Toxic Time Capsule:

Why nuclear energy is an intergenerational issue

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for

The Intergenerational Foundation

April 2016

The New Weather Institute, a co-operative think tank forecasting change and designing a rapid transition to a fair, ecological economy was commissioned by the Intergenerational Foundation to produce this report. http://www.newweather.org/.

The Intergenerational Foundation (www.if.org.uk) is an independent, non-party-political charity that exists to protect the rights of younger and future generations in British policy-making. While increasing longevity is to be welcomed, our changing national demographic and expectations of entitlement are placing increasingly heavy burdens on younger and future generations. From housing, health and education to employment, taxation, pensions, voting, spending and environmental degradation, younger generations are under increasing pressure to maintain the intergenerational compact whilst losing out disproportionately to older, wealthier cohorts. IF questions this status quo, calling instead for sustainable long-term policies that are fair to all – the old, the young and those to come.

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A bad deal for those not yet born

This report reveals the intergenerational costs and benefits of different choices for energy technology and generating capacity in the UK. It argues that doubts growing over the viability of building new nuclear power stations create an important and timely opportunity to rethink the UK's energy strategy and get a better deal for the nation. It argues there will be significant and often hidden costs that would be passed on to future generations in the event of a significant expansion in nuclear power, and that other, renewable options offer a better intergenerational contract.

The costs of the nuclear option include: higher prices paid per KWh for generating electricity; high and long-term costs for managing radioactive waste; complex and long-term security requirements; missed opportunities for capturing greater economic value from our energy system; undermining effective action on global warming that includes the development of better alternatives; and the locking-in of a less flexible, less secure and more vulnerable energy infrastructure, subject to unsolved problems and a lasting toxic legacy.

Some of these costs are clear and in the public domain. Others are either not available or uncertain, but with cost liabilities lying more heavily on the down, or negative side. In the latter case, it means already large risks being passed on to the public and future generations, with an unknowable ceiling of liability. Toxic Time Capsule finds that a better intergenerational deal, in economic, environmental and security terms, is to be had in the rapid expansion of renewable energy. Not only does this imply the active creation of an intergenerational economic and security burden, but also the worst of all worlds environmentally. The greatest danger is that an expansion of nuclear power, justified on the grounds that it is a significant solution for global warming, in fact represents a major obstacle to more effective action, making runaway climate change more likely, whilst at the same time leaving an unwelcome environmental toxic time capsule for future generations to handle.

This report finds that:

- Following the urgency and agreed targets for tackling climate change given by the 2015 Paris conference, nuclear power cannot tackle global warming and will, if anything, undermine efforts and better, effective solutions.
- Nuclear power passes on high and rising economic costs to future generations which will grow with any expansion of the sector, alongside a rising burden of long-term waste for which no satisfactory management regime exists.
- Nuclear power already represents a significant global security risk for which no effective answers have been found, where a black market in nuclear materials exists, and expansion of nuclear power will pass an even less secure world on to future generations.
- Cheaper, safer, quicker energy options exist, representing better economic value, more effective responses to climate change, greater all-round security and more convivial, responsive energy systems to pass to future generations.

Key figures include:

- From an early promise of delivering electricity that would be "too cheap to meter", at more than £24 billion, the next nuclear power installation proposed for Britain, Hinkley Point C, would be the most expensive building on Earth.
- A highly conservative estimate puts the additional cost of power from Hinkley Point C for its 35-year initial contract period, compared to onshore wind and solar power, at £31.2 billion and £39.9 billion respectively. If similar costs applied to other currently planned or proposed reactors for the UK, the nuclear premium would be between £175 billion and £220 billion compared to the renewable options.
- The above represents a nuclear premium of between £2,700 and £3,400 for every individual in the UK's current population, but if the cost were applied just to the population below the age of 16 - who have no choice over the matter, stand to inherit new nuclear's infrastructure and will make up the working population during its operating life - it would represent a bill of between £14,200 and £18,000 each.

- Again, conservatively, between £54 billion and £132 billion at least could be added to the bill for waste management beyond what is accounted for under the operators' obligation to meet costs in the new nuclear programme envisaged for Britain.
- Even at its current high price, we do not pay the real cost of nuclear power. A major hidden subsidy is underinsurance. If consumers carried the insurance cost of premiums adequate to cover a major disaster, electricity would be much more expensive. Different national energy systems are not exactly comparable, but if costs based on studies in Germany were applied to Hinkley C, the annual cost of its output would rise between £2.5billion and £41.7billion (or £150 billion and £2,500 billion over its lifespan).
- Nuclear power carries other large, unique costs. The Civil Nuclear Constabulary overseen by the Civil Nuclear Police Authority, which is just one element of a large and complex security matrix required to protect the nuclear supply chain, alone costs around £100 million per year.

The report concludes that intergenerational concerns should be designed into the process for making energy choices, and suggests guiding principles and minimum criteria to achieve those ends. The report also finds that, if applied, such criteria point to an energy system in transition to renewable energy which would serve both current and future generations equally well.

Introduction

Which energy technologies will future generations thank us for? Once hyped as providing electricity that would be too cheap to meter, at more than £24 billon, the next nuclear power installation proposed for Britain, Hinkley Point C, will be the most expensive building on Earth.[1] Given the current economic climate with its emphasis on austerity, and the range of other energy options on offer, why, is the government so keen to give the nuclear industry a second life?

Much of Britain's electricity generation relies on ageing technology with many power plants set for retirement. Unplanned extensions to the lifespans of existing nuclear power plants represent playing for time while alternatives are chosen and built. A major and controversial question has been raised over the role that nuclear power should play in our future energy supply. Energy Secretary at the time, Ed Davey, speaking in late 2013 when the government agreed a deal with French energy company, EDF, to build the first new nuclear reactor in Britain for decades, said that investing in new nuclear capacity was needed because without it, "we're going to see the lights going out." He added that the deal was "good value" for money and for the nation.[2] At the same time, the Prime Minister, David Cameron, explained a motivation to provide, "long-term, safe and secure supplies of electricity far into the future".[3]

Combined in these comments by policy-makers is the attraction of an apparently simple solution to energy security, together with the political desire to project a competent economic management of the energy system. Added to that is an old, political fear about "not letting the lights go out" while in office. Large, centralised generating capacity can seem to fit the bill. Hinkley C, for example, it is claimed by its builders, EDF, would at a stroke provide 7% of the UK's electricity generating needs. But how well does the broader reality match this overall policy presentation, and what are the implications for future generations?

[1] For comparisons see: Business Insider (3 May 2012), The 15 Most Expensive Mega-projects In Modern History.

[2] The Telegraph (21 October 2013), Ed Davey defends nuclear deal as "good value for money".

[3] The Guardian (21 October 2013), David Cameron hails nuclear power plant deal as big day for Britain.

This report reaches very different conclusions about which energy options represent good value for Britain today, and which will best provide "long-term, safe and secure" electricity supplies for future generations. In fact, a range of renewable options already prove to be cheaper, safer, more secure, quicker to deliver and, overall, better value for Britain. A substantial premium is attached to the nuclear option for future generations in terms of both cost and passing on risks.

Where costs are known, for example in the contract to supply electricity from the proposed Hinkley Point C power station, they are large. Nuclear is already more expensive than key renewable energy alternatives. Conservatively,[4] the additional cost of power from Hinkley Point C for its 35-year initial contract period, compared to onshore wind and solar power could be £31.2 billion and £39.9 billion respectively. If similar costs applied to other currently planned or proposed reactors for the UK, the nuclear premium would be between £175 billion and £220 billion compared to the renewable options.[5] That's a bill of between £2,700 and £3,400 for every individual in the UK's current population.[6] If the cost was applied just to the 19% of the population below the age of 16[7] – who have no choice over the matter, but will inherit nuclear's long-lived energy infrastructure, and constitute the large part of the working population during its operating life – it would represent a bill of between £14,200 and £18,000 each.

Where definitive costs are not known, for example with regard to waste disposal and new reactor construction (which have a strong tendency to overrun), the industry's past record suggests they are likely to grow, leaving future generations to bear the risk. Even here, though, a reasonable estimate for an additional nuclear premium resulting from the cost of waste management suggests that between £54 billion and £132 billion at least could be added to the bill for waste management in the new nuclear programme envisaged for Britain.

But risks passed to young and future generations are not just financial. They emerge where the most effective strategies are being sought to tackle systemic problems like

[4] This excludes other large but hard to quantify costs to do with risk, security and long-term waste disposal which are unique to nuclear power.
[5] For just over a five-fold (5.6) increase on the same terms.
[6] Based on the most recent available estimate of 64.6 million for mid-2014 from the Office for National Statistics (25 June 2015).
[7] Office for National Statistics (25 June 2015), Overview of the UK Population, Part of Population Estimates for UK, England and Wales, Scotland and Northern Ireland, Mid-2014 Release

climate change and building an energy infrastructure which is itself secure, and doesn't, for example, worsen threats like terrorism. We find, on balance, that a programme to expand nuclear capacity is likely to weaken our response to climate change by undermining and substituting for better solutions. We also find it would be likely to worsen an already unstable international security situation.

Any policy-maker concerned with the side of history on which their decisions will fall can study the current, differing fates of renewables and nuclear. In 2014, the most recent year for which data are available, more renewable energy capacity was added globally than coal and gas combined, and much more than nuclear. Renewables accounted for 58.5% of net additions to global power capacity.[8] The UN comments that, "In response, policymakers in some jurisdictions are requiring utilities to update their business models and grid infrastructure."[9]

But, while renewables leap ahead, in the long shadow of the Fukushima disaster[10] the situation of the nuclear industry is far more complex. The UK is attempting to restart its sector with a commercially unproven reactor design whose first construction attempt in Finland is nine years behind schedule and three times its original cost estimate. Even then, there are fears that much of any spending on new reactors could leak abroad. For example, many of the facilities lie unused at a Nuclear Advance Manufacturing Research Centre near Sheffield, developed with nearly £40 million of public money, because, its management say the developers of projects like Hinkley C want to provide work and jobs in their own countries, France and China. Meanwhile, Germany is experiencing new, expensive problems with long-term nuclear waste disposal.

On everything from pensions to public services, our current economic crises and ageing population already present a bad and worsening deal for the next generation. This report questions the wisdom and right of decision-makers unnecessarily to pass such a multiple, additional burden of cost and risk on to children not yet born.

[8] UNEP (2015), Ren 21 – Renewables 2015: Global Status Report.
[9] UNEP (2015), op cit.
[10] Scientific American (1 March 2016, 5 Years Later, the Fukushima Nuclear Disaster Site Continues to Spill Waste (the report cites a rising level of radiation leakage from the Fukushima plant).

Instead, we propose the adoption of key policy criteria to ensure energy choices are made from a rational, evidence-based platform to protect and promote the interests of this and future generations.

Designing-in future generations: a rational intergenerational system for making energy choices

To develop an energy system that would operate in the best interests of future generations, certain guiding principles can be applied. Minimum design criteria would need to include:

- An energy system most likely to preserve a climate convivial for future generations
- An energy system with the least toxic environmental burden for future generations
- An energy system that maximises ancillary economic benefits such as local jobs, manufacturing and services
- An energy system that improves a nation's security situation – broadly defined – and is not itself a security risk
- An energy system with the most resilient, flexible infrastructure of the highest adaptive capacity
- An energy system that does not foreclose or limit the ability of future generations to choose their own technology pathways that support the types of community, society and economy they wish to build. This might include whether an energy system is more or less prone to community ownership and control, less centralised or distributed generation, is vulnerable in either an environmental sense or as security risk, and costly in economic, environmental or democratic terms.

To turn such guiding principles into a tool for rational, evidence-based policy making, we propose that a broader range of measures than currently used by government should be employed. We argue that, without them, it is not possible to make choices which can protect the interests of current or future generations.

To fulfil that function, government energy planning needs to be based on at least these **key design criteria**:

- **Employment and broader economic return on investment** (how much value to the broader economy does investment in different technologies bring; in other words, what is its economic multiplier effect?)
- **Environmental return on investment** (how efficiently does an investment lower carbon emissions and minimise other toxic pollutants and contribute to a healthy environment?)
- **Energy return on investment** (how much energy is generated for the amount of money invested to produce that energy?)
- **Energy return on energy investment** (how much energy is generated for the amount of energy invested to produce that energy?)
- **Security return on investment** (how much does the technology contribute to domestic energy security and what other security risks does it carry?)
- **Transition return on investment** (how does it contribute, comparatively to the speed and scale of deployment of low carbon energy generating capacity)
- **Conviviality return on investment** (the degree to which a technology can be responsive to and supportive of a society's or a community's own vision and pathway for its development, and that of future generations)

1. The intergenerational economic burden

> "We will look back and think that nuclear was a expensive mistake. It's one of those deals where my children, and my children's children, are going to be thinking 'was that a good deal?'"
>
> **Paul Massara, Chief Executive, RWE NPower[11]**

In this section we look at the difficult question of the costs of nuclear power. Regardless of the confidence with which different voices in the debate will discuss the relative costs and benefits of different energy technologies, there are important reasons that make it almost impossible to arrive at a single, definitive real cost for nuclear power. There are technical, economic and even philosophical issues – for example, to do with insurance, long-term waste management, who should own and control energy technologies (whether community, corporation or state), and the future behaviour of markets – that resist meaningful attempts at precise costing. Also, decisions based on values, ethics and, often, crystal-ball gazing with regard to a host of issues fundamentally change the actual and perceived relative costs of technologies. On a more prosaic level, much of the information necessary to make informed estimates of the full costs of nuclear power is simply not available. In that light, here we review a range of estimates and ways assessing costs in the hope that they both contribute to, and spur a bigger debate on, the real cost of nuclear power to future generations.

Poor value: costing nuclear power

In the early days of the energy source in the UK, civil and military nuclear facilities were all under the control of the state and highly secretive, meaning that any reliable breakdown of costs was not available.

After its initial decades of expansion, the prospects for civil nuclear power faltered. The long shadow of the reactor failure at Chernobyl in Ukraine (when part of the Soviet Union) shifted public opinions and political calculations decisively at a time when all aspects of the nuclear cycle, civil and military, were subject to high-profile protest. In the

[11] Sunday Times (9 August 2015), Hinkley branded "expensive mistake".

UK (see below) it meant that even an ardent supporter of the technology, the Prime Minister Margaret Thatcher, only managed to see one new reactor start construction. But existing reactors remained, many with life-spans eked out far beyond those intended. What did their power cost and who was to pay?

In 1989 the government halted any further new reactors, pending a review of the future prospects of nuclear power to take place in 1994. When it reported to Parliament in 1995, and foreshadowing the initial stance of the Liberal Democrat/Conservative coalition government in 2010, its conclusion was that the economic and commercial viability of new nuclear power stations should not be based on public support, or "subsidy" which would be an inappropriate intervention in the market. That same year, 1995, Nuclear Electric which succeeded the CEGB, gave up plans for further reactors as not economically viable.[12]

Subsidies[13] [14]

"A new generation of nuclear power stations will cost taxpayers and consumers tens of billions of pounds…in addition to posing safety and environmental risks, nuclear power will only be possible with vast taxpayer subsidies or a rigged market."

Ed Davey, Liberal Democrat Shadow Trade and Industry Secretary, 17 July 2006[15]

"There have been understandable concerns given the expensive mistakes made in the past which the taxpayer is still paying for. But the Coalition agreement is crystal clear – new nuclear can go ahead so long as it's without subsidy."

Ed Davey, Secretary of State for Energy and Climate Change, 6 February 2012

"The Government confirms that it is not continuing the "no public subsidy policy" of the previous administration."

Department of Energy and Climate Change, 21 October 2015[16]

As detailed in this report, the official government position on the acceptability of subsidy to nuclear power was the subject of public opposition until very recently. The report details some known, explicit nuclear subsidies, but the full picture is in fact so

[12] World Nuclear Association: Nuclear Development in the United Kingdom, Nuclear Power in the United Kingdom Appendix 1, (Updated January 2016): http://www.world-nuclear.org/info/country-profiles/countries-t-z/appendices/nuclear-development-in-the-united-kingdom/

[13] Energy Fair (June 2012), Nuclear Subsidies http://www.mng.org.uk/gh/private/nuclear_subsidies1.pdf

[14] Energy Fair (November 2011), Subsidies for nuclear power in the UK government's proposals for electricity market reform: http://www.mng.org.uk/gh/private/EMR_subsidies.pdf

[15] Quoted in: Tom Burke, Tony Juniper, Jonathon Porritt, Charles Secrett (26 March 2012), Subsidising the Nuclear Industry: A briefing for the government.

[16] https://www.gov.uk/government/news/hinkley-point-c-to-power-six-million-uk-homes

broad as to be impossible to fully quantify. Below is a typology of the general range of subsidies, produced by analysts Energy Fair, and of specific issues relating to recent changes in the energy market.

Limitations on liabilities: The underinsurance of nuclear facilities (see below)

Underwriting of commercial risks: The public underwriting of commercial risks.

Protection against terrorist attacks: Multiple publicly-funded agencies contribute to protection against terrorist attacks on vulnerable nuclear facilities (see below).

Subsidies for the short-to-medium-term cost of disposing of nuclear waste: Government is likely to bear much of the risk of cost overruns in the disposal of nuclear waste.

Subsidies in the long-term cost of disposing of nuclear waste: Given that nuclear waste remains dangerous for thousands of years, there is no guarantee that the private operating companies will remain in existence so the public sphere is exposed to and underwrites long-term risk

Underwriting the cost of decommissioning nuclear plants: Government bears much of the likely risk of cost overruns in decommissioning nuclear plants.

Institutional support for nuclear power: Support is embedded in multiple departments.

Types of subsidy in the new energy market regime:

Exemption from tax. Uranium is exempted from the tax on fuels used for the generation of electricity, now established in the Finance Act 2011.

Feed-in tariffs with contracts for difference, now known as CfD (see below).

Capacity mechanism. The use of a “capacity mechanism” as a backstop for the power supply system appears to provide unjustified support for nuclear power.

Emissions Performance Standard. Although nuclear power emits between 9 and 25 times more fossil carbon than wind power, the effect of the standard inadequately distinguishes between them in terms of their carbon emissions, in effect causing wind to subsidise nuclear.

(Source: Energy Fair 2011, 2012)

Officially, the last explicit nuclear subsidies were removed in 2000 when an obligation on energy utilities to buy 3% of power from renewables was introduced. In 2002, however, the parlous financial condition of the nuclear sector led government to create a £650 million credit facility to keep it afloat. It was another foretaste of administrations finding ways to circumvent a stated “no subsidy” policy.

An energy review carried out the same year, 2002, by the Cabinet Office's Performance and Innovation Unit (PIU),[17] raised questions about issues of concern and the costs of nuclear power that remain highly relevant today.

It found that:

- the nuclear sector is inherently over-optimistic about how it can reduce costs through "learning and scale effects". This is because the time-frames, particularities of construction and, indeed, scale of the industry function to minimise potential gains.
- the sector is over-optimistic about construction costs and, as detailed elsewhere in this report,
- the 20-plus years that it would take for a new generation of reactors to be built would be too late to help with the immediate challenge of preventing the crossing of critical climate thresholds.

A subsequent government White Paper in 2003 called "Our energy future – creating a low carbon economy" concluded that the future lay with energy efficiency and renewables, energy as Government's priorities.[18] The White Paper said that "the current economics of nuclear power make it an unattractive option for new generating capacity and there are also important issues for nuclear waste to be resolved." The responsibility for any future for nuclear power was pushed to the market and the generating companies.

When nuclear costs for a new series of reactors were considered by the PIU back in 2002, they rejected industry estimates of power at between 2.2p and 3.0p/kWh as unrealistically low. Instead, they suggested a range of a range of 2.2–5.0p/kWh was more likely, with a most likely, narrower range of 3–4p/kWh.

In 2005, in a different estimate that seemed controversial at the time, the new economics foundation (nef) suggested that a still more realistic estimate for the cost of nuclear power lay in a range of 3.4–8.3p/kWh, more than two and half times the industry claim. This was arrived at by adjusting for a more typical expectation of

[17] Cabinet Office Performance and Innovation Unit (2002), The Energy Review, Cabinet Office Performance and Innovation Unit: London.

[18] DTI (2003) White Paper, Our Energy Future: http://webarchive.nationalarchives.gov.uk/+/http:/www.berr.gov.uk/files/file10719.pdf

construction time and cost overruns, such as a five year delay and 50% cost overrun, and by bringing the industry estimate for a reactor's operating availability into line with the more conservative output assumed by the International Energy Agency, based on then-current average reactor performance in the OECD.[19]

After a few years which saw the industry strategically promote itself in tandem with rising concerns about climate change (see section on lobbying below) and the high and volatile price of fossil fuels, political interest was renewed in the technology.

This culminated in the UK government agreeing a deal in 2013 with the largely state-owned French energy company EDF, and a consortium including Chinese investors, to build the UK's first new reactor since Sizewell B at Hinkley Point in Somerset. That year the wholesale electricity price varied from around 4.9 to 5.4 p/kWh.[20] But in the deal with EDF the government agreed a "strike price" – a price guarantee to lower risks to operators and hence persuade them to invest in new capacity – under its new energy market regime and written into a so-called "Contract for Difference". Under this, EDF was guaranteed 9.25p/kWh for electricity generated by the first of its new reactors. The price would be locked in to the initial 35-year operational life span of the reactor and protected against inflation. The price would drop marginally to 8.95p/kWh if a second set of reactors is built under the same agreement at Sizewell, allowing for efficiencies of scale. For context and illustration, the market price for electricity – whereby generators and suppliers trade before selling to consumers, at the time of writing in early 2016 – was around 3.7p/kWh. If that were the wholesale price at the point EDF began generating from the new reactor it would receive the difference, in other words an extra 5.5p/kWh from energy users. To put that into perspective by international comparison, it represents the most expensive new nuclear capacity currently envisaged (See Figure 1).

News of this deal, seen in terms of setting precedents for new nuclear generating capacity, and setting the scene for current government energy strategy, was met with broad criticism. In 2008 a Government White Paper formalised the new political enthusiasm for nuclear power. Its projections suggested that the cost of new capacity

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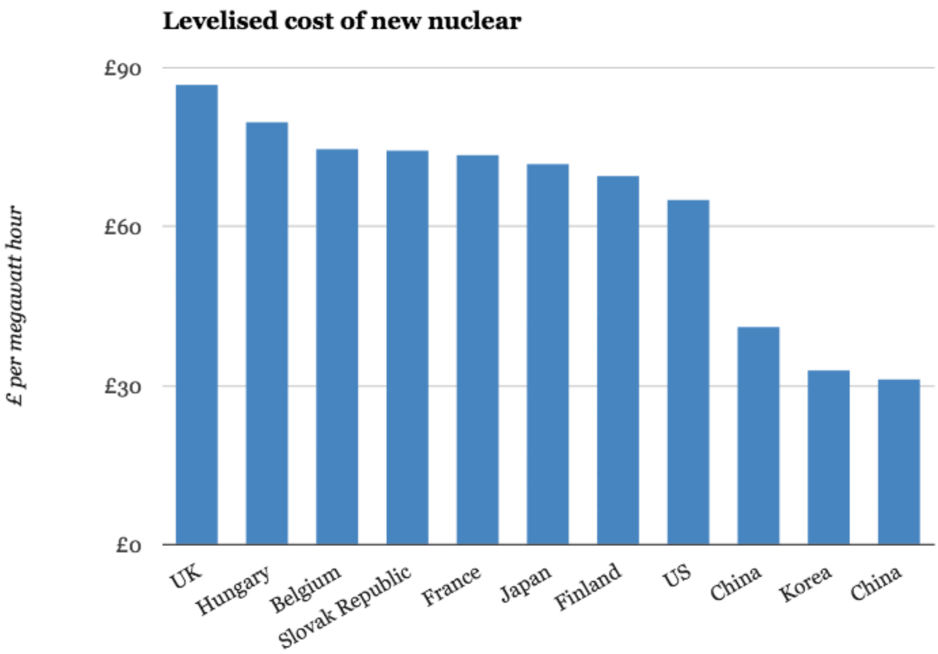
[19] Mirage and Oasis: Energy Choices in an Age of Global Warming (2005), Andrew Simms & Petra Kjell, nef, London.

[20] Energy UK, Wholesale Electricity Market Report: https://www.energy-uk.org.uk/publication.html?task=file.download&id=3241

equal to what is planned for Hinkley C would be around £5.6 billion. In 2013 the government then estimated the cost of Hinkley C to be £16 billion.

When the deal with EDF was finally approved by the European Commission in 2014 (evading its rules prohibiting unacceptable "state aid" subsidies), the cost had risen to £24 billion. What is striking is that escalation in projected costs occurred during a period following the global financial crises when interest rates (and hence the cost of capital) were very low, and the costs of renewables were steadily falling.

Figure 1: An international comparison of the cost of new nuclear – levelised cost of electricity – per megawatt hour produced in 2020.



(Sources: data: International Energy Agency / Nuclear Energy Agency: Projected Costs of Generating Electricity 2015 Edition. Graph: CarbonBrief)

The record of newly built reactors for cost overruns suggests that, even now, £24 billion may well not be the final figure. It is also possible that complicated formulas used in the "gain share mechanism" governing operators' profits might create perverse incentives for operators to allow cost overruns in such a way that it would maximise their returns.

Industry, financial analysts and academics said that the deal represented poor value to tax payers and consumers. Dr Paul Dorfman of the Energy Institute at University College

London, described it as a subsidy (which the then Coalition government had ruled out) equivalent to £800m to £1 billion per year going from UK taxpayers and energy consumers to state-controlled Chinese and French corporations.[21]

In October 2015, during a Chinese state visit to the UK, the new Conservative government officially abandoned the policy of not providing subsidy to nuclear power,[22] with the price guarantee being worth between £4.4 billion and £19.9 billion in current prices. Allowing for inflation, analysts at the organisation E3G estimated the 35-year contract value of the subsidy to be £45 billion.[23] In addition to issues over the scale of subsidy were concerns that greater benefit in terms of energy saving or greater additional capacity could be achieved with the same amounts invested differently. In terms of comparison, Peter Atherton, utilities analyst at the investment bank Jeffries, calculated this put the price for the new reactor at equivalent to £6.9 million per megawatt. This compared to his estimate of £3.5m/MW for offshore wind and £1.5m/MW for onshore wind. The same full reactor cost, he said, could have paid for London's Crossrail, the London 2012 Olympics and the Terminal 2 renovations at Heathrow airport combined.[24]

The parliamentary Select Committee on Energy and Climate Change investigated a range of issues surrounding a new fleet of nuclear reactors for the UK and expressed "A great deal of concern about the level of transparency of the strike price negotiations between nuclear developers and the Government."[25] They also urged clarification on, "who is going to take the risk of construction costs being higher than anticipated: consumers (by incorporating this risk into Contracts for Difference), taxpayers (through the UK Guarantees scheme) or project developers." In the government's responses to the committee there was no comment on the issue of a lack of transparency and a non-specific response on the risk of cost overruns and who would bear their burden, but

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[21] BBC (21 October 2013), UK Power Plant gets go-ahead, UK nuclear power plant gets go-ahead.
[22] DECC (21 October 2015), Hinkley Point C to power six million UK homes: https://www.gov.uk/government/news/hinkley-point-c-to-power-six-million-uk-homes
[23] Guardian (29 October 2015) Hinkley Point C will cost customers at least £4.4bn: http://www.theguardian.com/environment/2015/oct/29/hinkley-point-c-nuclear-power-station-cost-customers-4bn
[24] Financial Times (21 September 2015), Amber Rudd rejects concern over £24bn Hinkley nuclear plant cost.
[25] Building New Nuclear- the challenges ahead: Government Response to the Committee's Sixth Report of Session 2012-13 – Energy and Climate Change

which clearly communicated that the risk could be paid for by several actors, which would highly likely include consumers and taxpayers.[26]

Missing generations: models, exemptions and caveats

All economic models are wrong.[27] All simplify reality and none can capture the full dynamics of a real, complex economy nor accurately predict what happens when an economy is subject to shocks or when other changes occur. Models can, however, be useful, in that they allow the posing and answering of particular, often limited questions. Cynically, some argue that economic models can be created in order to validate answers and political decisions that have already been arrived at for reasons other than purely rational economic choice, such as the desirability of building a new runway, road or high-speed railway.

For example, the approval by government in principle to build a third runway at London's Heathrow airport in 2009 was partly justified by economic modelling from the Department for Transport (DfT) suggesting it would generate annual economic benefits of £5.5 billion. But when the same model was rerun by other researchers using revised assumptions, and including the impact of increased flights on local community, it suggested no benefits, but a net cost to the nation of between £5 billion and £7.5 billion.[28]

Similarly the economic case for a high-speed rail link between London and Birmingham, known as HS2, relied on the amount of travel time that would be saved by passengers. But this in turn only came to that conclusion by assuming that time spent on the train was entirely unproductive, when in fact many working travellers might find the opposite to be true. Hence, all exercises to identify true costs are fraught, values-driven, and often based on models that are extremely sensitive to shifting assumptions.

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[26] Appendix: Government Response to: Building New Nuclear – the challenges ahead: Government Response to the Committee's Sixth Report of Session 2012–13 – Energy and Climate Change: http://www.publications.parliament.uk/pa/cm201314/cmselect/cmenergy/106/10604.htm

[27] Scientific American (26 October 2011), Why Economic Models Are Always Wrong: http://www.scientificamerican.com/article/finance-why-economic-models-are-always-wrong/

[28] Helen Kersley, Eilis Lawlor, Ian Cheshire (2010), *Grounded – a New Approach to Evaluating Runway 3* (London, nef).

This is exceptionally true in the case of assessing different energy technology pathways. Before attempting further to characterise the intergenerational benefit or burden that a new generation of nuclear reactors represents, it is worth noting that full like-for-like costing is extremely difficult, as mentioned above. Full opportunity costs, environmental costs and definitive estimates of subsidy are very hard to arrive at, especially when definitions of what even constitutes a subsidy are themselves contentious.

In terms of comparing returns on investment it is not enough, obviously, to think in purely financial terms. Other important factors include: the energy return on investment, included in which must also be demand reduction (as a way of lowering pressure on generating capacity – i.e. – it can be cheaper to invest in reducing energy consumption than building the equivalent in new generating capacity); the carbon reduction return on investment in terms of both quantity and, importantly, speed of transition; broader environmental returns such as air quality, land use and persistent pollutants; and economic and social returns such as employment creation and the conviviality of technologies for communities.

There are further complexities too. For example, several security costs surrounding the nuclear fuel cycle are absorbed by other budgets. Two major issues that are particular to the nuclear industry, and of very special importance to questions of intergenerational equity and responsibility, concern long-term waste disposal and the insurance of reactor facilities.

Underinsured and over here

To buy a house most people require a mortgage, and lenders in turn require the property they lend on to be insured. If, however, an insurer considers the risks are too high, such as the case increasingly where climate-driven flood risks are concerned, a property may become uninsurable and the purchase never goes ahead. Things work differently for the nuclear industry because its liabilities are capped under a mix of national law and international conventions, meaning the technology is protected from the normal risk equations that determine whether or not something is economically viable. In this sense, the sector was born with a silver insurance spoon in its mouth which it still feeds from today.

Two conventions provide the nearest thing to an international legal framework governing nuclear liability: the OECD's so-called Paris Convention of 1960 and the International Atomic Energy Agency's (IAEA) so-called Vienna Convention of 1963, both linked by a subsequent protocol from 1988, and revised and updated periodically since. The UK is a party to the conventions,[29] but several, major nuclear states like Japan and the US are not, and only around half the world's reactors are in states that are.[30] States operating outside the international conventions manage nuclear liability under national legislation.

Canada, for instance, updated its nuclear liability regime in 2015, allowing it to become party to the latest version of the regime prescribed by the International Atomic Energy Agency (IAEA). In the Canadian example, the new law increases the compensation payable to third parties affected by a nuclear accident from $75 million to, initially, $650 million, and rising annually to $1 billion, with the amount subsequently reviewed every five years.[31] France similarly had liability set at €91 million per plant, which is being raised to €700 million. Some countries like Germany and Japan require theoretically unlimited operator liability, but whose reality is challenged by events. Following the Fukushima disaster in Japan, the operating company, TEPCO, was effectively nationalised in May 2012, meaning the state would absorb liabilities.[32]

That same year, 2012, the UK similarly upgraded its third-party nuclear liability arrangements to make them compatible with the international conventions. Operator liability had been limited to £140 million ($224 million at the time) per incident, but was increased to €1.2 billion ($1.6 billion at the time).[33] The United States provides cover for a "catastrophic nuclear accident" under the Price-Anderson Act of 1957; it limits liability at a significantly higher sum of $13.6 billion, which is in practice covered by a pool of industry-wide insurance.[34]

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[29] Nuclear Energy Agency: Third Party Liability: https://www.oecd-nea.org/news/press-kits/nuclear-law.html
[30] International Expert Group on Nuclear Liability (INLEX), "Civil Liability for Nuclear Damage: Advantages and Disadvantages of Joining the International Nuclear Liability Regime": http://ola.iaea.org/ola/treaties/documents/liability_regime.pdf
[31] Sarah V. Powell and Alexandria J. Pike (3 March 2015), New Nuclear Liability Regime Passed, Davies Ward Phillips & Vineberg LLP.
[32] World Nuclear News (19 August 2015), Tepco announces restructuring.
[33] World Nuclear News (2 April 2012), UK boosts nuclear liabilities: http://www.world-nuclear-news.org/NP-UK_boosts_nuclear_liabilities-0204124.html
[34] World Nuclear Association (March 2015), Liability for Nuclear Damage: http://www.world-nuclear.org/info/Safety-and-Security/Safety-of-Plants/Liability-for-Nuclear-Damage/

These, and especially the figure for the US, sound like significant sums of money, and are until compared to the various estimates for the potential costs of actual, nuclear incidents. Such estimates diverge by several orders of magnitude. One paper written to inform the revision of international nuclear liability conventions in the 1980s suggested a large incident leading to damages up to $695 billion.[35] An early 1990s study for the German Federal Government looking at a worst case scenario incident at the Biblis-PWR power station applied a cost of $6.8 trillion.[36] Following the Fukushima disaster, in 2012 French public safety authorities overseeing nuclear risks put the cost of a serious incident at upwards of €540 billion.[37]

These all represent informed speculation, but the world has actual experience of such events to test them against. Again, a range of methodologies produce sometimes a wide range of costs for nuclear incidents. Estimates for the cost of the Chernobyl nuclear disaster have been put at between $75 billion and $360 billion. A Japanese government estimate in 2011 put the cost of the Fukushima reactor disaster at around ¥5.8 trillion ($60 billion), but this was revised upwards in 2014 by a Japanese academic study to ¥11.1 trillion ($106 billion).[38] The Japanese Centre for Economic Research gave an upper range of total costs that was nearly double even this higher figure, reaching ¥20 trillion.

Liability caps mean therefore, both in theory and practice, that nuclear facilities are underinsured to a significant degree, meaning that significant risks are passed to the public to be carried by current and future generations. The nuclear industry argues that having the state as "insurer of last resort" is simply the same as "in all other aspects of industrial society".[39] Given the extremely long-term, persistent and highly toxic nature of radioactive pollution, however, it stretches credibility to suggest that nuclear power is merely like all "other aspects of industrial society". Assessing its viability as a technology option should, at the very least, involve a realistic costing of the full liability being

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[35] Faure, M. (1995), "Economic Models of Compensation for Damage Caused by Nuclear Accident: Some Lessons for the Revision of the Paris and Vienna Conventions", European Journal of Law and Economics 2 (1995).
[36] cited in: Fukushima Fallout (2013), Greenpeace, London.
[37] Nucleonics Week (15 November 2012), "Major French nuclear accident would be a 'European catastrophe'", cited op cit: Fukushima Fallout (2013) Greenpeace, London.
[38] Japan Times (27 August 2014) Fukushima nuclear crisis estimated to cost ¥11 trillion: http://www.japantimes.co.jp/news/2014/08/27/national/fukushima-nuclear-crisis-estimated-to-cost-%C2%A511-trillion-study/#.VpZ8H_mLSUk
[39] World Nuclear Association (updated 25 February 2016): http://www.world-nuclear.org/information-library/safety-and-security/safety-of-plants/liability-for-nuclear-damage.aspx

carried by the public. The cost of what insurance there is, sooner or later is passed on to consumers in some form or other. In all cases, there is an implicit assumption that the public sphere – that is, the state and its tax payers – will pick up the tab for the difference between the real and insured cost of the sector. In the light of this, Swiss Re, the insurance and reinsurance company, said it believed that "one of the most perilous shortcomings in traditional property insurance and reinsurance concerns inadequate nuclear risk exclusions."[40]

Following the Fukushima disaster, and in the context of debate over life extensions for Germany's nuclear reactors, insurance agency Versicherungsforen Leipzig looked at the issue of underinsurance of nuclear facilities.[41] They concluded that if consumers of electricity generated by nuclear power were to carry the cost of remedying the damage caused by a major incident, apportioning costs based on an adequate insurance premium would require a net price increase for nuclear power of €0.139 to €2.36 per kWh for a duration of 100 years, based on the same payout period.

These are not precisely comparable to the UK as a combination of the technology, geographical location and site-specific adaptation and operating procedures mean that risks and costs will be different for Germany and the UK. But for the sake of illustration and to give an order of likely magnitude for a hidden subsidy, a price increase of €0.139 to €2.36 amounts to £0.10 to £1.67 per KWh.[42] Applied to Hinkley C, those figures multiplied by the plant's assumed annual output of 25billion KWh per year gives an additional amount of between £2.5 billion and £41.7 billion. Applied in turn to the lifetime of the plant, 60 years, this comes to between £150 billion and £2,500 billion.

Opportunity costs

From an intergenerational perspective, a full and meaningful comparative technological assessment would need to involve a wide range of factors. These include: returns on investment for: employment and broader economic value; environmental returns in terms of carbon reduction and other persistent pollutants; energy returns on both

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40 Swiss Re (2003), Nuclear risks in property insurance and limitations of insurability.
41 Versicherungsforen Leipzig (2011), Calculating a risk-appropriate insurance premium to cover third-party liability risks that result from operation of nuclear power plants. (NB: again, to make the calculation numerous clarifying assumptions were necessarily applied).
42 The exchange rate at the time of the calculation was €1.4159 = £1.

financial investment and energy invested in subsequent generation; relative security of energy infrastructure; contribution to the speed of energy system transition; and, importantly, what could be called the conviviality return on investment, that is to say, the degree to which a technology can be responsive to and supportive of a community or society's own vision and pathway for its chosen development. This kind of comprehensive assessment – vital to questions of intergenerational equity – is not yet conducted.

These issues overshadow much more limited cost - benefit exercises used to inform energy policy choices. In the absence of official comprehensive assessments, even more limited exercises can be left to non-official groups to conduct. With these significant caveats in mind, in which "shorthand" ways is it possible to characterise the differing economic value or, indeed, burden that different energy technology pathways will pass on to future generations?

The Solar Trade Association (STA) compared the cost of electricity generation from Hinkley Point C with solar power and flexibility mechanisms.[43] They did not attempt to assess various of the issues above such as questions of security, vulnerability, speed of potential dissemination, broader economic questions such as jobs or compatibility with different ownership models – many of which arguably would favour solar power in a comparison with nuclear. They did, however, allow for solar's "variable but predictable" nature, and the costs of developing a storage infrastructure and other "flexibility" adaptations to align energy output with consumer patterns of consumption. It is noted too that the cost of solar power has fallen approximately 70% since 2010 when Hinkley Point C came under consideration. But, while the costs of renewables are falling, and are expected to continue to do so,[44] the opposite has been the case for nuclear power. Between an initial study by MIT in 2003 and its revised version in 2009, researchers found that costs had risen at the rate of 15% per year. Whilst an initial UK government estimate in 2008 for the new nuclear capacity scheduled for Hinkley C suggested a cost of £5.6 billion, by the time plans were actually approved the cost had risen to £24 billion.

[43] Solar Trade Association Analytics (October 2015), Comparing the cost of electricity generation from Hinkley Point C with solar and flexibility mechanisms.
[44] Michael Liebreich (12 October 2015), Global Trends in Clean Energy Investment, Bloomberg New Energy Finance (presentation to the EMEA Summit London: http://about.newenergyfinance.com/content/uploads/sites/4/2015/10/Liebreich_BNEF-Summit-London.pdf

In the new regime under which EDF's planned Hinkley Point C reactor was offered a guaranteed 35-year strike price of £92.50/MWh,[45] large-scale solar power was required to bid in a competitive auction with other renewable energy technologies. That first Contract for Difference auction saw three solar projects awarded a strike price of £79.23/MWh, but guaranteed only for 15 years (even though solar panels have an expected 35 year life span). To arrive at a cost comparison they calculated the value of the subsidy in the nuclear price guarantee for the 35 year contract period against government projections for future energy wholesale prices and energy output (leaving out some additional costs such as government loan guarantees). They then made calculations for the equivalent in solar output, but limited to the potential contribution from large-scale solar only (similar calculations would apply to onshore wind that utilises the same infrastructure and has costs that are relatively alike). Even on this limited basis, they conclude that the cost of nuclear subsidy to be double that of large-scale solar, costing £29.7 billion compared to £14.7 billion. In the case of the solar subsidy, it is also worth noting that a significant proportion of that – £10.9 billion – is for the development of energy storage and flexibility infrastructure that would also be of benefit to other variable but predictable renewable sources, such as wind, therefore bringing added value.

Renewables operators argue that an additional hidden price benefit of renewable energy exists as a result of the "Merit Order", a benefit which rises with increased deployment. It happens because, in order to keep electricity prices as low as possible, potential sources that are used to ensure that supply always exceeds demand may be ranked in order of the cost of their marginal production. Once built, renewables have the particular advantage of their fuel source being essentially free, making them the cheapest generators with the lowest marginal cost. This creates what is called a "Merit Order Effect", and renewable sources of power beat nuclear, coal, gas and oil, in that order. Increasing the share of producers with a positive Merit Order Effect pushes down wholesale electricity prices. The UK renewable energy company Good Energy sought to quantify the effect for wind and solar generation.[46] They concluded that for 2014 it had reduced the wholesale cost of electricity by £1.55 billion, that the effect would indeed increase with greater deployment, and that that this could deliver net benefits, effectively cancelling out the cost of remaining renewable subsidies.

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45 Quoted at 2012 prices.
46 Good Energy (2015), Wind and solar reducing consumer bills: An investigation into the Merit Order Effect

Taking as a basis the initial issuing round of Contracts for Difference which set the strike prices for power to be generated by Hinkley Point C and from other sources, it is possible to illustrate at face value the additional cost of the new nuclear capacity compared to onshore wind and solar photovoltaic (PV) as shown in Figure 2.

This exercise uses solely existing figures from the Department of Energy and Climate Change (DECC's) initial 35-year agreement with EDF for Hinkley Point C, and the first round of Contract for Difference auctions. Because renewable strike prices are guaranteed for a shorter period, to arrive at comparisons we also project their nominal reductions over time due to learning and scale effects in line with projections from Bloomberg.[47] This basic comparison does not include other potential premiums such as the underinsurance of nuclear risk, the unspecified share of national security operations concerned with nuclear protection, the share of waste management not included in the strike price, and new infrastructure development for particular technologies.

On this basis, and remembering that a range of other potential costs are left out, the additional cost of Hinkley Point C in comparison to onshore wind is £31.2 billion and in comparison to solar PV £39.9 billion for the 35-year period of its guaranteed strike price. But, over five times the new nuclear capacity of Hinkley Point C is planned or proposed for the UK according to the World Nuclear Association.[48] If similar costs applied to other planned or proposed reactors, on this strictly limited basis of comparison, the additional cost would be a nuclear premium of between £175 billion and £220 billion compared to the renewable options, for just over a five-fold increase on the same terms. See figures 2 and 3 overleaf.

[47] Bloomberg New Energy Finance (October 2015) Global Trends in Clean Energy Investment, Bloomberg EMEA Summit London, 12 October 2015: http://about.newenergyfinance.com/content/uploads/sites/4/2015/10/Liebreich_BNEF-Summit-London.pdf

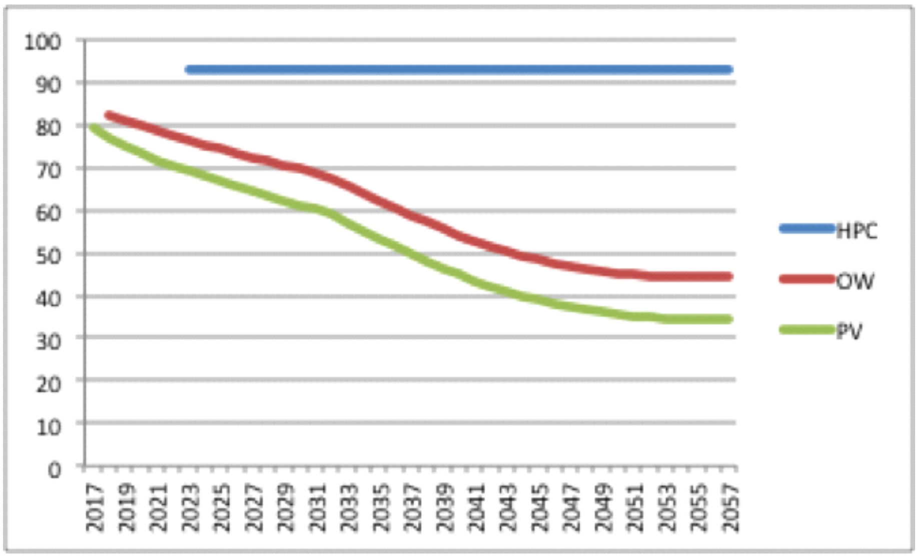
[48] World Nuclear Association (December 2015) Nuclear Power in the United Kingdom: http://www.world-nuclear.org/info/Country-Profiles/Countries-T-Z/United-Kingdom/

Figures 2 and 3: The additional cost of the new nuclear capacity compared to onshore wind and solar PV

	Strike prices (£/MWh)			Difference cf HPC (£/MWh)		Additional cost (£m pa)	
	HPC	**OW**	**PV**	**OW**	**PV**	**cf OW**	**cf PV**
2023-37	92.50	71.06	61.17	21.44	31.33	536	783
2038-52	92.50	46.81	36.79	45.69	55.71	1142	1393
2053-57	92.50	44.27	34.38	48.23	58.12	1206	1453
Total						**31,204**	**39,906**

(Sources:[49] DECC, strike prices, Bloomberg, renewable projections. HPC = Hinkley Point C; OW = onshore wind; PV = solar PV)

Figure 3:



(Sources: DECC, strike prices, Bloomberg, renewable projections. HPC = Hinkley Point C; OW = onshore wind; PV = solar PV)

In the light of the UK context, it is striking that, at a time when record-breakingly expensive new nuclear reactors have been officially approved, financial incentives for renewable energy have faced a series of cuts. Figure 4 lists nuclear reactors currently operating in the UK. Figure 5 lists the nuclear reactors proposed or planned for the UK.

[49] For this exercise, figures are all at 2012 prices and assume 2% pa inflation throughout. This assumes the Hinkley Point C strike price of £92.50 with delivery on schedule, starting 2023, maintained for 35 years and with EDF's stated output of 90% of full generating capacity equalling 25m MWh pa. Strike prices for solar PV and onshore wind are projected from the base of those in Round One of the Contract for Difference auction: solar PV = £79.23, 2016/17; onshore wind = £82.50, 2018/19. We assume that onshore wind and PV are index-linked, but that strike prices for new capacity fall in each subsequent year, by 3.2% pa starting in 2018 for PV and by 1.3% pa starting in 2019 for OW, in nominal terms (as the years after which current contracts come on stream), with equal amounts coming on stream each year. The figures shown then are the average strike prices for installed capacity of each type in each year.

Figure 4: Nuclear reactors currently operating in the UK

Plant	Type	Present capacity (MWe net)	First power	Expected shutdown
Dungeness B 1&2	AGR	2 x 520	1983 & 1985	2028
Hartlepool 1&2	AGR	595, 585	1983 & 1984	2019 or 2024
Heysham I 1&2	AGR	580, 575	1983 & 1984	2019
Heysham II 1&2	AGR	2 x 610	1988	2023
Hinkley Point B 1&2	AGR	475, 470	1976	2023
Hunterston B 1&2	AGR	475, 485	1976 & 1977	2023
Torness 1&2	AGR	590, 595	1988 & 1989	2023
Sizewell B	PWR	1198	1995	2035
Total: 15 units		**8883 MWe**		

Figure 5: Nuclear reactors planned and proposed for the UK

Proponent	Site	Locality	Type	Capacity (MWe gross)	Construction start	Start-up
EDF Energy[n]	Hinkley Point C-1	Somerset	EPR	1670		2023
	Hinkley Point C-2		EPR	1670		2024
EDF Energy[n]	Sizewell C-1	Suffolk	EPR	1670?		?
	Sizewell C-2		EPR	1670?		?
Horizon	Wylfa Newydd 1	Wales	ABWR	1380		2025
Horizon	Wylfa Newydd 2	Wales	ABWR	1380		2025
Horizon	Oldbury B-1	Gloucestershire	ABWR	1380		late 2020s
Horizon	Oldbury B-2	Gloucestershire	ABWR	1380		late 2020s
NuGeneration	Moorside 1	Cumbria	AP1000	1135		2024
NuGeneration	Moorside 2		AP1000	1135		?
NuGeneration	Moorside 3		AP1000	1135		?
China General Nuclear	Bradwell B-1	Essex	Hualong One	1150		
China General Nuclear	Bradwell B-2*		Hualong One	1150		
Total planned & proposed	**13 units ***			**17,900 MWe**		
GE Hitachi	*Sellafield*	*Cumbria*	*2 x PRISM*	*2 x 311*		
Candu Energy	*Sellafield*	*Cumbria*	*2 x Candu EC6*	*2 x 740*		

(Source: World Nuclear Organisation[50])

[50] World Nuclear Organisation: Country profiles: http://www.world-nuclear.org/info/Country-Profiles/Countries-T-Z/United-Kingdom/

2. The Intergenerational energy system burden

Apart from nuclear's high cost, it also represents a comparatively inflexible energy which is hard to turn on and off and requires a particular type of energy grid to give best value, which differs from the kind of infrastructure that optimises the potential of renewable energy.[51] Advocates of nuclear power tend to argue on the basis of the need for a "balanced" energy supply. In practice however, technically and economically large-scale co-existence of nuclear and renewables proves problematic.

On the economic side, shortly prior to nuclear's political rehabilitation in the UK, the Labour government's Performance and Innovation Unit (PIU) warned in 2002 that, "A sustained programme of investment in currently proposed nuclear power plants could adversely affect the development of smaller scale technologies."[52] In a report two years later by the Science and Technology Committee of the House of Lords, while applauding the "inexhaustible, indigenous and abundant" potential of renewable energy in the UK, that could enhance long-term energy security and cut carbon emissions, the Committee deplored as lamentable "the minimal amounts that the Government have committed to renewable energy related R&D."[53]

On the technical side, one crux of the argument revolves around the necessity of providing "baseload" energy capable of balancing supply and demand, and the supposed "intermittency" of renewables. For various reasons, however, nuclear power's contribution to baseload supply can prove problematic, while issues to do with the intermittency of renewables tend to be overstated, and for which there are known technical and planning-based solutions. Analysts Energy Fair describe the concept of baseload as now "obsolete",[54] arguing that what matters is "dispatchable" energy able to provide supply on demand. Several renewable energy sources are suited to this, such as hydropower, enhanced geothermal systems, power from biomass; concentrated solar

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[51] Tom Burke, Tony Juniper, Jonathon Porritt, Charles Secrett (2012), Climate Change and Energy Security: Why Nuclear Power is Not the Answer to the problems of Climate Change and Energy Security: http://www.jonathonporritt.com/sites/default/files/users/BRIEFING 5 - Climate_and energy security_27_April 2012.pdf
[52] Cabinet Office Performance and Innovation Unit (2002), The Energy Review (London, Cabinet Office Performance and Innovation Unit).
[53] Renewable energy: practicalities, House of Lords, Science and Technology Committee Fourth Report, 28 June 2004.
[54] Energy Fair (02 March 2015), Briefing: Nuclear subsidies (Hinkley Point C): http://www.energyfair.org.uk/home

power with heat storage and tidal lagoons. In a future with greater proportions of wind and solar power (explored further below) it is possible to have dependable, resilient power supplies by employing complementary dispatchable sources, demand management and techniques to balance the grid.[55]

The issue of so-called "intermittency" in particular has been used to argue against a greater role for renewables, because the wind does not blow constantly, and the sun doesn't shine day and night. Both are daily and seasonally variable. A perception has been fostered that this limits what share of the energy mix renewables can provide. The more there is, it is argued, the more conventional energy will be needed for "backup" when the wind blows less or the sun shines weakly.

US scientists Mark Jacobson and Mark Delucchi devised a global plan in which wind, water and solar energy technologies provide 100% of humanity's electricity, moving to a zero-carbon energy system by 2030. The model used 3.8 million large wind turbines, 90,000 solar plants, geothermal, tidal and rooftop solar-photovoltaic installations. And it discounted both nuclear power and coal plants with carbon capture and storage.[56] Conventional power generation, they noted, also has problems with "intermittency". Whereas a typical coal plant in the US is "offline" for the equivalent of six and a half weeks per year, modern wind turbines require downtime (for maintenance) of under a week on land and around two and a half weeks at sea. Also, when single wind turbines are down, this affects just a small proportion of overall energy production, whereas significant amounts are lost if a coal, nuclear or gas power plant has to cease generating. Over one-fifth of nuclear plants built in the US up to 2008 were shut down early and for good due to operational or cost problems, while a quarter more were closed for at least a year.[57]

Intermittency is overcome in models like Jacobson and Delucchi's by blending renewable technologies, and because overall, across their range, seasonally and in the daily cycle together they are mostly predictable and reliable (i.e. the sun shines in the day and in good weather, wind blows more in poor conditions). They are aided too by

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55 See Appendix B, op cit, Energy Fair (02 March 2015); & Mark Diesendorf (March 2010) The Base Load Fallacy and other Fallacies. Briefing paper 16, Energy Science Coalition: http://www.energyscience.org.au
56 Mark Z. Jacobson and Mark A. Delucchi (13 November 2009), A Path to Sustainable Energy by 2030, *Scientific American* 301, 58–65.
57 Amory B. Lovins, Imran Sheikh and Alex Markevich (2008), Nuclear Power: Climate Fix or Folly? RMI Solutions, April 2008 updated and expanded by Amory B. Lovins, 31 December 2008.

ever-improving forecasting, smart grids, rapidly developing energy storage technology, and demand management, which all help even out variability.

It is also a myth that conventional sources don't themselves require some kind of back-up. According to energy analyst David Milborrow, "A large pool of backup generation capacity called 'short term reserve' is used to step in when coal, gas and nuclear power stations stop generating at short notice; they can and do 'trip' without warning, leading to the instantaneous loss of large chunks of UK generation – as occurred on 27 May 2008, with the Sizewell B nuclear power station." In a centralised system over-dependent on large-scale generation, such outages create the danger of so-called "through tripping", a domino-effect working around an overburdened system. However, in a more decentralised or "distributed" system, fed by a diversity of different-scale technologies, it is almost impossible for an equivalent amount of generating power to disappear in an instant. In January 2009 there was a significant spell of weather in the UK that was both cold and still. There was a spike in demand, but although the output from wind was low, existing backup arrangements were more than enough to manage. Strikingly, by coincidence around half of the UK's nuclear output was also not available at the time. So, even in advance of developments to make the grid system more renewable-friendly, it managed to cope with wind power's variability.

Experience in France, which has a very high penetration of nuclear power, also contradicts the reputation for nuclear power always being reliably "on". A heat wave hit the country in July 2009, driving up energy demand for air conditioning. But at the same time France's nuclear power plants were recording their lowest output for six years. In a case that raises questions over the impact of climate change for the nuclear sector, their poor output was linked to the heat wave. Fourteen out of nineteen reactors are inland and utilise river water for cooling, and river levels were running low.

Beyond a certain point, higher ambient temperatures force reactors to close to avoid overheating, and during this spell about one-third of nuclear capacity was unavailable and France had to import energy.[58] Coastally located reactors, on the other hand, are vulnerable to extreme events and rising sea levels due to global warming. The relationship between weather, nuclear and renewables can work in other counter-

[58] France imports UK electricity as summer heatwave puts a third of its nukes out of action (6 July 2009), Climate Progress: http://thinkprogress.org/romm/2009/07/06/204331/france-imports-uk-electricity-summer-heatwave-puts-nuclear-power-plants-out-of-action/

intuitive ways. France also struggled for sufficient capacity during a cold spell in the winter of 2012 and imported energy from Germany. And, in that case, it emerged that solar PV in southern Germany was being relied on.[59]

While intermittency as a problem for renewables has been greatly overplayed, the dependability of nuclear as an energy source equally has been exaggerated. The more widely deployed renewables become, the more benefit will be drawn from their complementarity. Equally, with technological advances in energy storage and the development of infrastructure better geared toward renewables, their prospects stand to improve still further.

[59] German power exports to France increasing (6 February 2012), Renewables International: http://www.renewablesinternational.net/german-power-exports-to-france-increasing/150/537/33036/

3. The intergenerational climate burden

Scientists at the world-leading Massachusetts Institute of Technology conducted an assessment into the prospects for nuclear power based on the premise that "this technology is an important option for the United States and the world to meet future energy needs without emitting carbon dioxide and other atmospheric pollutants." They created an interdisciplinary team to analyse a range of technical, economic, security and safety issues. It was a rare kind of comprehensive assessment for a technology and an industry often shielded from broader scrutiny due to a history of secrecy linked to both national security considerations and commercial confidentiality.

A key question was to work out what might be the maximum potential contribution that nuclear power could make to the global energy mix. They published a first report, *The Future of Nuclear Power,* in 2003, which was then updated in 2009.[60] They applied scenarios for deployment that ranged from modest to highly ambitious. The most ambitious scenario involved unprecedented expansion in both speed and scale for the industry, envisaging a near-trebling of nuclear capacity by 2050. This would mean building between 1,000 and 1,500 large nuclear power plants. But if successful even this, the boldest of the approaches, would have increased nuclear power's share of electricity generation (electricity only note, not overall energy, something often missed or confused) from 17% to 19% – an increase of just 2%.

Since then, Professor Kevin Anderson of the Tyndall Centre for Climate Change Research at Manchester University assessed the potential role of nuclear power in addressing climate change on the basis that, compared to fossil fuels, it is a low-carbon fuel source. The share of nuclear power in global electricity generation has fallen since the MIT study to around 11%.[61] And any future prospects build on the foundation that civil nuclear power is a mature technology, having been around since the 1950s, and hence rapid learning effects are likely to be limited, and scale efficiencies are already well tested and known. Today 441 reactors are currently in use[62] in around 30 countries.[63] Not including the lengthy planning and licensing process, it takes around 5–7 years to build a

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60 MIT (2003), *The Future of Nuclear Power: An Interdisciplinary MIT Study* (updated 2009), Cambridge MA, Massachusetts Institute of Technology.
61 http://www.nei.org/Knowledge-Center/Nuclear-Statistics/World-Statistics
62 IAEA PRIS: https://www.iaea.org/PRIS/home.aspx
63 Nuclear Energy Institute: http://www.nei.org/Knowledge-Center/Nuclear-Statistics/World-Statistics

new nuclear plant.[64] However, as with typical initial cost estimates compared to the final bill for major construction works, build times too are prone to overrun.

The Olkiluoto 3 reactor in Finland, for example, began construction in 2005 with an initial completion date set for 2009. It was a new reactor type called a European Pressurised Reactor, or EPR, which was meant to be not only safer and more efficient, but cheap and fast to build. However, after numerous technical and contractual problems, it is currently not expected to begin operation until 2018, nine years late.[65] From an initial estimate of €3 billion (£2.2 billion), costs have also tripled.

The reactors planned for Hinkley Point C are of the same type, EPRs, as Olkiluoto 3. EDF, Hinkley Point C's builders, at first committed to a rapid construction programme. EDF's chief executive, Vincent de Rivaz, famously promised that the first reactor would be operating in time for the British public to cook their Christmas dinners on it in 2017.[66] When that didn't happen due to various delays, de Rivaz's promise changed to a commitment that, "in 2023, this project will arrive exactly when the country will need it."[67] Then, in September 2015, Jean-Bernard Levy, the EDG group CEO, admitted that they were unlikely to meet a 2023 start date.[68]

Apart from in Finland, the other EPR currently under construction is at Flamanville in France. It is the first new reactor to be built in the country for 15 years and has been described as EDF's "flagship". As such, it is surprising that this shop window hasn't deterred other buyers, because the EPR at Flamanville has also been beset by repeated delays and cost overruns.[69]

That nuclear power is so often a triumph of hope over reality should not come as a surprise to planners and politicians. The UK's own history is instructive. During her time as Prime Minister, Margaret Thatcher commanded huge authority, changing the economic doctrine and structure of the nation. As well as dramatically reducing the scale

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[64] OECD Nuclear Energy Agency: How long does it take to build nuclear power plants. A briefing: https://www.oecd-nea.org/press/press-kits/economics-FAQ.html
[65] Reuters: Finland's nuclear plant start delayed again: http://www.reuters.com/article/finland-nuclear-olkiluoto-idUSL5N0R20CV20140901
[66] Utility Week (15 June 2009) Hopes and fears of EDF's man on the nuclear frontline: http://utilityweek.co.uk/news/Hopes-and-fears-of-EDFs-man-on-the-nuclear-frontline/787042#.VpjVBPmLSUk
[67] The Telegraph (12 October 2015) Hinkley Point new nuclear power plant: the story so far.
[68] The Telegraph (03 September 2015) Nuclear delay: EDF admits Hinkley Point won't be ready by 2023.
[69] The Financial Times (3 September 2015), EDF admits delay to new UK nuclear reactor.

of the coal industry, she also planned a whole series of new nuclear power plants. However, even with the political momentum she generated, apart from Sizewell B in Suffolk, the UK's first pressuried water reactor (PWR), no other nuclear reactors have been built or ordered in the UK until now.

Even that single reactor carries lessons. A public inquiry into Sizewell B ran from January 1983 to March 1985 and the plant didn't begin operations until early 1995. An even more cautionary tale concerns the Dungeness B reactors, which instead of taking 5 years to build took respectively 18 and 20 years, and were only scheduled to be in operation for 25 years, until planned closure dates were successively deferred. Dungeness B also cost four times its original estimate. Currently, most UK nuclear reactors are scheduled to close by 2023.[70] Sizewell B has a longer life to 2035 and Dungeness B is likely to continue now until 2028.

Speaking at the UN Paris climate conference in December 2015, Professor Anderson estimated that if nuclear power were to make a meaningful contribution to tackling climate change as part of a global low-carbon energy system, it would need to provide around 25% of current energy demand within a short timeframe,[71] but that to do so would require the construction of 2,500 large power plants in the next 20-plus years. From an engineering perspective Anderson, who is also a trained engineer, says that a combination of resource constraints in terms of raw materials, the necessary skilled personnel and finance for investment conspire to make this a practical impossibility.

There are around 66 reactors currently under construction, according to the International Atomic Energy Agency (IAEA).[72] In 2015 ten new nuclear power plants were connected to grids, eight in China, one in South Korea and one in Russia. But in the same year eight reactors were permanently closed, one each in Germany, Sweden and the UK and the rest in Japan. All told, in 2015 operable global nuclear generating capacity rose marginally from 377.7 GWe to 382.2 GWe, an increase of just 1.2%.[73]

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[70] UK Parliamentary Research Briefing, 9 March 2015: http://researchbriefings.parliament.uk/ResearchBriefing/Summary/SN03841#fullreport
[71] Prof Kevin Anderson, presentation, A carbon budget for 2 degrees: file:///C:/Users/oem/Downloads/Prof_Kevin_Anderson__13_February_2015.pdf
[72] International Atomic Energy Agency PRIS World Statistics: https://www.iaea.org/PRIS/WorldStatistics/UnderConstructionReactorsByCountry.aspx (other sources give marginally different figures for reactors under construction)
[73] World Nuclear News (6 January 2016), World starts up 10, shuts down eight, nuclear reactors in 2015: http://www.world-nuclear-news.org/NP-World-starts-up-10-shuts-down-eight-nuclear-reactors-in-2015-411601.html

By comparison, the same year solar PV capacity was expected to increase by 55 GW, representing a 36% increase.[74]

Regardless of this, and in a global economy still so dependent on fossil fuels, nuclear power cannot be considered a "fossil free" form of energy. In fact, there are several fossil fuel intensive processes involved in the full production cycle from uranium mining to conversion, enrichment, transport and construction of power stations, and waste management. Full life cycle assessments are hard to compare simply due to the range of technologies used under each category. An estimate from the US-based Nuclear Information and Resource Service suggested direct and indirect greenhouse gas emissions of 73 to 230 grams of CO2 per kWh electricity, much higher than nearly all renewable sources.[75] A 2008 comparative assessment[76] suggested that nuclear was over six times worse for greenhouse gas emissions than small hydro, offshore and onshore wind, and around twice as bad as solar PV, various kinds of biomass and geothermal.

In 2014 the Intergovernmental Panel on Climate Change (IPCC) published an assessment harmonizing various studies and giving an emissions range for nuclear of 3.7 to 110 gCO_2 (eq)/kWh.[77] All these ranges give nuclear power a substantially smaller carbon footprint for electricity generation than a range of fossil fuels. But this upper emissions range also gives nuclear a bigger carbon footprint than offshore wind, onshore wind, rooftop solar PV, concentrated solar PV, wave, tidal and geothermal power. Utility scale solar was given a higher upper value, but as a fast-maturing technology it is more susceptible to rapid efficiency gains.

In a Stanford University study nuclear was found to emit up to 25 times more carbon than wind energy. It ranked the desirability and effectiveness of energy options to "improve energy security, mitigate global warming and reduce the number of deaths caused by air pollution" as follows: 1, wind power; 2, concentrated solar power; 3, geothermal power; 4, tidal power; 5, solar photovoltaics (PV); 6, wave power; 7,

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[74] GTM Research (June 2015) Global PV Demand Outlook, 2015-2015: Exploring Risk in Downstream Solar Markets: http://www.greentechmedia.com/articles/read/55-gw-of-solar-pv-will-be-installed-globally-in-2015-up-36-over-2014
[75] Folkers, C. (August 2004), Nuclear power can't stop climate change, Nuclear Information and Resource Service, Washington DC.
[76] Sovacool, Benjamin K. (2008). Valuing the greenhouse gas emissions from nuclear power: A critical survey, Energy Policy 36: 2950–2963.
[77] IPCC Working Group III – Mitigation of Climate Change, Annex III: Technology - specific cost and performance parameters; IPCC (2014)

hydroelectric power; 8, a tie between nuclear power and coal with carbon capture and sequestration (CCS).[78]

[78] Mark Z. Jacobson (2009), Review of solutions to global warming, air pollution, and energy security, Energy & Environmental Science 2, 148–73, RSC Publishing.

4. The intergenerational security and waste burden

In the UK, the unique risks associated with nuclear power as an energy source are reflected in it having its own, dedicated police force, the Civil Nuclear Constabulary, overseen by the Civil Nuclear Police Authority, costing around £100 million per year.[79] A wide range of other bodies and parts of the UK's police and security services also contribute to nuclear security measures,[80] which can include covering everything from state-sponsored espionage and proliferation to terrorist threats, but their costs are hard to isolate. These immediate, additional concerns relating to nuclear power and, due to the longevity of nuclear materials, also represent a unique intergenerational risk.

Terror-related dangers range from radiological dispersal devices, known as "dirty bombs," attacks on nuclear installations, and improvised nuclear devices stemming from either military or civil nuclear sources. The consequences of any such incidents would be long-term contamination. Increased awareness of such risks after the 9/11 terror attacks is partly why insurers Swiss Re commented, as mentioned above, on a perilous shortcoming in traditional property insurance being, "inadequate nuclear risk exclusions."[81] Private nuclear industry calculations reportedly showed that the effect of a plane being flown into the intermediate-level waste stores at Sellafield could result in 3,000 deaths within two days of the attack.[82]

In spite of this awareness, evidence abounds of both a thriving black market in nuclear materials,[83] and lax security along the nuclear supply and waste chain. In July 2006, a fake bomb was easily planted on a train in the UK carrying nuclear waste by a report from the Daily Mirror.[84]

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[79] Civil Nuclear Police Authority Strategy and Business Plan 2014-17: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/318897/strategy_and_business_plan_2014-17.pdf

[80] These include, for example, the Office of Civil Nuclear Security (OCNS); Radioactive Materials Transport Team (RMTT), the Joint Terrorism Analysis Centre (JTAC), the Centre for Protection of National Infrastructure (CPNI), the Office for Security and Counter-Terrorism (OSCT), M.I.5, the Special Branch of the Metropolitan Police, the Ministry of Defence Police and the British Transport Police.

[81] Andris, D., Galley, G., Reitsma, S. and Walker, R. (2003), Nuclear risks in property insurance and limitations of insurability, Swiss Reinsurance Company.

[82] Alex Evans (2003), The Generation Gap, ippr: London.

[83] The Economist (19 June 2008), Viz Pakistan: The nuclear network of A.Q. Khan: *http://www.economist.com/node/11585265*

[84] Daily Mirror (21 July 2006), "We plant 'bomb' on nuke train".

An investigation by the Associated Press revealed several attempts to sell radioactive material taken from Eastern European facilities to Middle Eastern extremists, including one specific plot to sell highly contaminating caesium to the Islamic State group.[85] Other investigators claimed to have revealed a black market even for nuclear warheads.[86] The advent of drone technology and cyber attacks significantly increases the threat of attacks on nuclear installations. Developments of civil nuclear power in both Iran and North Korea have heightened fears over the consequences of proliferation.

In their comprehensive assessment of the global prospects for nuclear power, the MIT analysis (referred to above) concluded that:

> "The current international safeguards regime is inadequate to meet the security challenges of the expanded nuclear deployment contemplated in the global growth scenario. The reprocessing system now used in Europe, Japan, and Russia that involves separation and recycling of plutonium presents unwarranted proliferation risks."[87]

A toxic time capsule

The Nuclear Decommissioning Authority (NDA), established in 2005 by the previous year's Energy Act, describes the "Nuclear Provision" as the "best estimate" of what it will cost to decommission and clean seventeen existing nuclear sites across the UK.[88] These represent the first two generations of nuclear power in the UK, with sites dating back to 1940, and the programme of work is set to last for more than a century. Work will continue "well into the 22nd century" says the NDA. It involves decommissioning, dismantling and demolishing buildings and the management and disposal of waste. The types of facilities involved include research, reactors and fuel reprocessing.

Acknowledging how unknowable the full cost is likely to be, the NDA says no more than that the costs are "an informed estimate, within a wide range of assumptions". Because

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[85] Associated Press (7 October 2015) INVESTIGATION: Nuclear black market seeks IS extremists: http://bigstory.ap.org/urn:publicid:ap.org:6fd1d202f40c4bb4939bd99c3f80ac2b
[86] Vice magazine (28 August 2015) You can buy a nuclear warhead on the black market (video report on Bulgaria): http://www.businessinsider.com/you-can-buy-a-nuclear-warhead-on-the-black-market-2015-8?IR=T
[87] MIT (2003/2009), *op.cit.*
[88] Nuclear Decommissioning Authority (11 February 2015), Explaining the Nuclear Provision: https://www.nda.gov.uk/2015/02/explaining-the-nuclear-provision/

the liabilities of private operators are capped, it means that anything beyond them is effectively underwritten by the public. It is for reasons like this that, historically, critics of nuclear power have referred to it operating with a "blank cheque" from government. The NDA even admits that in the early days of civil nuclear power "plans for future dismantling were barely considered." Taking account of "numerous uncertainties", the NDA says that the cost range spread over 120 years "is likely to be somewhere between £90 billion and £220 billion."[89] A huge proportion of this cost, 74% relates to Sellafield, which is home to both reactors and fuel reprocessing.

In 2012 it was estimated that 86% of the budget for the Department for Energy and Climate Change (DECC) went towards managing waste and other liabilities from the UK nuclear programme (this meant, the research claimed, that the department was spending "over eight times as much on the cleaning up the nuclear past" as it was on securing "our future energy and climate security").[90] Figure 6 below represents an estimate by the NDA for the volume and mass of additional radioactive waste forecast to arise after 1 April 2013, nearly 5 million tonnes in total. It is enough to fill the new Wembley Stadium four times over.[91] A negative value is given for high level waste not because it disappears, but because a process of vitrification is used to condition it which reduces its volume, and also because the UK reprocesses high level waste for other countries and returns it.

Figure 6: Estimated waste arising from April 2013 onwards (not including planned new reactors).Volumes and masses reported by operators

Waste type	Volume (m)	Mass (tonnes)
High Level Waste	-695	-560
Intermediate Level Waste	190,000	190,000
Low Level Waste	1,300,000	1,700,000
Very Low Level Waste	2,840,000	2,900,000
Total	4,330,000	4,700,000

(Source: NDA UK Radioactive Waste Inventory)[92]

[89] Nuclear Decommissioning Authority (11 February 2015) *op.cit*
[90] Tom Burke, Tony Juniper, Jonathon Porritt, Charles Secrett (26 March 2012) Subsidising the Nuclear Industry: A briefing for the government.
[91] Nuclear Decommissioning Authority (23 October 2015), Managing Waste: http://www.nda.gov.uk/managing-waste/
[92] UK Radioactive Waste Inventory 2013: http://www.nda.gov.uk/ukinventory/the-2013-inventory/2013-uk-data/waste-forecasts/

High-level waste requires cooling before it can be stored. This means it is stored as a liquid in water-cooled, stainless steel tanks, or the glass blocks mentioned above. Thick concrete walls are needed to shield people from its radiation levels. Confusing in lay terms, intermediate level waste can be as radioactive as high-level waste, but generates less heat, meaning it can be managed differently, although it still requires protective concrete shielding.[93]

A new fleet of nuclear reactors will, of course, add to the amount of nuclear waste to be managed, but estimates for these are not included in the figures. To consider the effect of the new programme means assessing both the volume and the radioactivity of new wastes to be produced over a likely 60-year reactor operating cycle. Official figures for an additional 10GW of nuclear capacity would increase the volume of nuclear waste by just 10% but, because of the radioactive nature of the waste, its deep geological storage almost doubles the footprint, or space, needed for existing waste. However, it has been estimated that a 16 GW programme of new build (excluding the two more speculative reactors proposed for Bradwell) could lead to nearly a tripling of the footprint for likely nuclear waste repositories.

Problems with deep geological storage were highlighted recently when cracks appeared and walls collapsed in the Asse salt mine, a long-term nuclear waste storage facility in Germany, previously thought safe and permanent.[94] Corrective work in these circumstances is extraordinarily difficult, dangerous and expensive.

Where the amount of radioactivity, rather than the volume, of waste is concerned, against a previous inventory from 2010 covering existing nuclear reactors, figures produced for the NDA point to a four-fold increase in the inventory of radioactivity contained in nuclear waste resulting from 16GW of new capacity.[95] With all the official caveats above, if we were to assume just a similar spread of costs for the new waste, and the lower order of a three to four-fold increase in the waste repository/amount of radioactivity to be managed over a 120-year period, the NDA's cost range could rise to between £270 billion and £660 billion. Highly radioactive waste has to be safely managed, of course, for countless more generations, over many thousands of years.

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[93] Nuclear Decommissioning Authority (23 October 2015), *op.cit.*
[94] New Scientist (29 January 2016) Radioactive waste dogs Germany despite abandoning nuclear power.
[95] Radioactive Waste Management Ltd/NDA (July 2015), Geological Disposal: An overview of the differences between the 2013 Derived Inventory and the 2010 Derived Inventory: http://www.nda.gov.uk/publication/differences-between-2013- and-2010-derived-inventory/

The government says that the cost of waste management is included in the strike price. However, given the NDA's open admission about the difficulty of estimating waste management costs, it is hard to see how the government's position can be taken with confidence. And, in fact, official language refers to operators taking their "share of the costs of waste management."[96] Yet, with so many uncertainties on the cost of waste disposal and management, capping costs to operators in a fixed price in effect transfers the risks of higher costs and cost overruns (not to mention operators going bust) to the public and future generations. In a complicated formula that involves the government ultimately taking responsibility for the waste, and the final price for waste disposal being set several decades after initial contracts are signed, the price charged to market may be only 70% of costs.[97]

Leaving aside other uncertainties, and with that as a basis, 30% of the potential costs of additional waste management adds between £54 billion and £132 billion to the potential nuclear premium already identified to pay over renewable alternatives of between £175 billion and £220 billion, significantly increasing the cost and risk of the nuclear option to future generations.

The official bodies responsible in the UK for the oversight of nuclear waste management themselves acknowledge that much to do with its intergenerational burden is unknown. The MIT study cautioned that it is therefore a safety and economic gamble passed over time to subsequent generations, were there to be a significant growth of nuclear generation, not much was known – beyond the operation of the reactors themselves – about the safety of the overall fuel cycle. [98]

On nuclear waste disposal, they found that little progress was being made on the problem and that, while geological disposal (dubbed the bury-and-forget approach) is technically feasible, "execution is yet to be demonstrated or certain". And that "a convincing case has not been made that the long-term waste management benefits of advanced, closed fuel cycles involving reprocessing of spent fuel are outweighed by the short-term risks and costs."

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[96] DECC (21 October 2013) Initial agreement reached on new nuclear power station at Hinkley; No2Nuclear Power (September 2015) Waste and Decommissioning Financing Arrangements: http://www.no2nuclearpower.org.uk/new-reactors/facilitative-actions/waste-decommissioning-financing-arrangements/

[97] According to Ian Jackson, former government advisor and associate fellow at Chatham House, quoted *op.cit*: No2Nuclear Power (September 2015), Waste and Decommissioning Financing Arrangements.

[98] MIT (2003/2009), *op.cit.*

Thorium: a new nuclear magic bullet?

There has been much debate over the prospects of a new generation of thorium-fuelled nuclear reactors that are said to overcome many of the problems of current civil nuclear technology. The World Nuclear Association calls the technology a "tantalising prospect," whilst conceding that making it cost-effective "remains a challenge" requiring substantial R&D.[99] And, its development faces many of the same problems experienced by reactors using uranium and plutonium: high costs of development, build and operation, security, pollution and proliferation hazards, and long lead-time for introduction.[100] Key drawbacks are:

- the very high costs of technology development, construction and operation;
- marginal benefits for a thorium fuel cycle over current uranium and plutonium fuel cycles;
- significant nuclear weapons proliferation hazards: the molten salt reactor (MSR) technology promoted for thorium could be used to produce fissile uranium and plutonium at very high purities, well above ordinary "weapons grade";
- the danger of both routine and accidental releases of radiation, mainly from continuous "live" fuel reprocessing in MSRs;
- the very long lead time for significant deployment of MSRs of the order of half a century – rendering it irrelevant in terms of addressing current or medium-term energy supply needs.

[99] World Nuclear Association (September 2015) Thorium http://www.world-nuclear.org/information-library/current-and-future-generation/thorium.aspx
[100] The Guardian (23 June 2011) Don't believe the spin on thorium being a greener nuclear option http://www.theguardian.com/environment/2011/jun/23/thorium-nuclear-uranium

5. Conclusion: energy futures, open debate and intergenerational choices

Earlier it was noted that growing concern over the action needed for climate change in the first decade of the new millennium coincided with a revival of lobbying by the nuclear sector. The 2003 Energy White Paper appeared to rule out further nuclear expansion, dubbing it an "unattractive option". Up to that point it had become, at least in Western democracies, an industry that was virtually moribund in terms of expansion. But since then a long list of heavy-hitting public relations and lobbying firms have been employed by the nuclear sector, including Bell Pottinger, Weber Shandwick, Grayling PR, Brunswick and others.[101] Through firms like these, pro-nuclear messaging was channelled through third parties such as MPs, academics and NGOs. Philip Dewhurst, then Group Corporate Affairs director at British Nuclear Fuels Ltd (BNFL) and chair of the Nuclear Industry Association, explained that they communicated "via third-party opinion because the public would be suspicious if we started ramming pro-nuclear messages down their throats."[102] Political interest duly followed in the UK.

Figure 7 demonstrates how the nuclear industry presented itself as a combined lobby under the banner of "Nuclear for Climate" at the 21st Conference of the Parties to the UN Framework Convention on Climate Change (COP21) in December 2015 in Paris.

Figure 7: Nuclear industry stand at the 21st Conference of COP21, December 2015, Paris

[101] Spinwatch (2008), Spinning the Wheels: A guide to the PR and lobbying industry in the UK
[102] Spinwatch (2008), op.cit.

This report argues that, as an energy source, nuclear power creates several unique intergenerational burdens of an economic and environmental nature, and in terms of predetermining the options available to future generations of the kind of energy systems and use they may wish democratically to choose. This is due to the way nuclear power locks in infrastructure which is inflexible, and because decommissioning a nuclear power station has an entirely different order of magnitude compared to moving a wind turbine.

In addition to cost and legacy problems, this report also argues that, in terms of resource allocation, nuclear power is a dangerous distraction to the challenge of solving climate change. Firstly, even if expanded under highly ambitious scenarios, the technology is incapable of making a difference in the time window that remains to meet the climate targets agreed at the Paris Conference. Secondly, as this report argues, cheaper, quicker alternatives exist, meaning that any resources diverted to new nuclear capacity are being spent sub-optimally, and are deferring and delaying more effective possible action to decarbonise the global electricity supply or manage demand.

Nevertheless, sophisticated presentations were given at the industry's glossy trade stand in the "Gallery of Solutions" at COP21. They promoted examples of new reactors being built, and argued that incidents like the Fukushima disaster were not reasons for second thoughts. "Nuclear for Climate" presented itself a "grassroots initiative" of developed and emerging nuclear societies.

In the UK, however, far from a groundswell of support at the "grassroots", the UK parliamentary Select Committee on Energy and Climate Change found fundamental flaws in the relationship between nuclear power installations and the local communities they affected.[103] These included that:

- "Unlike renewables, nuclear power stations take a long time to build and therefore have the potential to cause considerable disruption to local communities for an extended period of time."
- It was disappointing that there was no "natural forum" for debate for the "important" function of local communities having "an opportunity to engage in

103 Select Committee on Energy and Climate Change (26 February 2013), Sixth Report Building New Nuclear: the challenges ahead: http://www.publications.parliament.uk/pa/cm201213/cmselect/cmenergy/117/11702.htm

genuine dialogue about risk management with both the regulators and the developers."

- "There is a mismatch between the capacity of developers and that of local communities to participate fully and effectively in the planning process, particularly where large, complex and technical projects such as building a new nuclear power station are concerned."

Rather than a forum for open dialogue about risk, from its stand, the Nuclear for Climate group actively disseminated material specially produced for the conference which dismissed, or rather condemned, critics of nuclear power who proposed renewable energy solutions for "endangering both human civilisation and the Earth's ecosystem."[104]

Practical problems concerning the coexistence of renewable and nuclear technology have been described, but there are political ones too. Once the prospects for new nuclear power in the UK regained political favour, it emerged that, behind the scenes, civil servants were also undermining EU renewable energy targets.[105] It seems, as Walt Patterson, an Associate Fellow of the energy programme at the Chatham House think tank, observed, "Nuclear power needs climate change more than climate change needs nuclear power."

An urgent rethink is needed on UK energy policy to create an optimal system for this and future generations. An over-reliance on new nuclear capacity is expensive, poor value, slow, insecure and an obstacle to better alternatives. Without a rethink we risk passing on a huge intergenerational economic burden in which known costs are high, and risks exist heavily on the downside.

We also risk locking in an energy infrastructure which will be vulnerable to security and climate risks, whilst also restricting the flexibility of the energy system, and reducing the room for manoeuvre of future generations. Worse still, we will leave for our children and countless future generations a toxic time capsule of waste for which no satisfactory means of disposal yet exist.

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[104]See, for example, the COP 21 edition of: Rauli Partanen & Janne Korhnen (2015), Climate Gamble: Is Anti-Nuclear Activism Endangering Our Future (a copy of which was handed to the author of this report at the Nuclear for Climate exhibition stand).
[105] Ashley Seager & Mark Milner (13 August 2007): Revealed: cover-up plan on energy target, The Guardian: http://www.theguardian.com/environment/2007/aug/13/renewableenergy.energy

And, perhaps worst of all, our government stands to make all these choices knowingly, and while missing a once-an-era opportunity to lead the world with better, safer, cheaper alternatives.