also cut carbon emissions.

This Report “The False Economy of Abandoning Nuclear Power”, which has been commissioned by The New Nuclear Watch Institute, examines these arguments. It considers both the environmental impact and the financial costs of phasing out nuclear and relying instead on a combination of extra renewables and gas.

It compares this impact and these costs with an alternative approach designed to minimise levelised system cost of electricity. This alternative involves keeping nuclear in the energy mix, together with renewables and a small but diminishing role for gas as a balancing fuel.

The Report’s conclusions are stark. Abandoning nuclear power leads unavoidably to a very big increase in carbon emissions which will prevent Britain from meeting its legally binding climate change commitments. It also raises the cost of electricity.



These conclusions are consistent with the experience of Germany after its decision several years ago to phase out nuclear. They emphasise the folly of following the German example and the need for choices about the energy mix in all countries to be made on the basis of objective analysis.

NNWI has always believed that both nuclear and renewables have an important contribution to make. In our view both are needed to ensure that dangerous and irreversible climate change is successfully averted.

ABOUT TIM YEO

Tim Yeo was a Member of the UK Parliament for over 30-years, from 1983- 2015. During his time as an MP, Tim was Chair of the influential Energy & Climate Change Select Committee (2010-2015), and of the Environmental Audit Committee (2005-10). Prior to this he served in several Government departments (1988-1994) including Minister for the Environment and Countryside (1993-1994) in the John Major Government.

Since leaving the House of Commons in 2015, Tim has been working in various energy and climate change related roles in the business and academic worlds. These include Chair of New Nuclear Watch Europe (NNWE), an industry supported body which campaigns for new nuclear development across Europe, Board membership (and former chair) of AFC Energy plc, an AIM listed UK based hydrogen fuel cell developer, and Chair of the University of Sheffield Energy 2050 Industrial Advisory Board. Tim remains a director of Getlink SE (formerly Groupe Eurotunnel), one of the largest listed companies in France, where he chairs the Board Strategy and Sustainable Development Committee.

In 2016 KOTRA, the South Korean trade office, appointed Tim as the Honorary Ambassador of foreign investment. He is also a frequent visitor to China where he works with the UK-China (Guangdong) CCUS Centre on carbon capture projects, with academic collaborators on the design of China's emissions trading system and with business colleagues on inward investment from China to the UK.

Founded by Tim Yeo at the end of 2014 New Nuclear Watch Europe (NNWE) is an interest group which has been established to help ensure nuclear power is recognised as an important and desirable way for European governments to meet the long-term security needs of their countries. Membership is open to all companies, individuals and organisations active in the nuclear industry including those involved in the supply chain.



The New Nuclear Watch Institute (NNWI) is the first think-tank focused purely on the international development of nuclear energy. It believes that nuclear energy is vital for the world to achieve their binding Paris Climate Agreement objectives. Its research will aim to promote, support, and galvanise the worldwide community to fight the greatest challenge of our time: climate change.

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1

EXECUTIVE SUMMARY

5

INTRODUCTION

6

**NATURAL GAS AND THE TRANSITION
FUEL NARRATIVE**

10

THE EXCLUSION OF NUCLEAR POWER

14

**THE SYSTEM COST OF ABANDONING
NUCLEAR**

24

**OTHER CONCERNS WITH THE TRANSI-
TION FUEL NARRATIVE**

30

CONCLUSION

32

ANNEX

34

BIBLIOGRAPHY



EXECUTIVE SUMMARY:

A. OVERVIEW

A recent feature of energy policy debate has been the ardent promotion – or indeed strident denigration – of particular generation technologies. Despite a large body of research – and indeed common sense – demonstrating that energy systems will be best able to deliver decarbonisation if all mitigation technologies are available to it, the technological zealot seeks to restrict the range of options to his or her chosen few. Clearly, this is a profoundly unwelcome development as increasing the cost of decarbonisation serves only to make its realisation that much more difficult.

The significant decrease in the cost of renewable energy – notably wind and solar – that has occurred during the last decade – juxtaposed with the escalated cost and delayed construction of new nuclear reactors across Europe and North America – has given weight to the view that cost-effective decarbonisation is best achieved with an amalgamation of renewable energy sources and temporary ‘bridge’ solutions that compensate for wind and solar variability. In the long-term, storage technologies – as yet nascent – are thought to provide the grid flexibility made necessary by intermittency.

In the UK, the bridge solution that has garnered the most attention is that of a ‘transition fuel’: the use of natural gas as a means to both encourage the further penetration of renewable energy sources into the power sector and substitute for carbon-intensive coal-fired electricity generation. The environmental benefit of coal-to-gas fuel-switching is well documented, direct emissions of carbon dioxide (CO₂) per unit of energy produced from gas are 40% lower than coal¹. Moreover, the low cost of gas – a result of increased supply from unconventional sources – has added further appeal.

There is nothing innately problematic with the logic of this view as described thus far – aside perhaps from its dependence on the timely commercialisation of grid-level storage technology that is by no means certain – however an often-associated and vociferously made addendum that urges the abandonment of nuclear power – after hydropower the largest source of low-carbon power in the world – is exceptionally misguided. A report published by MIT² leaves no doubt as to the consequences of such dogmatism, stating that “including nuclear in the mix of capacity options helps to minimize or constrain rising system costs, which *makes attaining stringent emissions goals more realistic*” (emphasis added).

The focus of this report is on the deteriorative impact on system generation cost of omitting nuclear energy from the power sector in the context of meaningful cli-

¹ <https://www.iea.org/geco/emissions/>

² MIT, *The Future of Nuclear Energy in a Carbon-Constrained World: An Interdisciplinary Study*, (2018)

mate policy. It compares two distinct scenarios, of an enforced nuclear phase out and of an unconstrained optimisation, using a deterministic partial-equilibrium model of the power sector of the UK in 2030. The inter-scenario cost differential is then proposed as the opportunity cost of excluding nuclear power in this particular setting, while the fundamental reasoning is more widely applicable. The results make clear the folly of technological tribalism, system cost rises by 15% in the absence of nuclear power – from £82/MWh to £95/MWh at an annual cost in excess of £3 billion – and carbon intensity rises from 51 gCO₂/kWh to 186 gCO₂/kWh as the share of low-carbon generation falls from 87% to 48% and an additional 35 million tonnes of CO₂ are emitted.

B. THE FALSE ECONOMIES OF ABANDONING NUCLEAR POWER

The central economic metric of interest to this report is levelised system cost of electricity, measured as the generation-weighted levelised cost of electricity from all energy technologies. It represents the electricity price at which the power system will break even over the course of its lifetime, assuming no indirect or direct subsidies are introduced. At the level of an individual technology, the required input parameters (calculated on an annual basis) include:

- construction cost;
- fixed O&M (FOM) cost;
- variable O&M (VOM) cost;
- fuel cost (if applicable);
- carbon emission cost (if applicable);
- plant capacity;
- load factor;
- plant lifetime;
- and, a discount rate.

However, before technology-specific levelised costs can be calculated the power system as a whole must be derived – according to scenario-explicit technological constraints – as some of the input parameters above are not independent. Within an energy system, generator load factors are interdependent; an increase in the share of total generation accounted for by a particular technology must – all other things being equal – reduce the load factor of other technologies, unless retirement occurs.

A notable example of this phenomenon concerns rising feed-in from renewable energy sources – as seen across much of western Europe – that decrease load factors of the conventional fleet – via the merit order effect – but whose intermittency prevents conventional retirement. This has reduced the profitability of con-

ventional generation – compounded by the low electricity prices associated with increased renewable penetration – and has led to the development of capacity markets, to compensate conventional generators for the dispatchability of their capacity.

To determine the installed capacity and actual production from the utilised energy sources – for simplicity here assumed to be natural gas (CCGT and OCGT), wind (offshore), and nuclear (PWR NOAK) – a least-cost optimisation was performed in conjunction with an analysis of the residual load duration curve. The result is a deterministic, partial equilibrium of the power sector that prioritises the take-off of renewable generation – here, offshore wind – at each hourly point and subsequently meets residual demand entirely using the aforementioned generation technologies at the lowest cost.

The opportunity cost of an enforced nuclear phase out was evaluated as the cost differential between two hypothetical scenarios, structured as follows:

Scenario	Wind Capacity (MW)	Nuclear Capacity	Residual Demand (Tech.)
Nuclear Phase Out	30,000	<i>Excluded</i>	CCGT / OCGT
Unconstrained Optimisation	25,000	<i>Unrestricted</i>	CCGT / OCGT / Nuclear

The derivation of technology-specific generation cost curves was used to determine the optimal operation – in terms of full load hours (FLHs) – of the conventional technologies. An analysis of residual load using the optimal FLHs was then conducted to establish the required capacity and generation of each technology. Next, a load factor for each technology was imputed and then used to determine the scenario-specific levelised cost. Finally, the system-level generation cost could be imputed using the levelised cost figure and the proportion of total demand accounted for by each energy source.

C. RESULTS AND FINDINGS:

#1

Economic Impact:

The effect of an enforced nuclear phase out on the generation cost of the UK power system in 2030 is to raise it by 15% – from £82/MWh to £95/MWh – at an annual incremental system cost of £3.2 billion. This illustrates that – while storage technologies remain unable to manage system-level

el intermittency in an economic and technical manner – nuclear power represents the future-fit choice of dispatchable, low-carbon power generation. It should also be noted that the greater penetration of an intermittent renewable energy source – offshore wind – in the phase out scenario most likely results in a higher level of integration cost – the cost of establishing higher grid flexibility to cope with intermittency – that further raises system cost.

#2

Environmental Impact:

The imposition of a nuclear phase out reduces the share of low-carbon generation in total generation in 2030 from 87% to just 48%. As a result, the power sector emits an additional 35.2 million tonnes of CO₂eq emissions, an increase of 265% from the unconstrained scenario. This increases the carbon intensity of the power sector – the ratio of carbon emissions to generation – from 51 gCO₂/kWh to 186 gCO₂/kWh. As noted by the UK Committee on Climate Change³ (CCC), an effective policy to support the steady development of low-carbon technologies implies a transition to a power system intensity of below 100 gCO₂/kWh by 2030.

#3

Rising Cost of Gas-Fired Electricity:

The low price of natural gas – stimulated by the technical advances that have resulted in a significant increase in unconventional supply – is often used as an argument in favour of the ‘transition fuel’ narrative. Nevertheless, the cost of gas-fired generation faces increasingly acute upward pressure caused by the rising price of carbon emissions. The UK BEIS Cost of Generating Electricity (2017) states that the levelised cost of gas-produced (via CCGT) electricity will rise by 8% to 2020 and by 60% to 2030.

More broadly, this paper demonstrates that much of the perceived wisdom surrounding the energy transition deserves closer examination, founded, as much of it is, on assertions that do not stand up to analytical rigour. The subject of nuclear power and its role in the UK is hotly contended but if the UK is to maintain the reliability of its power generation, confront rising generation costs head-on, and achieve the required decarbonisation of its energy sector, nuclear power must feature strongly in its ambitions.

³ Committee on Climate Change, *Meeting Carbon Budgets: Closing the Policy Gap*, (2017)

INTRODUCTION

The Paris Agreement commits signatories to restrict the global temperature rise to well below 2°C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5°C. This is to be achieved via the implementation of nationally determined contributions (NDCs), which delineate the domestic mitigation measures that each state will enact in pursuit of the ambitious climate target. In this context, a consensus has emerged on the urgent need to decarbonise the power sector should economy-wide emission reduction targets be met.

While steep decarbonisation as embodied in the Paris Agreement is an almost universally accepted climate target, the task of bringing about the required emission reductions has been left to national and regional governments. This decision – founded on the straightforward assumption that those bodies are best placed to identify the policies most effective within their specific circumstances – has led to a diverse range of proposed transition pathways. Regrettably, the urgent need to decarbonise has acted to narrow the minds of many.

It ought to be clearly apparent that the impetus must be on developing holistic energy strategies that deliver the decarbonisation of the power network in a manner not only economic but also reliable and lasting, but the reaction of many has been to fervently promote – or indeed denigrate – specific generation technologies without due consideration of the long-term system impact of doing so.

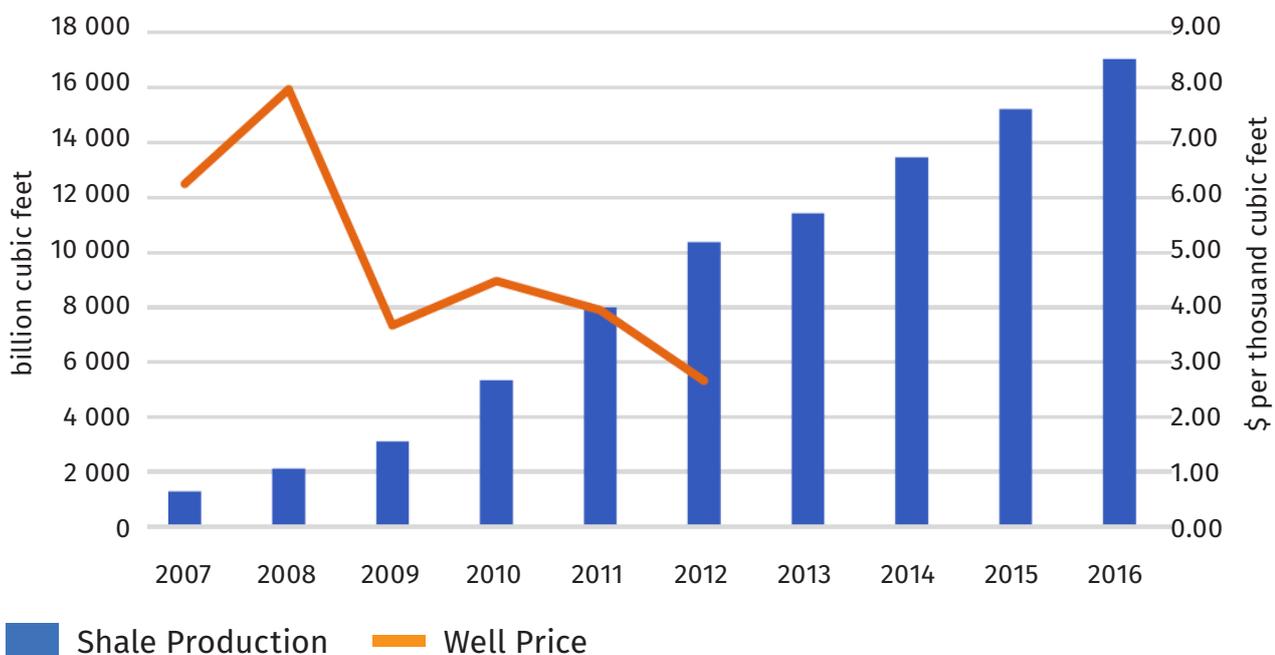
The influence and focus of this way of thinking differs between regions and nations but the underlying threat is that meaningful, persistent decisions regarding energy infrastructure – a notably inert form of capital stock – will be made while blind to their full ramifications, thus not only adding to the difficulty of the decarbonisation challenge but perhaps also making it unachievable within the required time frame.

A frequent target of such techno-zealotry is nuclear power, to the point where the exclusion of nuclear from the power sector is vehemently encouraged even when doing so would sustain – and even prolong – the presence of carbon-intensive sources of electricity. This report evaluates one such case, the so-called transition fuel narrative that argues that the decarbonisation of the UK – although the narrative is also applied elsewhere, such as Spain and South Africa – would be best achieved by phasing out nuclear power in the near-term and instead relying on natural gas to deliver greater renewable energy penetration in the long-run.

NATURAL GAS AND THE TRANSITION FUEL NARRATIVE

The transition fuel narrative – the view that natural gas has an important if not vital role to play in achieving the decarbonisation of the power sector by means of its superior environmental profile when compared to coal and its potential to support the further grid-level integration of renewable energy sources – is increasingly prevalent. Its proponents argue that the continued – even expanded – use of natural gas presents multiple advantages: lower power costs, improved energy security (dependent on location and resource endowment), reduced air pollution, and a less carbon-intensive generation system. The development of the transition fuel narrative has taken place in conjunction with significant technical advances – in horizontal drilling and hydraulic fracking – in the gas industry that have increased access to unconventional sources of supply, most notably in North America.

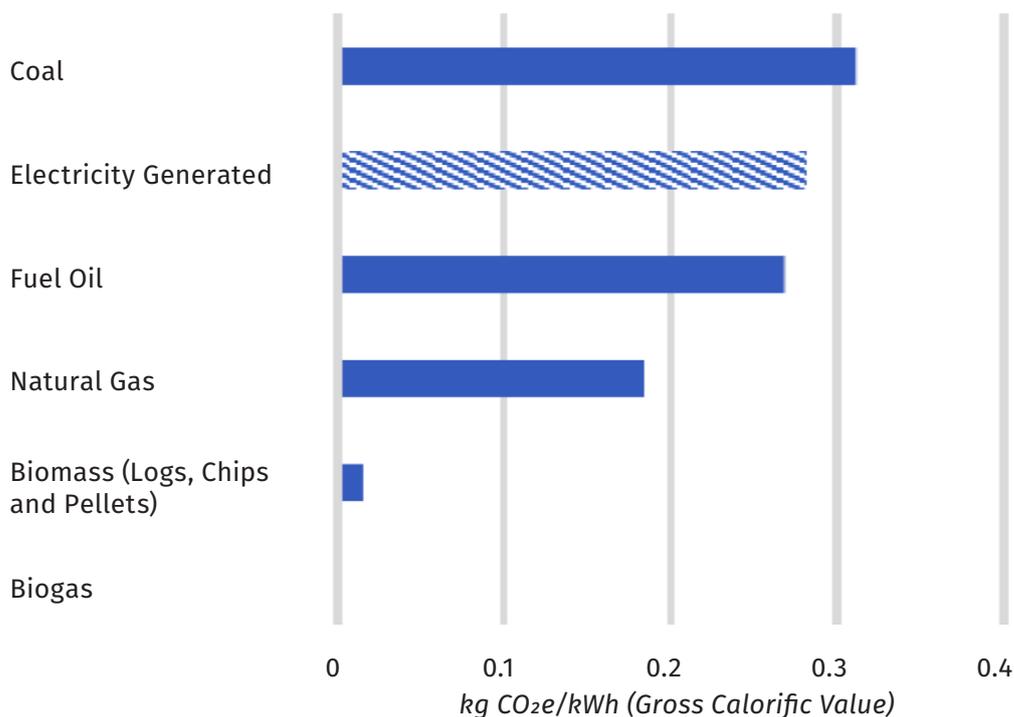
The USA Shale Revolution (USA EIA)



The role played by natural gas in facilitating the transition to a low-carbon power system is twofold. Firstly, coal-to-gas fuel-switching results in a reduction in direct carbon emissions due to the lower carbon intensity of natural gas. From a corporate perspective, the decision to switch fuel type is a financial one; there exists a relative price at which coal-to-gas switching becomes a coherent economic choice regardless of applicable policy. However, governments are able to influence the ‘switch price’ via the implementation of carbon-targeting policies – such as the European Union’s Emission Trading Scheme (ETS) and the supplementary

Carbon Price Floor in the UK – that increase the relative cost of carbon-intensive generation and so favour a shift to gas-fired generation. The impact of such policies has been augmented by the reduction in the price of natural gas relative to coal – a result of expanded unconventional supply – that has further worsened the competitive position of coal use.

UK Fuel Conversion Factors* 2018 (UK BEIS and DEFRA)



**for use by UK-based organisations reporting on UK operations*

Secondly, the flexibility of natural gas – with regard to load following potential and ramping constraints – supports the greater penetration of renewable energy sources into the power sector, thus further reducing its carbon intensity. The intermittency of renewable energy – power generation is not dispatchable due to the uncontrollable nature of the underlying resources – necessitates the installation of flexible back-up capacity in order to maintain current system reliability and security of supply. In the long-term, it is envisaged that the development of power storage technologies will allow them to manage this intermittency, providing the means by which renewable energy can be time-shifted. However, storage technologies remain in relative infancy in the present-day – particularly so at the

levels required for non-residential consumers and for intra-seasonal transfer of energy – and despite recent cost reductions do not yet represent a feasible solution on either economic or technical grounds. Thus, gas-fired generation provides the flexibility necessary to sustain and accelerate the penetration of renewable energy through the medium-term.

Quantifying the Integration Effect:

In *Bridging the Gap: Do Fast Reacting Fossil Technologies Facilitate Renewable Energy Diffusion?*⁴, the authors present a macro-analysis of the historic relationship between renewable and fossil fuel installed capacity and assess the long-term impact of the latter on the former. The principal conclusion of the report is that a 1.00% increase in the share of total installed capacity held by “fast reacting fossil technologies” – in contrast to baseload technologies – is associated with a 0.88% increase in renewable capacity over the long-term (while the short-term effect is marginal).

An important addendum to the transition fuel narrative is that increasing natural gas generation alone will not deliver net emissions savings in the absence of an active low-carbon policy. As mentioned above, one metric of critical importance in determining the extent of fuel-switching is the coal-gas relative price, which the imposition of a rigorous carbon price can influence. Another substantial issue is the interplay between the natural gas price and overall energy consumption as a low fuel price is likely to stimulate additional power demand – particularly in energy-intensive energies – that may partially or wholly offset the benefit of fuel-switching.

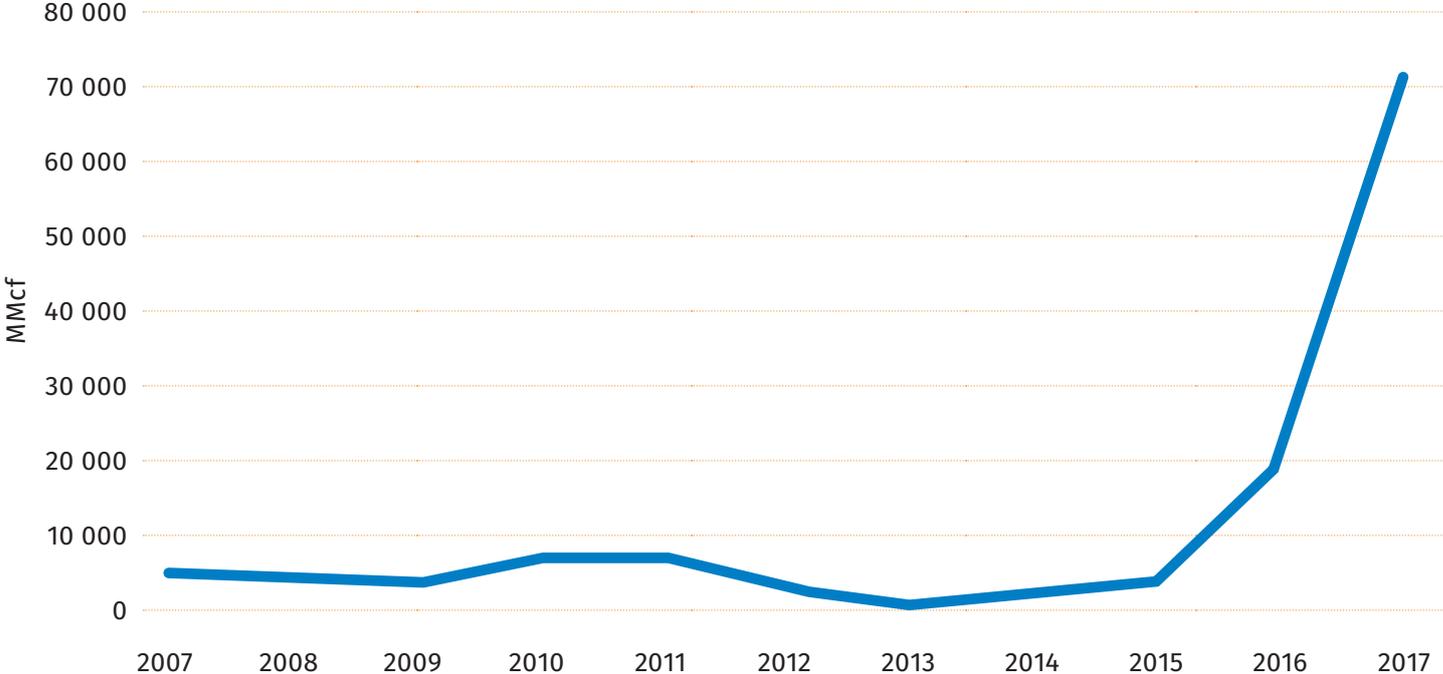
The flipside of high natural gas demand is a proportional decrease in coal demand that may stimulate demand for the more carbon-intensive fuel in nations or regions of the world in which climate action is not an explicit policy priority. Moreover, the eventual end-use of natural gas is another concern where increased gas supply has led to increase in exports, as is the case in North America.

This makes clear while market forces may drive the transition fuel narrative – insofar as natural gas use increases – it is for climate policy to deliver its proposed environmental benefits.

⁴ Verdolini, Vona, and Popp, *Bridging the Gap: Do Fast Reacting Fossil Technologies Facilitate Renewable Energy Diffusion?*, National Bureau of Economic Research, NBER Working Paper Series, no. 22454, (2016)

NATURAL GAS AND THE TRANSITION FUEL NARRATIVE

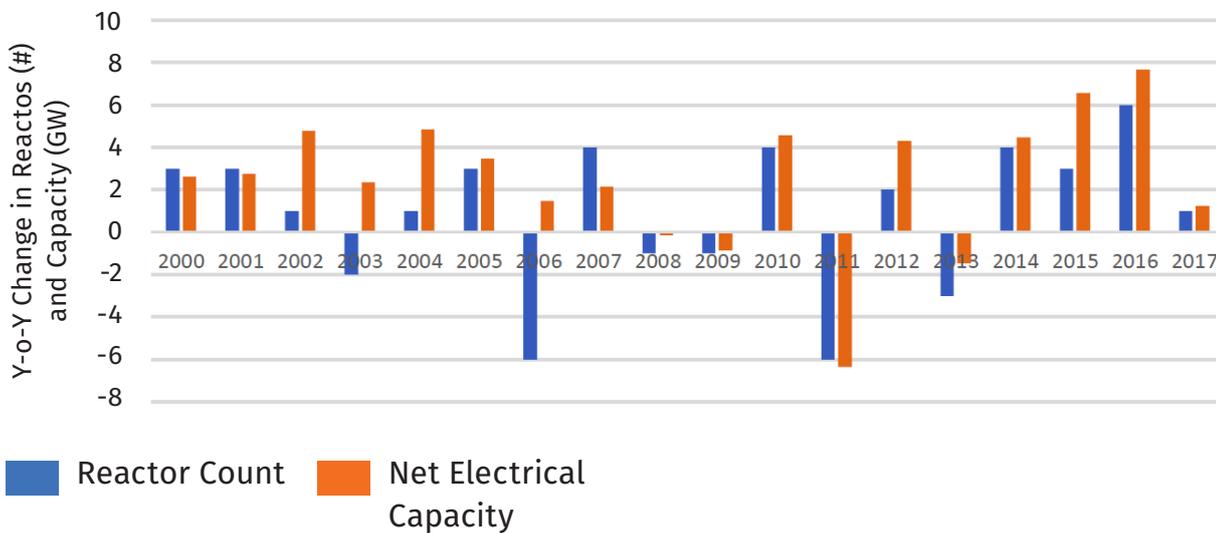
USA Liquefied Natural Gas Exports by Vessel (US EIA)



THE EXCLUSION OF NUCLEAR POWER:

The argument made in proposition of the abandonment is straightforward: renewable energy sources backed up by natural gas through the medium-term until grid-level, commercial power storage solutions are available represents the cost optimal means to decarbonise electricity generation in the UK and so the added cost of nuclear power precludes its consideration. In Europe and North America, this view has gained traction in light of recent cost and construction overruns in new build projects such as the EDF Flamanville reactor in France. However, it must be made clear that the issues experienced at such projects are a direct result of an induced policy context that is unfavourable towards them.

Evolution of World Nuclear Capacity (IAEA)



Perhaps the defining characteristic of the aforementioned policy environment is the unwillingness on the part of governments to fund – even partially – large infrastructure projects, in both the transport and digital sectors as well as energy. It might be argued that this reflects the recalibrating of public finances called for by the aftermath of the 2008 financial crisis. However, according to the World Economic Forum⁵ (WEF), financing for public infrastructure has returned to pre-crisis levels (albeit below the requirements of the present-day) but is largely being used to maintain or renovate existing assets. This may be the result of a multitude of factors, including: short political cycles, near-term investment horizons, a lack of suitable financing structures (WEF has proposed a new asset class called ‘buy-and-hold equity’ (BHE), a debt-equity hybrid), and a broader absence of vision or strategy at the national or regional level⁶.

The aversion to committing public funds to new nuclear projects – and infrastructure projects in general – is particularly deleterious to the prospects of commis-

⁵ <https://www.weforum.org/agenda/2015/03/do-we-need-a-new-way-to-encourage-infrastructure-investment/>

⁶ <https://www.weforum.org/projects/ceo-council-on-transformational-megaprojects>

sion due to their financial profile. As a substantial, capital-intensive endeavour – where pre-development and construction costs account for the largest share of project expense – the final cost of a nuclear plant is heavily determined by the project cost of finance (the weighted cost of capital). This being the case, access to public funding or support – in any meaningful form – that reduces debt risk towards a sovereign-like profile and so lowers capital costs has a significant, downward effect on the levelised electricity cost from nuclear power. As one example, had the UK government taken a 25% equity share in a public-partnership deal for Hinkley Point C the electricity strike price would have been up to £23/MWh (or 25%) cheaper⁷ (in 2012 prices).

In many nations, this situation has been exacerbated by energy policy strategies that amount to technology-specific interventions, in essence the practice of ‘picking winners’. In Europe, for instance, this has manifested itself in energy policies that have supported the development of renewable energy technologies and the renewable industry more broadly. However, nuclear power – in large part due to the above resistance to financing large projects – are rarely if ever included in such climate reforms, despite being the largest source of low-carbon in the developed world. Significantly, while nuclear power and renewable energy are both low-carbon resources, nuclear power is also a dispatchable resource and so does not require further investment in either carbon-intensive back up capacity or immature storage technologies.

The policy environment in Europe and North America as thus described has acted as a constraint on the growth of nuclear capacity. As a result, the supply chain of the nuclear industry – in the absence of repeat custom – has atrophied, further increasing the cost of industry coordination while arresting the accumulation of process-specific knowledge and experience. This has occurred alongside the technical development of a new generation of nuclear reactors (Gen III+), a period in which the inevitable inefficiencies of first-of-a-kind (FOAK) production – ‘teething’ issues – create upward cost pressures. Of particular note are the construction delays that can affect FOAK production, which postpone income generation and so translate directly into higher financial costs.

However, the disadvantageous situation – policy induced – as described is predominantly confined to western Europe and North America whereas the nuclear industry elsewhere – in particular, Asia – is delivering low cost, on-time projects. This makes clear two salient points: firstly, that the claim made in some quarters that nuclear power is unaffordable is an untenable one and secondly, that reduc-

⁷ House of Commons: Committee of Public Accounts, *Hinkley Point C: Third Report of Session 2017-19*, (2017)

THE EXCLUSION OF NUCLEAR POWER:

tions in the cost of new nuclear cost can be readily brought about by adopting the processes and codes that constitute best practice in low-cost regions, such as the fast-growing economies of Asia, who have not been hampered by the hiatus in nuclear construction that has occurred in the West . The scope for the latter – the adoption of best practice or benchmarking – is significant and even partial take up would deliver valuable cost reductions.

Country	Net Capacity (MW)	Investment Costs (USD/MWh)		
		3%	7%	10%
United Kingdom	3 300	100%	100%	100%
Finland	1 600	82%	85%	86%
France	1 630	85%	88%	89%
Japan	1 152	65%	67%	69%
Korea	1 343	33%	32%	32%
China	1 250	44%	45%	46%
China	1 080	30%	31%	32%

Source: IEA and NEA, *Projected Costs of Generating Electricity*, (2015)

A survey of international capital costs conducted by the Energy Technologies Institute⁸ (ETI) found that “very significant cost potential” exists with regards to UK nuclear new build and that cost reductions achieved outside Europe and North America are a “consequence of national nuclear programmes and consistent, rational implementation of best practices”. The latter point highlights the importance of bringing together all stakeholders – including representatives of the public sector and government – on a sustained, long-term basis to enhance knowledge accumulation and to maintain the process of continued improvement.

Case Study (ETI): Barakah, UAE

The Barakah power plant is the first nuclear power station in the United Arab Emirates, with four APR-1400 reactors planned. In 2009, the construction contract was awarded to a coalition led by Korea Electric Power Corporation (KEPCO) – of extensive experience in the nuclear industry – and building of the first unit began in July 2012, completed in March 2018. The consec-

⁸ Energy Technologies Institute, *The ETI Nuclear Cost Drivers Project: Summary Report*, (2018)

THE EXCLUSION OF NUCLEAR POWER:

utive nature of the reactor installation has allowed for multi-unit efficiencies – economies of scope – to be exploited as well as the swift acquisition and subsequent deployment of numerous on-site learning effects. Moreover, a combination of government and vendor finance, loan guarantees, and a power purchase agreement was utilised to limit financing costs. This structure has ensured that the average cost per unit (\$3,700/kW) is low by international standards and that large unit-on-unit cost reductions will be achieved (ETI report that Barakah 4 – currently under construction – will be built at a cost of \$2,300/kW).

Of the cost drivers identified by the ETI, three were evaluated as of the highest importance: the strength and management of the nuclear supply chain, the governance and development of individual projects (including the enactment of best practice), and the productivity and integration of the project labour force. In sum, the report demonstrates that the transition from worst to average practice results in a capital expenditure reduction – a value distinct from the rate of interest – of 35%. Moreover, these improvements in project execution can reduce project risk, thus lowering the cost of finance and reducing capital expenditure further.

Similarly, a report recently published by MIT⁹ stressed the importance of capital expenditure reduction, noting that “costs are dominated by civil works, structures and building; electrical equipment installation; and associated indirect costs for this work on site.” A later section highlights the importance of taking full advantage of the FOAK to nth-of-a-kind (NOAK) production transition, stating that “FOAK plants in any country are typically 30% more expensive than subsequent plants of the same design.” Moreover, as the report continues, “this ‘cost of leaning’ is likely to be even higher if the firm/industry responsible for construction has not built any new plants in a generation.”

A crucial driver of cost – also noted in the aforementioned in the ETI report – is the degree of plant design completion prior to construction; alterations during the installation period are not only expensive in and of themselves but also result in reduced construction productivity as on-site resources are left idle and a higher finance cost caused by delays to operation. In addition to design completion prior to the start of construction, modularisation of fabrication and construction is an often proposed means to reduce capital expenditure, especially in nations with high labour rates.

⁹ MIT, *The Future of Nuclear Energy in a Carbon-Constrained World*, (2018)

SYSTEM COST OF ABANDONING NUCLEAR — METHODOLOGY AND RESULTS:

To evaluate the opportunity cost – herein defined as the incremental system levelled cost differential – of an enforced phase out of nuclear power, a scenario-based approach is adopted. The two scenarios of interest – between which the discrepancy shall be evaluated – are: a) an exclusion of nuclear power, modelled as an exogenous constraint on installed nuclear capacity (set to nil) and, b) an unconstrained optimisation, in which the capacity of all generation technologies is assumed unconstrained and endogenous. The formulation of the analysis is presented below, followed by a description of the model framework and relevant input parameters and subsequently by an analysis of the main results.

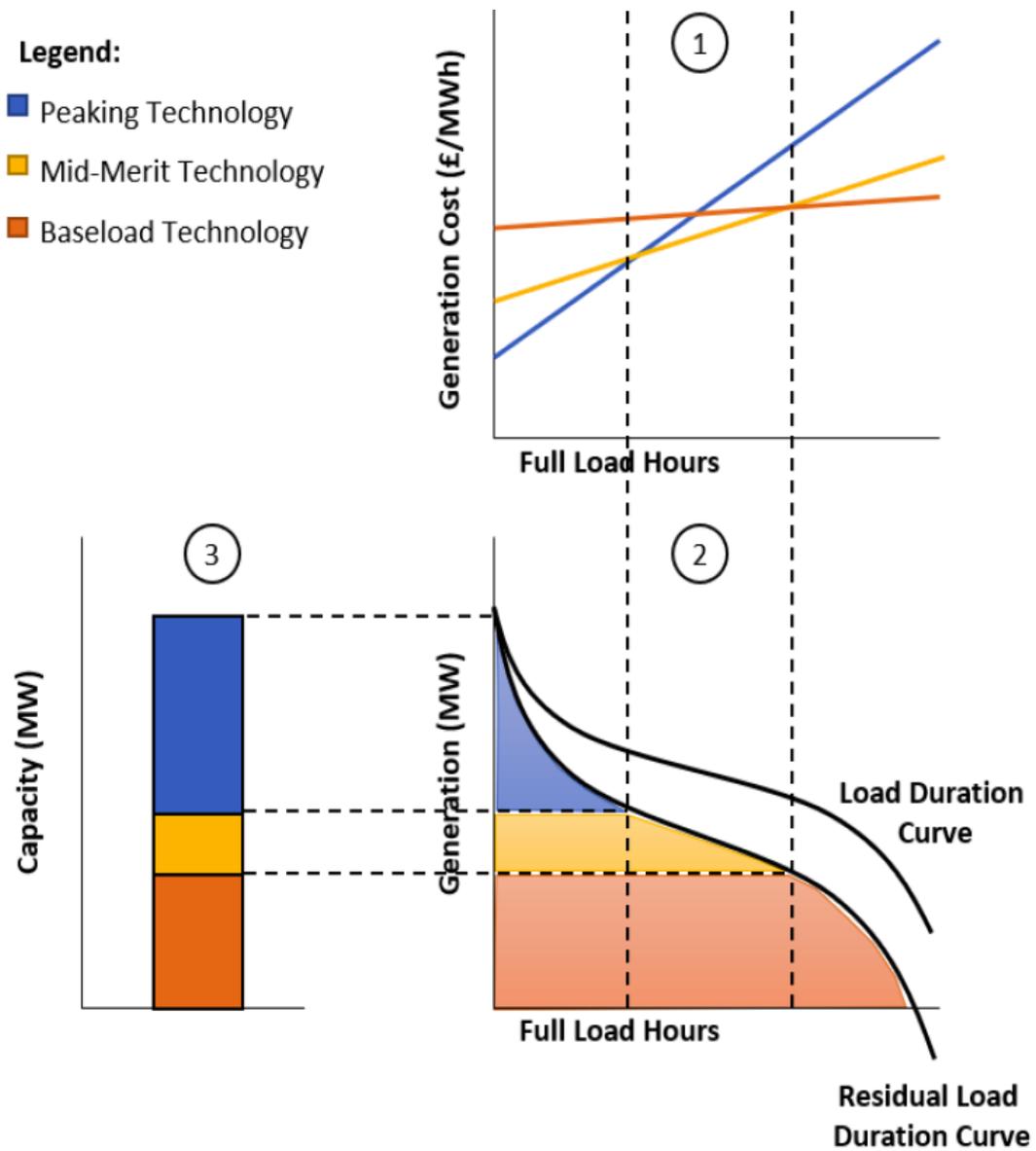
A. METHODOLOGY

Long-Term Generation Optimisation and Residual Load Duration Analysis

The least-cost long-term power sector generation combination is derived under the distinct constraints (or lack thereof) of the individual scenarios. This procedure entails the derivation of a load duration curve and of a wind generation profile (see section below on precise methods) that subsequently yield a residual load duration curve, the load curve of relevance to dispatchable technologies following the integration of low marginal cost intermittent renewable energy sources. Finally, the optimal technology configuration – the mix that minimises the production cost of satisfying the residual load over a single year – is obtained using technology-specific generation cost curves.

SYSTEM COST OF ABANDONING NUCLEAR — METHODOLOGY AND RESULTS:

SCHEMATIC APPROACH:



#1

The generation cost curve of a particular technology illustrates the relationship between its functional use and operational cost. From a system perspective, cost minimisation is achieved when the full load hour schedule of each technology is optimised.

SYSTEM COST OF ABANDONING NUCLEAR — METHODOLOGY AND RESULTS:

#2

The optimal full load schedules derived in the previous analysis are amalgamated with the residual load duration curve to evaluate the power generation – measured as the coloured area - accounted for by each individual technology.

#3

The required installed capacity of each technology can then be calculated; subsequently, load factors can be imputed (not illustrated here).

B. FRAMEWORK – CONTEXTUAL SETTING AND MODEL SCENARIOS

The analysis is set in the UK in 2030, chosen because it represents an organic nexus at which to investigate the consequences of a nuclear phase out. Should no new build occur in the UK, the current schedule of reactor decommission implies that nuclear power would be effectively phased out by 2030, with the exception of one unit at Sizewell. However, it would not be beyond possibility that Sizewell B be taken offline prematurely in the event of an accelerated (active) removal of nuclear power. Moreover, the recent reinvigoration of the Emission Trading System – supported in the near-term by the UK Carbon Price Floor – that will strengthen Phase 4 (2021-2030) of its operation signifies that the charge levied on carbon emissions will become an increasingly significant factor in the decision to renew natural gas capacity.

UK Climate Policy:

The Climate Change Act 2008 commits the UK to a legally binding reduction in its net carbon account of 80% compared to a 1990 baseline by 2050. In addition, the Act established a series of carbon budgets that limit net greenhouse gas emissions over successive five-year periods. The first carbon budget (2008 to 2012) was met with headroom of 36 MtCO₂e and the Department of Business, Energy & Industrial Strategy (BEIS) projects¹⁰ that the second (2013 to 2017) and the third (2018 to 2022) will also be met, with margins of 125 MtCO₂e

¹⁰ UK Department for Business, Energy & Industry, *Updated Energy and Emissions Projections 2017, (2018)*

SYSTEM COST OF ABANDONING NUCLEAR — METHODOLOGY AND RESULTS:

and 143 MtCO₂e in the central reference case respectively. However, BEIS projects a shortfall of 94 MtCO₂e against the fourth carbon budget (2023 to 2027), although the deficit has decreased from 146 MtCO₂e since its 2016 projections.

For the purposes of this analysis, the generation technologies considered are: open cycle gas turbines (OCGT), closed cycle gas turbines (CCGT), nuclear fission reactors, and offshore wind turbines. While it is certain that other technologies will be present in the generation mix of the 2030 UK power sector, the technologies selected serve to capture the particular implication of the transition fuel narrative that this report seeks to evaluate; that is to say, a nuclear phase out. The inclusion of both OCGTs and CCGTs is due to the likely impact of increased intermittent energy supply – herein captured by offshore wind – on the need for flexible reserve capacity.

THE TWO SCENARIOS EMPLOYED IN THE ANALYSIS ARE DEFINED THUSLY:

Nuclear Phase Out:

In this scenario, a total phase out of nuclear power is assumed, consisting of a cancellation of new build projects – Hinkley Point C and Wylfa – as well as an accelerated decommission of existing plants, resulting in a complete removal of the fuel from the energy mix. To compensate for this loss of capacity, it is assumed that offshore wind capacity is higher than otherwise would have been the case. The residual load – demand not met by offshore wind – is met by an endogenously determined combination of OCGTs and CCGTs.

Unconstrained Optimisation:

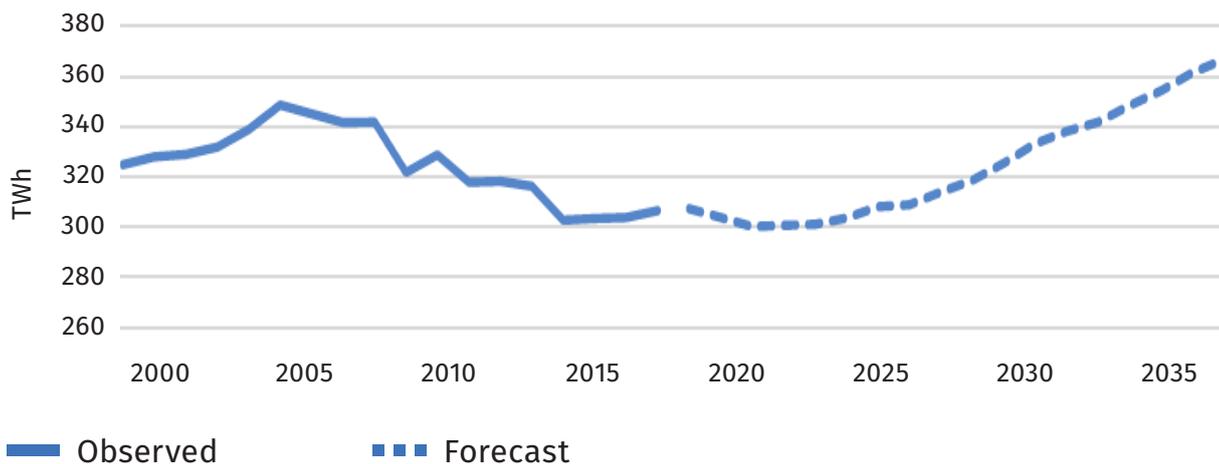
In the second scenario, it is assumed that nuclear power is not phased out and capacity is determined endogenously according to the least-cost optimisation procedure. As such, the capacity of offshore wind does not incrementally rise as in the nuclear phase out case but remains at its baseline figure.

Scenario	Wind Capacity (MW)	Nuclear Capacity	Residual Demand (Tech.)
Nuclear Phase Out	30,000	Excluded	CCGT / OCGT
Unconstrained Optimisation	25,000	Unrestricted	CCGT / OCGT / Nuclear

C. MODEL INPUTS — POWER SECTOR LOAD, WIND GENERATION, AND LEVELISED COST PARAMETERS

A model of hourly power demand in the UK in 2030 was constructed using the forecast for aggregate annual electricity demand published by BEIS and observed trends in the hourly distribution of UK power consumption. For the latter, historical data on hourly load demand was obtained from the National Grid¹¹, employing the assumption that observed generation (including imports) equals consumption. Subsequently, annual descriptive statistics – mean, standard deviation, skew, and kurtosis – of the data were collected and their trends – where present – extrapolated to 2030. Using the lognormal – to account for the observed positive skew in historical hourly load data, a result of the zero bound on actual generation – predicted values of mean and standard deviation in 2030, a random sample of 10,000 hourly load data points was then performed. Then, a stratified sample of 8,760 data points was collected – using decile subsamples populated in proportion to predicted 2030 allocations based on the trend in historical data – to reflect observed kurtosis, the ‘flat tails’ of demand. Finally, the 2030 data points were ordered according to the hourly rank observed in the historical sample.

UK Load Demand (UK BEIS)



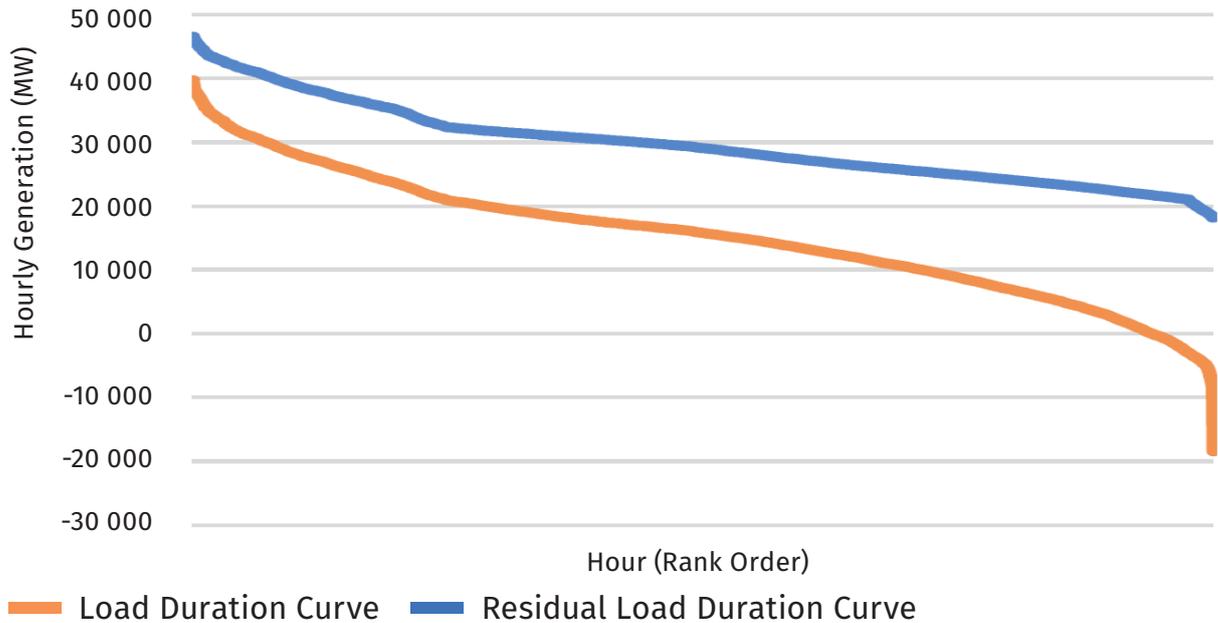
The first stage in constructing offshore wind generation was to determine the total output penetration of the resource using the scenario installed capacity and technical load factor. An output-equivalent dispatchable technology – an equal

¹¹ <https://www.nationalgrid.com/uk/electricity/market-operations-and-data/data-explorer>

SYSTEM COST OF ABANDONING NUCLEAR — METHODOLOGY AND RESULTS:

penetration rate but with constant rather than variable hourly output – was then modelled. Then, using data from Denmark – chosen due to the high penetration of wind in the Danish power sector and so assumed optimal spatial dispersion – the dispatchable output was adapted to account for the variation in relative hourly output – the intermittency – of offshore wind.

UK 2030: 30GW of Offshore Wind Capacity



The technology-specific parameters of interest to the analysis concern technical specification and discount rates. For the most part, the former was taken from ‘Electricity Generation Costs (2016)’, published by BEIS. The technical specifications for the mature technologies – here taken to encompass OCGTs and CCGTs – were assumed to be unchanged to 2030 while the capital costs related to the construction of a new nuclear plant were reduced by 20% to reflect the transition from first-of-a-kind production to nth-of-a-kind. This is considered to be a cautious estimate of the potential cost savings achieved should consecutive new build occur; the UK¹² is targeting a cost reduction of 30% by 2030. The scenario-specific load factor applied to each technology is an endogenous result of the optimisation procedure.

The Levelised Cost of Electricity:

The central economic metric of interest to this report is levelised system cost of electricity, measured as the generation-weighted levelised cost of electricity from all energy technologies. It represents the electricity price at which

¹² HM Government, *Industrial Strategy: Nuclear Sector Deal*, (2018)

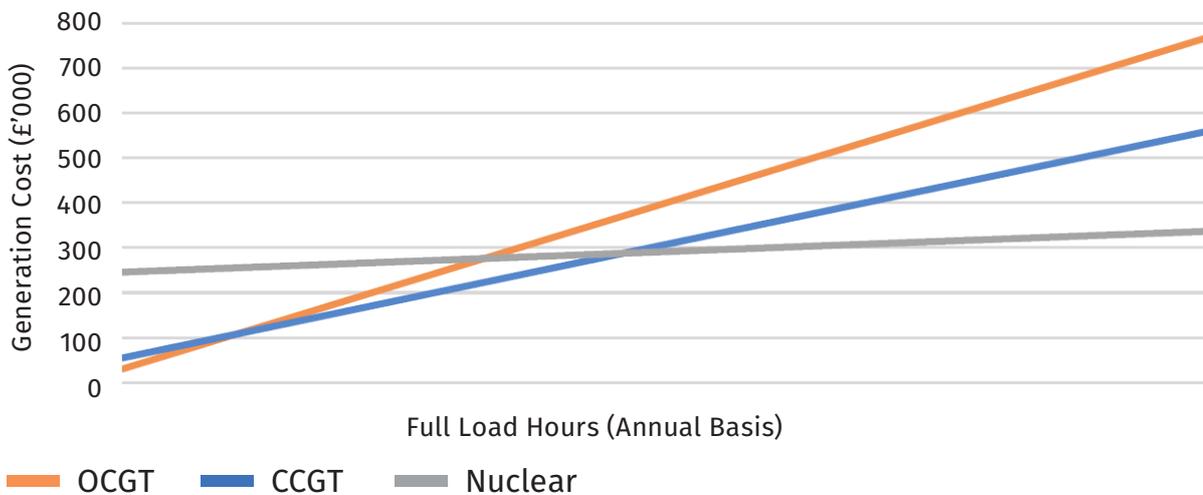
SYSTEM COST OF ABANDONING NUCLEAR – METHODOLOGY AND RESULTS:

the power system will break even over the course of its lifetime, assuming no indirect or direct subsidies are introduced. At the level of an individual technology, the levelised cost is the constant revenue figure that would enable project break-even over the life of the asset. It is given by the following equation:

$$\text{Levelised Cost} = \frac{\sum_{t=1}^n (\text{Construction}_t + \text{O\&M}_t + \text{Fuel}_t + \text{Carbon Cost}_t) / (1 + \text{Discount Rate})^t}{\sum_{t=1}^n (\text{Generation}_t) / (1 + \text{Discount Rate})^t}$$

The discount rate applied to generation cashflows was set at 7% except for nuclear power, the cashflows of which were discounted at 5% - the average cost of capital observed¹³ amongst firms under the regulated asset base (RAB) design - to represent government support for the energy source in the UK. While the exact nature of this support is uncertain - Hinkley Point C was supported via a Contract for Difference (CfD) whereas Wylfa may receive a direct financial contribution¹⁴ - the overriding aim is to reduce the project finance cost, a crucial determinant of viability in new capital-intensive infrastructure projects. To determine the suitable capital recovery factor - an input to the generation cost curve - for each technology, it was assumed that construction was debt financed at cost of capital and repaid over the full lifetime; a financing structure equivalent in many regards to a mortgage.

Generation Cost Curves



¹³ UK Regulators Network, Cost of Capital Report, (2018)

¹⁴ <https://www.bbc.co.uk/news/uk-wales-44161097>

SYSTEM COST OF ABANDONING NUCLEAR — METHODOLOGY AND RESULTS:

C. RESULTS

The model as described above solves for the least-cost power sector configuration in the UK in 2030 subject to exogenous scenario-specific technology constraints. The output is a partial equilibrium in model in which power sector generation exactly meets loads demand for each hourly period over the course of the year. This determines the electricity generation and installed capacity of each generator, from which a load factor is imputed and then used to determine the levelised cost of each technology. To calculate the levelised system cost, the individual levelised costs are weighted by the technology share in total output. The scenario differential is then taken to be the opportunity cost of a nuclear phase out as defined in this report. As a secondary focus of analysis, technology-specific carbon emission factors are then applied to generation figures in each scenario to determine the carbon intensity of the power sector in each scenario.

The results related to system cost (in £₂₀₁₄ per MWh terms) are as follows:

Nuclear Phase Out

	Generation	Load Factor	Levelised Cost	Contribution
<i>Wind</i>	48%	48%	£86	£41
<i>OCGT</i>	1%	3%	£257	£4
<i>CCGT</i>	51%	50%	£98	£50
Technology-Weighted System LCOE				£95

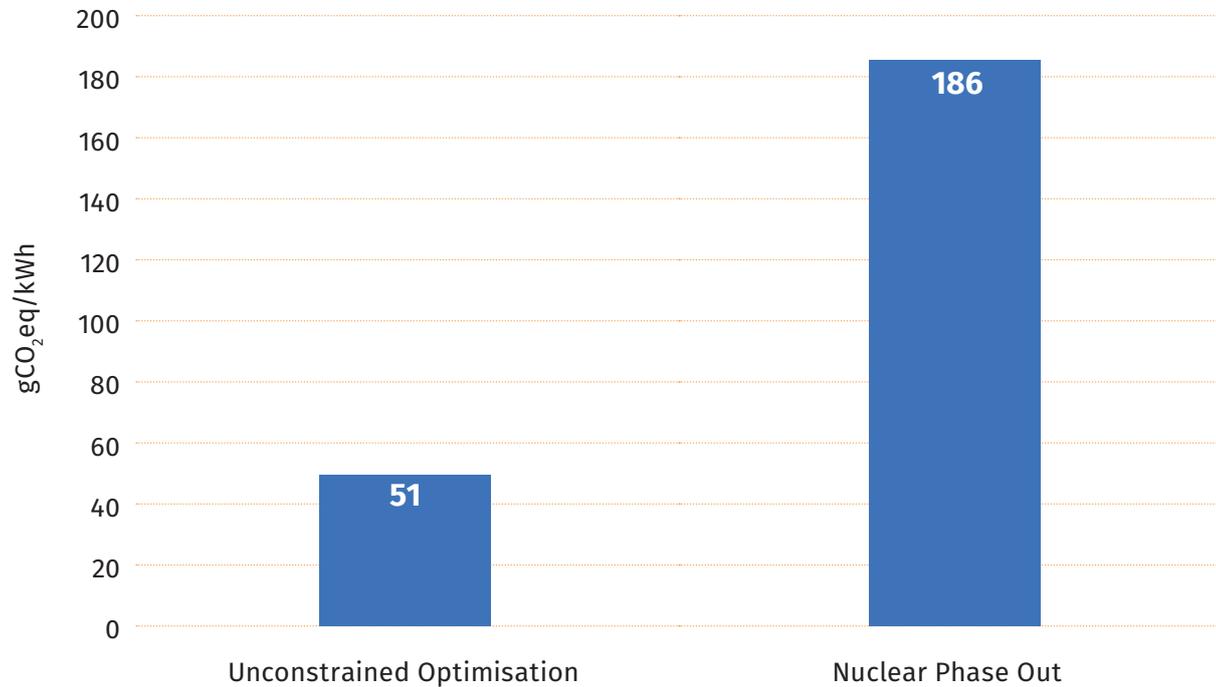
Unconstrained Optimisation

	Generation	Load Factor	Levelised Cost	Contribution
<i>Wind</i>	40%	47%	£86	£34
<i>OCGT</i>	2%	3%	£257	£4
<i>CCGT</i>	12%	26%	£112	£14
<i>Nuclear</i>	47%	65%	£64	£30
Technology-Weighted System LCOE				£82

And, the environmental profile of the respective scenarios is as follows:

SYSTEM COST OF ABANDONING NUCLEAR — METHODOLOGY AND RESULTS:

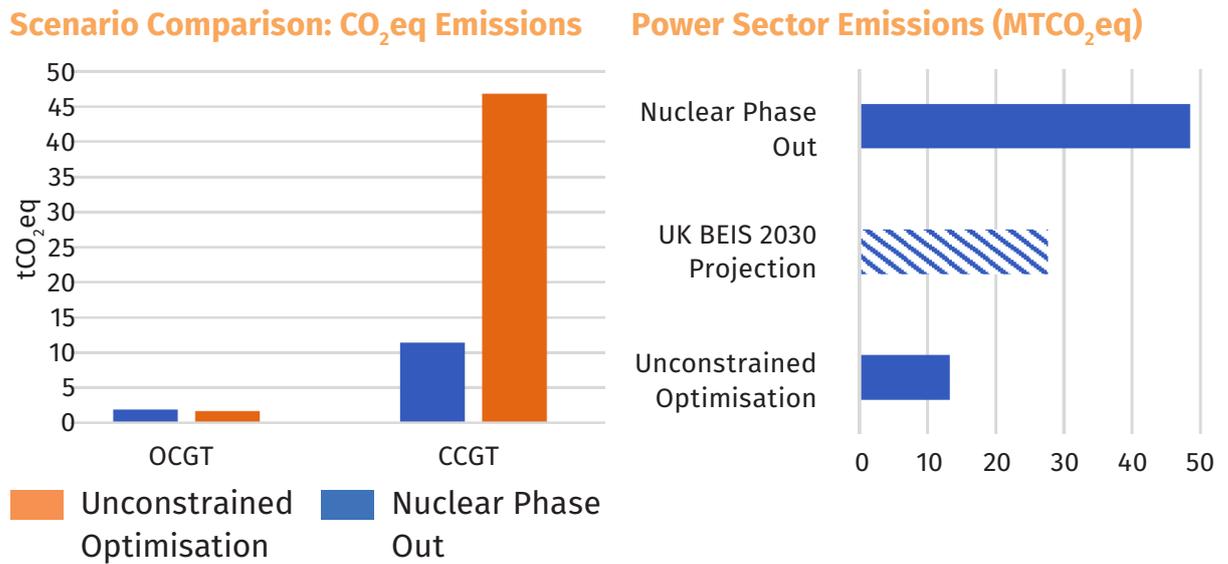
Carbon Intensity of System Generation



E. COMMENTARY

The dire consequences of abandoning nuclear power are now clear, such a course of action not only causes an increase of 15% in the levelised system cost of electricity but also results in an increase in the carbon intensity of power generation of 135gCO₂/kWh (a rise of 265% from the unconstrained scenario). In the course of 2030 alone, these differences represent an additional generation cost of £3.2 billion and the added emission of 35 million tonnes of CO₂eq. It should be noted that the rise in CO₂ emissions is a direct cause of the rise in system generation cost; carbon taxes and levies are a variable – and rising – cost for fossil fuel-fired generators.

SYSTEM COST OF ABANDONING NUCLEAR — METHODOLOGY AND RESULTS:



Equally, the results illustrate the tangible benefits of not restricting the set of technologies from which the power sector can be configured. The inclusion of nuclear power in the unconstrained optimisation scenario does not preclude gas-fired electricity generation; instead, as the comparative analysis of technology generation cost curves illustrates, natural gas generators (both OCGTs and CCGTs) provide dispatchable, cost-effective generation during peak load. However, this does imply that the business model for gas generators must adapt to a lower load factor – although this may be compensated by selling output during periods of high demand – that may necessitate investment in efficiency promoting measures. Equally, this highlights the need for a combination of affordable storage technologies and more flexible nuclear generation in the long-term if power sector carbon intensity is to decrease further beyond 2030.

Another notable outcome of the model is that the levelised cost of electricity of nuclear power is lower than that of gas-fired generation in the UK by 2030. The results on the previous page are without doubt contingent on endogenous load factors that have been determined by the optimisation procedure but when calculated using a specification load factor (net of availability) the pattern of levelised cost ranking is still apparent. This is supported by analysis from BEIS¹⁵ that reports levelised costs of £64/MWh for nuclear power and of £99/MWh for natural gas (using a discount rate of 7%) in 2030. This observation makes clear the contrasting cost pathways of gas-fired and nuclear power, while the former faces upward pressure in the form of increasingly active climate policy – in the UK, the combined effect of the Emissions Trading Scheme and the Carbon Price Support – the latter has significant scope to decline as economies emerge from the transition from first- to nth-of-a-kind production.

¹⁵ UK Department for Business, Energy & Industry, *Cost of Generating Electricity*, (2016)

OTHER CONCERNS WITH THE TRANSITION FUEL NARRATIVE

Beyond the negative impact on levelised system cost, there are three other major concerns with the transition fuel narrative that relate to the fugitive emissions from natural gas production, the likelihood of carbon-intensive path dependency, and the risk of carbon-intensive investments becoming stranded assets.

A. FUGITIVE EMISSIONS

One of the principal claims of the transition fuel narrative is that natural gas is best able to support and facilitate the low-carbon transition of the energy sector made necessary by the impetus of climate action. In the near-term, an often-observed benefit of increasing natural gas use in the power sector is that it allows for a corresponding reduction in coal use, a significantly more carbon-intensive source of energy. In the UK, power sector emissions of CO₂ have fallen by 62% in parallel with a 91% decrease in coal-fired generation since 2010¹⁶. This advantage has led to the touting of natural gas as a relatively 'clean' fuel, particularly in North America where new production techniques have resulted in a significant increase in proven reserves and contingent decline in fuel costs.

However, the focus on in-combustion emissions is an overly narrow basis upon which to evaluate the environmental impact of a particular fuel; the complete range of processes – upstream to downstream – must be analysed. In this regard, a major concern arising from the use of natural gas is the incidence of fugitive emissions, unintended leaks of methane (CH₄) that occur along the gas supply stream – in drilling, extraction, and transportation – and are notably abundant in the extraction of unconventional – or shale – gas. The potency of CH₄ as a greenhouse gas – 28 times more powerful than CO₂ over a 100-year period – has the potential to even offset the direct benefit of coal-to-gas fuel-switching.

According to a report published in PNAS¹⁷, a leakage rate for the entire gas supply of the USA in excess of 3.2% would render natural gas worse for the environment than coal. As such, it ought to be of extreme concern that a meta-study of academic and public reports conducted by Carbon Brief¹⁸ found estimates of the leakage rate ranging from 0.6% to 9%. Similarly, a top-down estimate – one based on atmospheric concentrations of CH₄ rather than bottom-up methods that estimate emission factors per unit of activity – of methane emissions in the USA found a 30% increase between 2002 and 2014, over which time production of shale gas grew ninefold¹⁹.

¹⁶ UK Department for Business, Energy & Industry, *Updated Energy and Emissions Projections 2017*, (2018)

¹⁷ Alvarez, Pacala, Winebrake, Chameides, and Hamburg, *Greater Focus Needed on Methane Leakage from Natural Gas Infrastructure*, (2012)

¹⁸ <https://www.carbonbrief.org/explained-fugitive-methane-emissions-from-natural-gas-production>

¹⁹ Turner, Jacob, Benmergui, Wofsy, Maasackers, Butz, Hasekamp, and Biraud, *A Large Increase in U.S. Methane Emissions over the Past Decade Inferred from Satellite Data and Surface Observations*, *Geophysical Research Letters*, (2016)

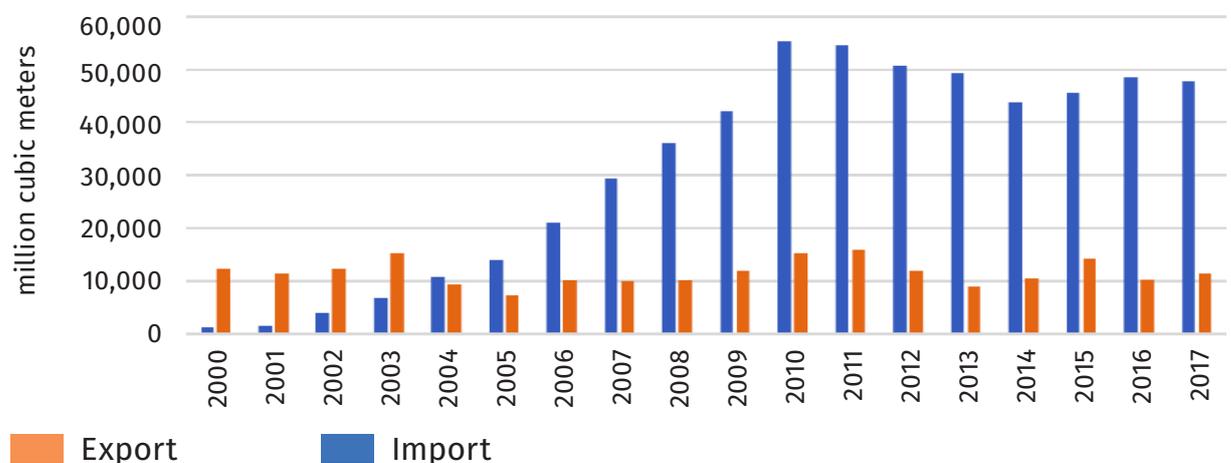


Methane Climate Science:

Methane is the most abundant reactive trace gas in the atmosphere and arises from both natural and anthropogenic sources, with the latter related to fossil fuel use, agriculture, landfill, and the burning of biomass and accounting for over half total emissions. The gas is removed from the atmosphere by a range of natural processes that occur in different regions of the atmosphere, with oxidation of methane in the troposphere being the largest methane sink. Methane is a short-lived gas with a high global warming potential (GWP) of 28 over a 100-year period, illustrative of its potent radiative forcing. However, the relatively short lifetime of methane (about 12 years) – unlike CO₂ that persists for far longer – indicates its potential as a means to slow global temperature increase in the immediate-term.

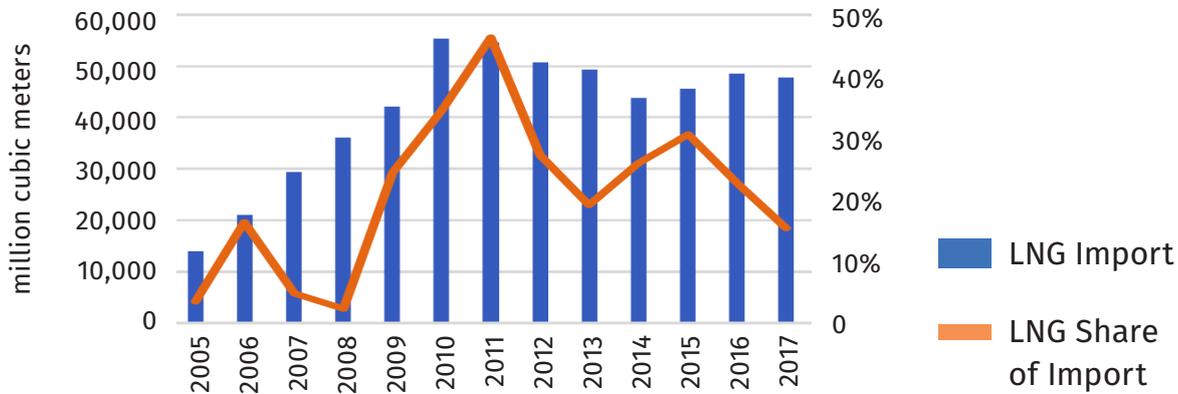
From the perspective of the UK, the issue of fugitive emission is likely to rise as domestic production of natural gas (predominantly from the North Sea) continues to decline and imports with greater associated upstream emissions increase²⁰. This not only makes clear the gradual loss of domestic energy security implicit in the adoption of the transition fuel narrative by the UK but also demonstrates that emission reductions from the further use of natural gas in the UK will be at least partially offset by greater emissions at the point of extraction and production, highlighting the significance of lifecycle (rather than in-combustion) greenhouse gas emissions in assessing the meaningful impact of transition fuels.

UK Natural Gas Trade Balance (BEIS)



²⁰ Hammond, and Grady, *The Life Cycle Greenhouse Gas Implications of a UK Gas Supply Transformation on a Future Low Carbon Electricity Sector*, Energy, (2016)

UK LNG Imports (BEIS)



B. PATH DEPENDENCY AND CARBON-INTENSIVE LOCK-IN

Path dependence is defined as “the tendency for past decisions and events to self-reinforce, thereby diminishing and possibly excluding the prospects for alternatives to emerge²¹”. The existence of path dependence in a particular market may prevent a transition to the socially optimal equilibrium and often results in lock-in, a situation in which it becomes prohibitively costly – if possible at all – to affect a meaningful, permanent shift away from the current pathway. One prominent mechanism that supports path dependence is increasing return – encompassing increasing returns to scale, learning and network effects, and induced technological change amongst other processes – which serves to limit external competition and supports a stable incumbent market regime.

In the present context, it is the capital inertia – the long lifetime – of energy infrastructure investments that is of particular concern as it raises the likelihood of path dependence, more so when combined with the relatively inexpensive operating costs of most power technologies. This implies that significant investment in natural gas capacity – as well as associated infrastructure – raises the likelihood of a persistent power sector equilibrium characterised by carbon-intensive (relative to low-carbon technologies, such as nuclear power and renewable energy sources) generation. Moreover, the incumbency advantage reduces the incentive to invest in alternative – here low-carbon – technologies, thus reducing energy system flexibility and increasing the eventual cost of achieving emission reduction goals.

²¹ Fleurbaey, et al., *Sustainable Development and Equity, Chapter 4 in Climate Change 2014: Mitigation of Climate Change, Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, (2014)

The issue of renewable energy crowd-out deserves significant attention as it has the potential to offset the benefit of coal-to-gas switching if sufficiently extensive. The purported environmental quality of natural gas use is highly contingent on the fuel being used as a direct (one-for-one) substitute for coal but if instead natural gas acts as a replacement for additional renewable energy it will serve to increase rather than decrease emissions. As noted by Shearer et al.²², “this suggests greater supplies of natural gas may accelerate the phase-out of coal-fired electricity but could also result in even longer delays in the deployment of renewable energy technologies.”

Quantifying Path Dependency:

The identification of path dependency is primarily a historical exercise; the process of path dependence – and eventual lock-in, should that occur – is not a static phenomenon. Meng²³ (2014) exploits a spatial reconfiguration of coal production that took place in the Illinois basin – caused by an exogenous technological development related to the advent of mechanised mining – to assess the impact of path dependency on the use of coal in the USA. While it might be assumed that present-day coal use in the USA is largely a result of resource endowment, Meng demonstrates that 60% of total coal-fired capacity was explained by path dependence by the 1990s. The suggested mechanism by which path dependency operates in this scenario is thought to be coal-specific technological change, accumulations of coal-based innovation that drive relative capacity.

Of further concern is that the two effects are not equally evident, the closing of coal-fired capacity is a visible, tangible occurrence – as is the consequent decline in emissions – but the substitution for as yet unconstructed renewable capacity – as well as the diversion of investment funds away from research and development (R&D) in innovative renewable technologies – is not as clearly quantifiable or discernible to the public at large. Moreover, the initial reduction in emissions that result from fuel-switching is not only constrained – coal-to-gas fuel-switching is a finite practice by definition – but also insufficient to bring about long-term emission reduction targets – such as net zero carbon emissions by 2050 – that are required to limit the average global temperature increase to below two degrees (2°C).

²² Shearer et al., *The Effect of Natural Gas Supply on US Renewable Energy and CO₂ Emissions*, *Nature*, (2014)

²³ Meng, *Path Dependence in the Development of 10th Century U.S. Coal-Fired Electricity Capacity*, (2014)

This indicates that the use of natural gas causes a loss of system flexibility, necessitates a greater cost in the future and so does not represent a cost-effective means to integrate renewable energy into power systems. As noted by Meng²⁴ (2016), “if climate damages turn out to be so large that optimal mitigation requires cleaner fuel than natural gas, the subsequent path dependence in natural gas would increase the cost of switching to a cleaner fuel that if the detour into natural gas had been avoided.”

Moreover, that which has already been said about the path dependency risk posed by gas-fired generation plants is only amplified by investment in related infrastructure. At the European level, a number of large infrastructure projects – so-called megaprojects – related to gas are in varying stage of development and deployment, such as the Southern Gas Corridor, the Midi-Catalonia pipeline, and the Eastring²⁵. Similarly, there are currently 22 large-scale liquefied natural gas (LNG) import terminals under consideration or planned in the region²⁶. Projects of this nature – that facilitate the further use of natural gas – only add to the threat of lock-in, due to their high construction costs and extended lifetimes.

C. STRANDED ASSETS

Should an active carbon policy – perhaps motivated by the above risks of fugitive emissions and carbon lock-in – lead to a reduction in gas-fired generation, the core risk becomes that carbon-intensive investments become stranded – or unusable – assets. To be clear, if the commitment to restricting the global average temperature increase to 2°C is to be considered genuine it necessarily implies a concurrent erosion in the competitive position of conventional fossil fuel-fired generation, whether market-driven (for instance, a shift to renewable energy due to cost decreases brought about by mass investment and deployment) or caused by regulation.

The ‘Carbon Bubble’:

According to Weyzig et al., the carbon bubble signifies “the overvaluation of fossil fuel reserves and related assets should the world meet its stated objective of limiting climate change²⁷.” The meeting of the 20C target – as detailed in the Paris Agreement – is contingent upon a restricted carbon

²⁴ Meng, *Estimating Path Dependence in Energy Transitions*, National Bureau of Economic Research, (2016)

²⁵ Rosa Luxemburg Stiftung, *Global Gas Lock-In: Bridge to Disaster*, (2017)

²⁶ King & Spalding, *LNG in Europe 2018: An Overview of LNG Import Terminals in Europe*, (2018)

²⁷ Weyzig, Kuepper, van Gelder, and van Tilburg, *The Price of Doing Too Little Too Late: The Impact of the Carbon Bubble on the EU Financial System*, Green New Deal Series (Volume 11), (2014)

emission budget, in turn limiting the amount of fossil fuels that can be combusted. This implies that the majority of reserves are stranded assets, investments that have been made but which are no longer able to earn an economic return prior to the end of their expected lifetime.

While the scope of this issue extends far beyond investment in gas-fired power generation capacity – it is estimated that the current exposure of the largest financial institutions (43) in the European Union to ‘high carbon assets’ exceeds €1 trillion²⁸ – the transition fuel narrative acts as a device to extend the apparent commercial viability of a set of fossil fuel assets. As a consequence, meaningful action to reduce the carbon emissions that result from fossil fuel combustion is delayed and subsequently concentrated into a shorter period of time.

In this light, infrastructure investments in gas pipelines and liquefied natural gas terminals take on greater risk due to their extended lifetimes; while a generation asset – a gas turbine – has an expected lifetime of 25 years, a natural gas pipeline – of the type mentioned in the previous section – is typically designed to have a useful lifetime of 50 years. However, it has been argued that gas infrastructure assets in Europe could be converted to biogas or biomethane use²⁹, thus potentially diminishing the risk of such assets becoming stranded.

As noted by the European Systemic Risk Board³⁰, “belated awareness about the importance of controlling emissions could result in an abrupt implementation of quantity constraints on the use of carbon-intensive energy sources” that would not only harm economic growth as “alternative sources of energy would be restricted in supply and more expensive at the margin” (an illustration of the ‘crowding out’ effect described above) but would cause a “sudden repricing of carbon-intensive assets, which are financed in large part by debt.” The threat of such a ‘hard landing’ is very real; according to the IEA³¹, emission pathways as embodied by Intended National Determined Contributions (INDCs) imply that the carbon budget consistent with a 50% chance of meeting the 2°C target would be exhausted by 2040.

²⁸ <http://www.lse.ac.uk/GranthamInstitute/faqs/what-are-stranded-assets/>

²⁹ Lambert, *Biogas: A Significant Contribution to Decarbonising Gas Markets?*, The Oxford Institute For Energy Studies: Energy Insight, (2017)

³⁰ European Systemic Risk Board, *Too Late, Too Sudden: Transition to a Low-Carbon Economic and Systemic Risk*, Reports of the Advisory Scientific Committee, (2016)

³¹ IEA, *Energy and Climate Change (World Energy Outlook Special Report)*, (2015)

CONCLUSION

This report set out to examine one facet of the transition fuel narrative, namely that it embodies the cost-effective means by which to support the low-carbon power transition as is frequently claimed. Advocates of the view state that the transition to a fully renewable system – backed up by storage technologies – is feasible in the medium-term and that natural gas ought to be employed until that point in time to provide system flexibility and back-up capacity. A significant corollary of this viewpoint is that nuclear power – labelled as unaffordable – ought to be abandoned and phase out of the generation network.

To assess this claim, an illustrative model of the power sector in the UK in 2030 was derived and used to quantify the opportunity cost – here defined as the levelised system generation cost differential – of excluding nuclear power. The result is clear: the proscription of nuclear power causes levelised system cost to rise by 15%, which represents an additional cost of £3.2 billion in 2030 alone. Moreover, the model also makes clear the environmental cost of the transition fuel pathway, notwithstanding attempts by some to portray natural gas a ‘clean fuel’. In the absence of nuclear power, natural gas – consisting of both closed- and open-cycle technologies – is the sole means of balancing the intermittency of renewable energy and this results in a power sector carbon intensity of 186 gCO₂/kWh, above both the 100 gCO₂/kWh target recommended by the UK Committee on Climate Change and the 51 gCO₂/kWh achieved in the presence of nuclear power.

However, cost is not the only standard by which the transition fuel narrative is found wanting. The occurrence of fugitive methane emissions – made increasingly likely by the recent global shift towards unconventional supply reserves – threatens to undermine even the environmental merit of coal-to-gas fuel-switching. Similarly, there is also a real threat that a medium-term commitment to natural gas – implicitly assuming the substantial role of sole baseload fuel – may prove a hard path to escape, locking the power sector into carbon-intensive production for far longer. Conversely, a sudden reduction in gas use – made necessary by late response to long-term 2050 targets embodied in the Paris Agreement – could have serious financial ramifications; the ‘carbon bubble’ may violently break rather than gradually subside, amplifying systematic risk.

While the critical analysis above has shown the transition fuel narrative to be an intrinsically flawed argument, it also speaks to a wider trend, that of energy tribalism – here dubbed techno-zealotry – which sees power generation technologies in competition with one another, as winners and losers. This

is a deeply concerning development as both common-sense and academic commentary make it clear that climate change mitigation is most likely to be successfully realised when all mitigation options are available. It is worth noting that the unconstrained optimisation scenario employed in this report does not treat natural gas and nuclear as mutually exclusive; both technologies are present in the optimisation result because their contrasting characteristics support broad-based system reliability and flexibility. In essence, this is the lesson of financial portfolio theory; diversification, whether in financial assets or energy technologies, has a tangible benefit. This simple truth must not be forgotten.

ANNEXES

1. TECHNICAL PARAMETERS OF GENERATOR TECHNOLOGIES

Measure	Unit	Nat. Gas (CCGT)	Nat. Gas (OCGT)	Offshore Wind (R3)	Nuclear (PWR)*
Reference Plant Size	MW	1,200	625	844	3,300
Efficiency	%	54	35	/	100
Pre-Development Period	Years	2	2	5	5
Pre-Development Cost	£/kW	10	20	120	192
Construction Period	Years	3	2	3	8
Construction Cost	£/kW	500	300	2,100	3,280
Infrastructure	£ 000s	15,100	15,100	323,000	9,200
Operation Period	Years	25	25	22	60
Fixed O&M	£/MW/Year	12,200	6,800	45,400	72,900
Variable O&M	£/MWh/Year	3	3	3	5
Connection and Use of System	£/MW/Year	3,300	2,500	48,900	500
Insurance	£/MW/Year	2,100	1,200	3,300	10,000

Note: All Values Refer to Commission in 2030

* Nuclear Power: UK BEIS Pre-Development and Construction Costs are Reduced by 20% to Reflect Transition to NOAK

Source: UK BEIS, (2016), Cost of Generating Electricity, Retrieved from: <https://www.gov.uk/government/publications/beis-electricity-generation-costs-november-2016>

2. GENERATION COST CURVE – DERIVATION

The technology-specific capital recovery factor (used below) was calculated as follows:

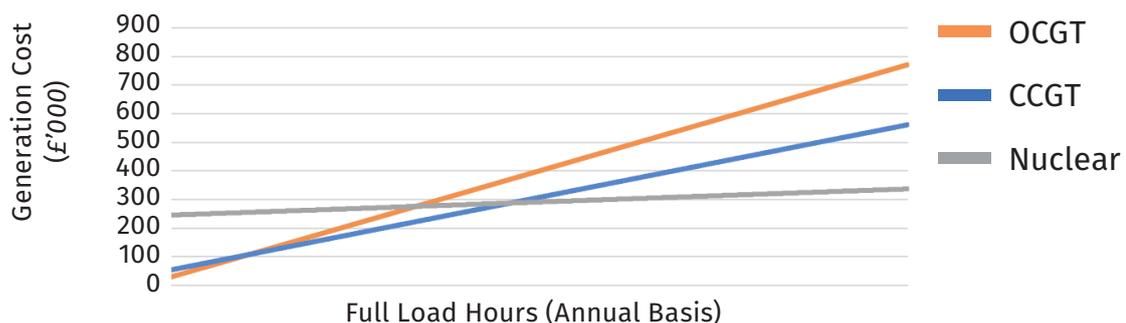
	CCGT	OCGT	Nuclear
Construction Cost	600,000,000	187,500,000	10,824,000,000
Cost of Capital	7%	7%	5%
Period (Y)	25	25	60
Annual Payment	50,888,100	15,902,532	569,743,188
%	8.48%	8.48%	5.26%

The remaining inputs required in the derivation of the generation cost curves are presented below:

Fixed Cost	Unit	Nat. Gas (CCGT)	Nat. Gas (OCGT)	Nuclear
Investment Cost (Annual)	£/MW	500,000	300,000	3,280,000
Capital Recovery Factor	%	8.5	8.5	5.3
Fixed O&M	£/MW/Year	12,200	4600	72,900
Intercept	£/MW	54,607	30,004	245,549
Variable Cost				
Fuel Price	£/MWh	42	65	5
Emission Factor	tCO ₂ eq/MWh	0.354	0.460	0.000
Price CO₂	£/tCO ₂	35	35	35
Variable O&M	£/MW/Year	3	3	5
Gradient	£/MWh	58	84	10

Finally, to determine system optimal operation schedules, the generation cost curves are compared:

Generation Cost Curves



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