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Delivering New Nuclear Projects: A Megaprojects Perspective

Purpose

This conceptual paper draws on the megaprojects literature and salutary lessons from previous megaprojects to make recommendations for policymakers, promoters and project managers on how to structure and deliver new nuclear build programmes.

Design/methodology/approach

This paper is underpinned by the extant literature and an analysis of public domain data from three proposed new nuclear power plants in the UK. It identifies the main challenges facing new nuclear build projects and subsequently proposes lessons that can be learnt from megaprojects, in order to plan, structure and deliver new nuclear build programmes successfully.

Findings

The paper argues that megaprojects are simultaneously trait-making, rather than trait-taking, possess a temporality and timescale in excess of typical infrastructure projects, suffer from high levels of uncertainty and ambiguity, are organisationally complex, costly and are highly likely to destroy rather than create value. Secondly, it argues that the challenges facing new nuclear build are not merely technological but also institutional, political and societal in nature. The nature of these challenges is exemplified using three proposed new nuclear build projects in the UK.

Originality/value

This is the first paper to draw on both extant megaproject theory and on an analysis of the public domain data from three proposed new nuclear power plants in the UK. It makes

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3 contributions to megaprojects theory and practice, and specifically to nuclear new build
4 projects. Importantly, it proffers recommendations for how new nuclear build programmes
5 around the world might be structured, planned and delivered to minimise the risks of failure.
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9 10 **Introduction**

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12 The UK government faces an acute energy dilemma; that of accessing sources of energy that
13 are both cheap for consumers, non-damaging to the environment *and* secure against geo-
14 political risks. An aging fleet of nuclear power plants that currently generate approximately
15 21% of the UK's electricity (Department of Business, 2017) are due to be decommissioned
16 by the mid 2020's leaving a sizeable gap in the generating capacity available to the National
17 Grid. Coupled with this, the last of the UK's coal fired power stations will go off-line around
18 the same time (Vaughan, 2017). The options for new energy generation are three-fold: gas
19 (either imported or from the North Sea), renewables (including solar, wind and wave power)
20 and nuclear (through an ambitious and expensive programme of new nuclear build projects).
21 Each of these energy options has its own strengths and weaknesses. For example, gas is
22 cheap but risks leaving the UK increasingly reliant on imported [suppliesgas](#). And
23 renewables, whilst falling in price, remain unreliable as a source of stable base-load power.
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40 Given that UK requires additional energy generation capacity before 2023, the government
41 has made the construction of a fleet of new nuclear power plants a central pillar of its energy
42 strategy: its argument being that nuclear power is able to provide large stable base load
43 electricity generation, whilst supporting the drive for CO2 reductions. However, nuclear
44 power comes at a financial cost (in terms of the construction of hugely complex, safe power
45 plants and long term decommissioning and waste disposal liabilities) and concentration of
46 risk in a small fleet of nuclear reactors (Ansar *et al.*, 2016; Morris, 2016).
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3 Research into the management of complex, socio-technological projects such as nuclear
4 power plants (Invernizzi, Locatelli, & Brookes, 2017) has grown rapidly since the early
5 2000's and there is growing traction within academic and practitioner communities for these
6 "megaprojects" to be considered a specialised field within the wider discipline of project
7 management (Flyvbjerg, Bruzelius and Rothengatter, 2003; Flyvbjerg, 2014b; Li *et al.*, 2017;
8 Pollack *et al.*, 2017). Megaprojects are large- scale complex infrastructure projects that
9 typically, although not exclusively, have a budget greater than US\$1 Billion; take many years
10 to plan and construct, involve multiple stakeholders and are carried out under the watchful
11 and often critical gaze of politicians, the public and the media (Zidane, Johansen and
12 Ekambaram, 2013; Flyvbjerg, 2014b; Mišić and Radujković, 2015). In a recent piece
13 work (Frick, 2017), which addresses the need for the US to embark on a similarly extensive
14 programme of infrastructure investment, Karen Trappenberg Frick captures articulates the
15 essence of megaprojects using 7 C's: *colossal, captivating, costly, controversial* and *complex*,
16 thus requiring effective *control* measures and constant stakeholder *communication*. These
17 characteristics of megaprojects manifest themselves as overoptimistic project forecasts
18 coupled with underestimated risks and inadequate levels of project contingency in budgets.
19 This leads to cost overruns, project delays and long-term benefits shortfalls or even a collapse
20 in the long-term project viability.

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42 Ansar et al., (2016) argue that big energy projects, such as new nuclear, are especially fragile
43 and susceptible to technical, operational and political risks. Nuclear power plants comprise
44 myriad interdependent components, sub-systems and systems, both to generate nuclear power
45 in a controlled fashion and to remain safe in the event of an exhaustive set of fault scenarios.
46 They have lengthy planning and construction horizons and are typically delivered by
47 complicated supply chains that span numerous organisational and national cultures
48 (Saunders, Gale, & Sherry, 2015). The additional complexities of the UK new nuclear build
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programme were articulated clearly at the *Nuclear New Build Forum* in London on 20 April, 2016 as follows:

Large infrastructure projects require a range of key features and sufficient risk management to attract financing, but a new nuclear project has to go further still to draw in potential backers New nuclear programs need to align with associated infrastructure, such as grid and transport networks, as well as develop a supply chain, receive planning consents and engage with national and local government, along with the businesses, education establishments and communities in the area the project is based. They also need to have their reactor design scrutinised by national regulators, a process that in the UK can take as long as five years. In addition, the project needs to have a fuel supply, operations, maintenance and decommissioning strategy, looking as much as 80 years ahead. (WNN, 2016)

This [conceptual](#) paper, which is based on publicly available information on the UK new nuclear build programme, argues that the challenges facing the UK's new nuclear build programme are not merely technological but also institutional, political and societal in nature.

It addresses three key research questions:

- 1) What are megaprojects and how do they differ from traditional or non-megaprojects?
- 2) What are the main challenges facing new nuclear build megaprojects?
- 3) What lessons can policy makers, promoters and project management professionals learn from [past](#) megaprojects, in order to plan, structure and deliver the new nuclear build programme successfully?

The next section of the paper summarises the extant research into megaprojects. Subsequent sections describe the status of, and challenges facing, the UK new nuclear build programme,

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3 and discuss recommendations on how to most appropriately structure and deliver the UK new
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5 nuclear build programme.
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7 **Megaprojects Research**

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9 The notion of the megaproject – as an extremely complex and costly infrastructure project
10 that attracts much public attention and has the potential to transform society - has been in
11 existence since Selznick's (1949) study of megaproject management within the Tennessee
12 Valley Authority in the United States. More recent megaprojects include the Channel Tunnel
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14 Fixed Rail Link, other large transportation projects such as London's Crossrail and the
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16 Edinburgh Tram Link project, bridges such as the Oresund link between Denmark and
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18 Sweden, energy projects and iconic public architecture such the Burj- Al-arab hotel in Dubai
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20 or Bilbao's Guggenheim museum. Irrespective of their particular form and function, all
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22 megaprojects involve large scale capital investments, a high level of political and public
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24 awareness and visibility and often substantial economic and environmental impact on local
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26 communities (Galloway, 2013). Flyvbjerg (2014) provides the most commonly cited formal
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28 definition of a megaproject as a *“large scale complex venture that typically costs US\$1Billion*
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30 *or more, takes many years to develop, involves multiple public and private stakeholders, is*
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32 *transformational and impacts millions of people”* (Flyvbjerg, 2014,p1).
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34 Mišić & Radujković (2015) describe megaprojects as *“important drivers of society change”*;
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36 a view echoed by (Zidane, Johansen and Ekambaram, 2013) who frame megaprojects as
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38 important landmarks for societies and nations. The potential for megaprojects to effect
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40 considerable societal change is, however, a double- edged sword. Politicians have often been
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42 too quick to seize on the potential of an iconic megaproject as a means of delivering a lasting,
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44 and high profile legacy (Contemporaneous examples of this in the UK alone are the planned
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46 High Speed 2 London-Birmingham Rail-link, the Edinburgh Tram project and the London
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48 2012 Olympics). Flyvbjerg (2014) characterises this temptation as the four sublimes of
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3 megaprojects: The first of these is the *technological* sublime: the excitement and buzz of
4 pushing the boundaries of current technology to create something innovative and spectacular.
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6 Second is the *political* sublime: the joy politicians get from the positive attention given by the
7 media when starting megaprojects, and the enticing prospect of building a political legacy of
8 iconic buildings or transport infrastructure. The third sublime is *economic* and is concerned
9 with the economic benefits and job creation potential of the megaproject, coupled with the
10 delight of engineers, architects, contractors, consultants, bankers, investors and lawyers who
11 can enjoy the benefits of the oversized project budget. Finally, megaprojects enjoy an
12 *aesthetic* sublime: the sheer pleasure of looking at something beautiful or iconic such as the
13 London Shard building. These four sublimes can create a potent and unstoppable wave of
14 enthusiasm for megaprojects amongst politicians, policymakers, project promoters and the
15 public at large; irrespective of the hard truths of the colossal size of the project budget, the
16 numerous, often downplayed risks facing the project and the questionable assumptions on
17 which the project benefits case has been made (see for instance: Flyvbjerg, Bruzelius, &
18 Rothengatter, 2003; Miller & Lessard, 2000; van Marrewijk, Clegg, Pitsis, & Veenswijk,
19 2008)

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39 To date, much of the literature on megaprojects has been case study based, drawing on single
40 or multiple exemplars of past megaprojects to explore and validate new ideas and theories in
41 megaprojects. The extant literature has focussed on the political nature of funding
42 megaprojects (strategic misrepresentation and the principle of the hidden hand) (Flyvbjerg,
43 2014b); front end decision making (optimism bias and the need for reference class
44 forecasting) (Flyvbjerg, 2013; Flyvbjerg et al., 2003; Williams, 2009) the poor performance
45 of megaprojects in terms of cost escalation, delayed delivery and benefits shortfalls (Eweje,
46 Turner and Müller, 2012; Winch, 2013; Boateng, Chen and Ogunlana, 2015; Davies, Gann
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3 and Macaulay, 2017) the risks and challenges facing megaprojects (Priemus, Flyvbjerg and
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5 Wee, 2008; Sanderson, 2012; Irimia-Diéguez, Sanchez-Cazorla and Alfalla-Luque, 2014;
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7 Sanchez-cazorla, Alfalla-luque and Irimia-dieguez, 2017) and the wider consequences to
8
9 society of this class of projects (Müller, 2011). More recent research has applied
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11 organisational theory to explore and explicate current practice in megaproject management.
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13 For example, (Biesenthal *et al.*, 2017) draw on institutional theory to recommend that
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15 megaproject promoters and sponsors devote more effort to getting the institutional
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17 arrangements within the project in place before addressing the technical challenges facing the
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19 project; thereby enabling previously divergent actors, governed by different institutional rules
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21 and logics to collaborate and make sense of the emerging megaproject. Similarly Brookes,
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23 Sage, Dainty, Locatelli, & Whyte (2017) explore the temporal nature of the megaprojects,
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25 arguing that megaprojects often outlast the Special Purpose or Joint Venture organisations
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27 that are created to deliver them.
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31 Other recent research has mapped out the development of megaproject management as a
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33 distinct domain of project management research. Notable recent contributions to this debate
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35 have been attempts to identify the classic texts and papers in the literature on megaprojects
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37 (Flyvbjerg, 2017; Pollack *et al.*, 2017) and bibliometric based analyses of the development of
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39 the megaprojects literature (Li *et al.*, 2017). Both of these streams of research speak of
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41 megaprojects research reaching a ~~tension point~~ crossroads in its genesis; a tipping point
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43 where the scope and aims of the field require rethinking as a prelude to reaching a theoretical
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45 consensus on what megaprojects are and how they might better be structured, governed and
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47 delivered. Li, Lu, Taylor, & Han (2017) end their paper with a call for the megaprojects
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49 research community to pursue more interdisciplinary and multilevel studies, to better
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51 combine theory and practice to address the real-life issues confronting megaprojects and to
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53 update the classic texts to reflect and lead practitioner practices.
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3 Given that the McKinsey Global Institute (McKinsey and Company, 2016) predicts global
4 infrastructure spending of US\$3.4Trillion per year between 2013-2030 mainly implemented
5 through large scale infrastructure projects (Flyvbjerg and Turner, 2017) and that the global
6 megaprojects market is estimated at US\$6-9Trillion per year (Flyvbjerg, 2014a)
7 megaprojects look highly likely to remain central to society: captivating yet costly and
8 controversial in equal measure . The question we now need to address is whether
9 megaprojects are a distinct class of project, requiring different governance and delivery
10 structures from those expected in more conventional projects.
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20 Megaprojects, typically but not exclusively, have a budget greater than US\$1Billion.

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22 However, (Pollack *et al.*, 2017) argue that “*the real mark of a megaproject is the*
23 *organisational complexity, ambiguity, ambition, politicality and risk that are entailed*”
24 (Pollack *et al.*, 2017, p2). Given that many smaller, arguably more conventional projects also
25 exhibit high levels of complexity, uncertainty and are highly political in nature (for example
26 nuclear decommissioning projects), what are the features of megaprojects that distinguish
27 them from more conventional projects? Table 1 draws on the relevant literature to highlight
28 the key features of megaprojects and how they might be differentiated from conventional
29 projects. It confirms the view expressed by Bent Flyvbjerg that “*Megaprojects are a*
30 *completely different breed of project in terms of their level of aspiration, lead times,*
31 *complexity, and stakeholder involvement. Consequently, they are also a very different type of*
32 *project to manage.*” (Flyvbjerg, 2014b, p6)
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48 49 **The UK new nuclear build programme**

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52 There are three planned nuclear new generation projects in the United Kingdom: Hinkley
53 Point C in Somerset, Moorside in West Cumbria and Wylfa Newydd on the Isle of Anglesey.
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Each involves a different consortium of promoters, different reactor design technology and, most likely, different approaches to financing the projects.

Hinkley Point C is a joint UK-French venture which will be part-funded by the Chinese nuclear industry. The power plant, comprising two European Pressurised Reactors (EPRs), is estimated to cost £19.6 Billion (WNN, 2017b) and is expected to be in operation by the end of 2025. The EPR design aims to be safer, more reliable and more fuel efficient than its predecessor. The EPR will work in similar fashion to existing generations of the reactor; EPRs have already been approved for use in the UK, confirming the reactor meets safety requirements.

Hinkley Point C is the most advanced project in terms of planning and construction; the UK government gave its approval to the project on 29th September 2016 following EDF's Final Investment Decision 28th July 2016. Consent for the placement of the structural concrete for the first nuclear safety-related structure at the site was granted in July 2017 and the groundworks and enabling infrastructure are proceeding at pace. (WNN, 2017b)

The Moorside nuclear plant in West Cumbria, will be delivered by Nugen, currently a wholly owned subsidiary of Toshiba. Originally the Moorside site would have comprised 3 AP1000 Pressurised Water Reactors supplied by Westinghouse (Westinghouse Electric Company, 2016). Although Nugen completed its Generic Design Assessment early in 2017 (WNN, 2017a), major financial problems within Westinghouse and its parent company Toshiba led to a major strategic review of the project. In December 2017, Nugen announced that KEPCO (Korean Electrical Power Company) was the new preferred bidder for acquiring Nugen from Toshiba. KEPCO will use their own APR1400 reactor design for Moorside, and work is now underway to secure Generic Design Assessment Approval for this technology (WNN, 2017d). No date has yet been set for either Final Investment Decision or negotiation with the UK government over the strike price at which the plant output will be sold.

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5 The third planned nuclear power plant is Wylfa Newydd on the Isle of Anglesey in North
6 Wales. This plant will comprise two Advanced Boiling Water Reactors (ABWRs). ABWRs
7 are known as “direct cycle reactors” so they pass the steam straight into the turbine from the
8 reactor rather than passing in and out of the steam generator as with the APR1400 and EPR
9 technology (Hitachi, 2014). The Wylfa Newydd plant will be built and operated by Horizon
10 (which is owned by Hitachi with the reactors supplied by Hitachi-GE). The ABWR remains
11 in the regulatory assessment phase, with the earliest construction start date estimated to be
12 2019. (WNN, 2017f). The cost of the Wylfa Newydd project is currently estimated at
13 £20Billion (WNN, 2016). (Saunders, Sherry and Gale, 2016)
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26 **Challenges facing the 3 UK new nuclear build projects**

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29 Table 2 compares the three new nuclear build projects, HPC, Moorside and Wylfa Newydd,
30 in terms of the first 5C’s of Frick’s classification of megaprojects as Colossal, Captivating,
31 Costly, Controversial and Complex (Frick, 2017). This analysis shows that the UK’s new
32 nuclear build programme faces a number of sizeable technical challenges. For instance, the
33 sheer technical complexity of the reactor technology and the differing levels of maturity of
34 each of the three proposed reactor designs, each of which must be assessed and approved by
35 the Office of Nuclear Regulation before final designs can be signed off. Each site also
36 requires extensive enabling infrastructure, from new transport and power connections to large
37 earthworks and vast temporary accommodation blocks. Each piece of the enabling
38 infrastructure must not only be delivered as a stand-alone project, but also contains myriad
39 interfaces to the other enabling works and to the main reactor and turbine design and
40 construction, thereby increasing overall programme complexity and with it the potential for
41 increasing costs and delaying the project. These challenges are compounded by two further
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3 technical obstacles; that of the fragmented and fragile nature of the nuclear supply chain in
4 the UK (Saunders, Gale, & Sherry, 2015) and the need to simultaneously mobilise 1000's of
5 highly-skilled workers across three remote locations in the UK. It is questionable whether
6 sufficient of these skilled resources a) actually exist, and b) are readily available to mobilise
7 onto a new project (typically, experienced complex project practitioners move from one
8 megaproject to the next, e.g. from Heathrow Terminal 5 to London 2012 to CrossRail and
9 now to the Thames Tideway Tunnel (Davies, Gann and Macaulay, 2017). In contrast, the
10 construction phases of HPC, Moorside and Wylfa Newydd will not only overlap, but will be
11 competing for specialist resources with other nuclear life-extension and decommissioning
12 projects that are already underway. Anecdotal evidence from nuclear industry project
13 professionals suggests that the solution to the resource constraints on these megaprojects will
14 be an eventual influx of Chinese nuclear workers, rapidly and expensively mobilised to
15 complete the projects, without allowing the UK to develop its own nuclear skills capability
16 and capacity.

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34 In addition to these technical challenges, Table 2 also demonstrates that many of the issues
35 facing the projects are also institutional, societal and political in nature. The size and
36 complexity of new nuclear build projects demands that they are delivered by multiple parties
37 located in different parts of the globe. This introduces cross-cultural challenges into an
38 already problematic set of complex institutional arrangements between the project promoters,
39 the contractors, investors and the UK government (Biesenthal *et al.*, 2017). This brings into
40 play a huge number of organisational interfaces within the projects, each of which requires
41 governance, contractual and behavioural mechanisms to be established, in parallel with the
42 project definition and design phases.

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54 At the societal and political level, national governments, local authorities and business groups
55 are focused on the economic benefits of the project and the resultant long-term development
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3 of nuclear plants' hinterland. However, the mere mention of the term nuclear tends to be
4 emotive and can lead to differences of opinion within a group of individuals and society as a
5 whole. Opposition to nuclear technology may arise from a particular political persuasion or a
6 deep affiliation to a green agenda. Individuals may have concerns over the safety and security
7 aspects of nuclear and favour renewable forms of energy over nuclear, without necessary
8 fully understanding the finer nuances of energy production economics. It is unfortunate that
9 successive governments (not just in the UK) have had a tendency to downplay the risks
10 associated with megaprojects and overplay the benefits that they deliver (Flyvbjerg, 2014b).
11 This has led to a justifiable public scepticism over the proposed costs and benefits of all
12 megaprojects, not just those in the safety-critical nuclear sector.

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25 The financial issues with nuclear new builds, however, are not just the huge sums of money
26 required up front, but also the many years that need to pass before there is any return of
27 investment. This, as Table 2 shows, means a strike price is necessary to give investors'
28 confidence in the long term financial viability of the project. Indeed the design and
29 construction lifecycle of these nuclear megaprojects spans multiple governmental terms, an
30 issue exacerbated by the UK's decision to serve notice on its membership of the European
31 Union and the associated Euratom treaty which governs all aspects of nuclear cooperation
32 and nuclear material transfers across European Union nations (Roberts, 2017).

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44 45 46 **Lessons for policy makers, promoters and project management professionals involved** 47 48 **in UK new nuclear build projects**

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50 For now, the UK government remains committed to new nuclear as a key part of its energy
51 strategy. Although the future of Moorside is currently uncertain given the change in
52 ownership from Toshiba to KEPCO, the construction of Hinkley Point C is officially
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3 underway and a final investment decision on Wylfa Newydd is expected in 2019 (WNN,
4 2017c). These three plants face myriad technical, institutional, societal and political
5 challenges. The recommendations set out in Table 3 take the lessons from the megaprojects
6 literature, with the aim of helping policy makers, promoters and project management
7 professionals deliver Hinkley Point C, Moorside and Wylfa Newydd, whilst minimising the
8 risk of overspend and delay on these colossal yet controversial projects. These
9 recommendations are again structured around Frick's (2017) 5C's of megaprojects,
10 acknowledging that these categories are not mutually exclusive and that many of the
11 recommendations will address more than one of the 5C's. For example, putting the
12 management of risk at the heart of these projects, will counter the colossal nature of the
13 project, as well as its complexity and cost. And, making project decision making and project
14 data as transparent as possible should minimise the temptation for policy makers and
15 promoters to become over-captivated by the projects and also mitigate inevitable controversy
16 that the project generates.

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33 Whilst the recommendations in Table 3 are grounded in the megaprojects literature and
34 evidence from a large number of past megaprojects – both good and bad – the real challenge
35 facing the UK's and other nuclear new build programmes is to take on board this advice
36 sufficiently early in the projects' scoping and feasibility phases. The reality is that many of
37 the recommendations set out in Table 3 come too late for projects such as Hinkley Point C –
38 which is already underway and which, according to Morris (2016) is a financial, technical,
39 contractual and governance “mess”. It is highly unlikely that the UK government would be
40 prepared or able to begin the procurement process for HPC again, as Morris (2016) suggests,
41 with sunk costs on the project already into the Billions of pounds.

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53 Additionally, there are practical limitations in a number of the recommendations. For
54 example, as Morris (2016) argues, what is the correct reference class to use for the time and
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3 cost forecasting of new nuclear build projects. Past UK nuclear projects were completed
4 decades ago in different times, using different technologies (Taylor, 2016) and worldwide
5 ~~those~~ nuclear power plants currently under construction are invariably running late and over-
6 budget. And, how feasible is it for politicians and policy makers to hold fast to a “wait or do
7 nothing option” as argued by (Davies, Gann and Macaulay, 2017) while energy analysts and
8 commentators warn apocalyptically of the “lights going out in the UK by 2025”. Finally,
9 would any of these vast projects ever pass a final investment decision without a sense of
10 optimism (Flyvbjerg, 2014b) that if we can put a man on the moon and contemplate travelling
11 to Mars then we can surely build a fleet of new nuclear power stations here on Earth.

12
13 The above caveats aside the recommendations provided in Table 3 provide a framework for
14 project scoping, delivery and decision making for worldwide new nuclear power plant
15 construction. At the very least the recommendations provide a set of questions that
16 promoters, policy-makers and project managers involved in these projects would be advised
17 to take heed of. Whilst the die may be cast for Hinkley Point C, Flamanville and Olkiluoto 3,
18 it is not too late for Moorside and Wylfa Newydd and other proposed plants around the globe
19 that are still in the feasibility and scoping stage to learn from the literature and practice of
20 megaprojects as described in this paper.

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INSERT TABLE 3 HERE

Conclusions

This conceptual paper makes contributions to theory and practice in the domain of megaprojects, and specifically to nuclear new build projects. Theoretically the paper reviews the literature on megaprojects and synthesises a set of features of megaprojects that distinguish them from more conventional projects. We argue that megaprojects are simultaneously trait-making, rather than trait-taking, possess a temporality and timescale in

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3 excess of typical infrastructure projects, suffer from high levels of uncertainty and ambiguity,
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5 are organisationally complex, costly and are highly likely to destroy rather than create value.

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7 Secondly, we argue that the challenges facing new nuclear build are not merely technological
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9 but also institutional, political and societal in nature. The nature of these challenges is
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11 exemplified using the three proposed new nuclear build projects in the United Kingdom.

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14 In terms of contributions to practice, we draw on the megaprojects literature and the lessons
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16 from previous megaprojects to proffer recommendations for how the new nuclear build
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18 programmes, both in the UK and in other regions of the world might be structured, planned
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20 and delivered to minimise the risks of failure.

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23 The major limitation in this study is that it is based on a theoretical literature review and
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25 public domain data only. That said, there is no shortage of case study based megaprojects
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27 research which has been used to propose and validate a number of theories of megaprojects.
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29 Indeed, (Li *et al.*, 2017) argues that the field of megaprojects research now requires more
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31 interdisciplinary and multilevel studies and studies that combine theory and practice to
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33 address the real life issues faced by mega projects. This paper contributes to this research
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35 agenda by drawing on both extant megaproject theory and the challenges facing a specific set
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37 of nuclear new build megaprojects, to propose a set of succinct recommendations for
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39 policymakers, promoters and practitioners tasked with delivering these colossal yet
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41 controversial projects.

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46 As such, this paper lays the groundwork for future empirical research into the planning and
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48 delivery of this new generation of new nuclear build projects. A future research agenda, with
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50 proposed research questions might encompass the following areas:

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53 Firstly, interviews with new nuclear build project policy-makers, promoters and project
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55 managers to identify the specific challenges involved in new nuclear build projects and the
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differences and similarities between new nuclear build and other megaprojects. This would validate and extend the findings of this current conceptual paper. Secondly, further empirical
Empirical work is now required to track the three nuclear new build projects, the extent to which they have adopted this set of recommendations and the subsequent performance of the projects. Such empirical studies are likely to be qualitative in nature, and utilise a number of research methods including semi-structured interviews and ethnographic observations.

Finally, the challenges facing the nuclear sector extend beyond the provision of new nuclear power capability. In the UK and across the globe, major nuclear decommissioning works are underway to dismantle, make safe and return former civil nuclear sites to a clean state. Many of these projects have budgets that are in excess of £1Billion, will span a number of decades and involve the same complexities and uncertainties of technology, stakeholders and funding as new nuclear build projects. Further empirical studies that specifically address the under-researched domain of nuclear decommissioning projects would also contribute to our conceptualisation of megaprojects, and to addressing the real life issues faced by nuclear megaprojects over the entire nuclear lifecycle.

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Distinguishing Feature of Megaprojects	Description and contrast with conventional projects	Underpinning studies
Trait-making	Megaprojects seek to change the structure of society, and can impact many thousands and even millions of people. In contrast more conventional projects are trait-taking, i.e., the project fits within existing societal structures and routines	(Hirschman, 1995; Galloway, 2013; Mišić and Radujković, 2015)
Temporality and Timescale	Megaproject design and construction timescales can outlast governments and often the organisational or corporate structures that deliver and manage them. Criteria of success for megaprojects need to include long-term benefits	(Eduardo Yamasaki Sato and De Freitas Chagas Jr, 2014; Biesenthal <i>et al.</i> , 2017; Brookes <i>et al.</i> , 2017)
High levels of risk, uncertainty and ambiguity	Megaproject success criteria can be vague and even misrepresented. Multiple stakeholders can increase ambiguity and uncertainty. Use of untried and novel technologies within highly complex interconnected infrastructure systems can increase risks.	(Priemus, Flyvbjerg and Wee, 2008; Nielsen, Dignum and Reilly, 2013; Irimia-Diéguez, Sanchez-Cazorla and Alfalla-Luque, 2014; Chapman, 2016; Biesenthal <i>et al.</i> , 2017; Li <i>et al.</i> , 2017; Sanchez-cazorla, Alfalla-luque and Irimia-dieguez, 2017)
Organisational Complexity	Megaprojects must bring into alignment a wide diversity of actors, organisations and stakeholders with often conflicting interests and conflicting visions of the megaproject.	(Priemus, Flyvbjerg and Wee, 2008; Zidane, Johansen and Ekambaram, 2013; Biesenthal <i>et al.</i> , 2017; D.C. Invernizzi, Locatelli and Brookes, 2017)
Cost	Huge budgeted costs (generally >\$US1B), require complex financing structures and often guarantees from host governments and/or international finance institutions. Accuracy of cost estimating, cost control and levels of contingency funding is reduced.	(Morris and Hough, 1987; Zhai, Xin and Cheng, 2009; Boateng, Chen and Ogunlana, 2015; Biesenthal <i>et al.</i> , 2017)
High propensity for value destruction	Due to their size, complexity and timescales megaprojects are highly likely to experience huge cost escalation and delayed delivery which can destroy value at the project, promoter, political and even national level. The megaproject may consume limited resources (people, finance, space etc) that might have been better employed elsewhere to generate value.	(Morrow, 1988; Flyvbjerg, Bruzelius and Rothengatter, 2003; Gellert and Lynch, 2003; Eweje, Turner and Müller, 2012)

Table 1: Distinguishing Features of Megaprojects

	Hinkley Point C	Moorside	Wylfa Newydd
Colossal	<ul style="list-style-type: none"> ➤ Plant will generate 7% of the total UK's energy needs (Each reactor will generate 1.6GW of electricity) ➤ Supply chains span Europe and the rest of the world. ➤ Installation of 35,000 supporting arrangements and 10,000 items of mechanical plant (Jones, 2017) ➤ Construction of 760 metre long and 13.5 metre high sea wall to protect the plant from natural disasters (EDF, 2016) ➤ One of largest and riskiest UK infrastructure projects currently underway (Morris, 2016) 	<ul style="list-style-type: none"> ➤ Project claims to be Europe's largest new nuclear project, requiring a 9km railway track for access (Macadam, 2016) ➤ There will be three separate accommodation sites covering over 200 acres, and providing accommodation for up 5000 people and car parking for almost 1500 cars (Whitehaven News, 2016) ➤ It will be one of largest and riskiest UK infrastructure projects 	<ul style="list-style-type: none"> ➤ Wylfa Newydd will provide 5.4 GWe of new capacity to power 10 million homes starting mid 2020's. ➤ Early in 2017 it was announced that Anglesey's old oil depot was the "front runner" to house thousands of Wylfa Newydd construction workers (Wyn-Williams, 2017) ➤ It will be one of largest and riskiest UK infrastructure projects
Captivating	<ul style="list-style-type: none"> ➤ Politically essential to UK government's energy strategy (Department of Business, 2017) ➤ 25,000 new employment opportunities created during construction ➤ Peak employment around 5,600 people ➤ 4 million cubic metres of earth to be excavated –equivalent to 1,300 Olympic swimming pools ➤ 3 million tonnes of concrete required – 75 times more concrete than in Millennium Stadium in Cardiff ➤ 230,000 tonnes of steel reinforcement to be used (EDF, 2016) ➤ The project is seen as the start up for the UK becoming the "global leader" in nuclear energy and is inspiring young engineers and scientists. ➤ Aim is to train 400 apprentices (Macalister, 2014) 	<ul style="list-style-type: none"> ➤ Politically essential to UK government's energy strategy (Department of Business, 2017) ➤ An estimated 6500 jobs will be required during peak construction. ➤ The sites may become permanent features once construction is complete, providing a legacy in the area for the locals. (NuGen, 2016) 	<ul style="list-style-type: none"> ➤ Politically essential to UK government's energy strategy (Department of Business, 2017) ➤ 4000+ jobs to be created during construction with 850 permanent jobs required post construction (Power-Technology, 2017) ➤ Opportunity to provide apprenticeship schemes and attract young engineers to the nuclear industry. ➤ New partnership between Horizon and Exelon towards becoming a "world class nuclear operator" (HorizonNews, 2017)

<p>Costly</p>	<ul style="list-style-type: none"> ➤ Hinkley was given an original £6Billion estimated cost, now estimated at £19.6Billion (Smyth, Lecoeuvre and Vaesken, 2017; WNN, 2017b) ➤ Hinkley Point C's strike price is £92.50/MWh (almost double the current wholesale price of electricity).(Jones, 2017) ➤ Financial impact of likely cost and schedule overruns may bankrupt an already debt laden EDF (Morris, 2016) 	<ul style="list-style-type: none"> ➤ Moorside is estimated to be a £10 billion project, representing the largest private investment project in West Cumbria (NuGen, 2016) ➤ This budget is expected to rise considerably. ➤ A guaranteed strike price has not yet been confirmed, but Nugen's intention is to seek a lower strike price than HPC, with the investment being considered a "long-term vision" (Bounds, 2015) 	<ul style="list-style-type: none"> ➤ Wylfa Newydd is a £14 billion project with hopes of delivering a "fair and acceptable" strike price, below that of Hinkley Point C. (Hughes, 2016) ➤ There is potential for a governmental 30% equity stake in the project, with ministers admitting that taxpayer's money will be required to underpin the project. (Hughes, 2017)
<p>Controversial</p>	<ul style="list-style-type: none"> ➤ Slow progress on project due to Greenpeace opposition and public concerns regarding the cost and long-term viability of the technology coupled with concerns about nuclear safety post Fukushima accident. ➤ Tom Burke, ex government advisor and chairman of the environmental pressure group E3G, argues that the UK's new nuclear builds are "unproven" and believes the UK is following in the footsteps of previous generations nuclear catastrophes. (Jones, 2017) ➤ Critics say that government should be focussing on incentivising wind and other renewables, rather than subsidising new nuclear ➤ Controversy over whether the UK government should trust the French and the Chinese companies to construct this new nuclear power station. (Chu, 2016) 	<ul style="list-style-type: none"> ➤ There are concerns over the tourism legacy in the Lake District as if the point of critical radioactivity is reached (low risk) over half the Lake District would be inaccessible for at least 20 years. ➤ Cumbria Tourist Board do not currently support the project due to fears over a Chernobyl style accident. ➤ However both Cumbria County Council and Guardians of the Lakes National Park hold no objections to the project (Lakestay, 2016) ➤ Campaigners from Radiation Free Lakeland have labelled the project an "intolerable burden" (News&Star, 2017) ➤ There is local concern over the impact of the project on the road and rail networks and the local health care and house prices. Mirehouse inhabitants heavily oppose the new accommodation developments 	<ul style="list-style-type: none"> ➤ Amlwch town council oppose the temporary accommodation camps to be built in the town, preferring to house workers in the former Shell oil depot (Wyn-Williams, 2017). ➤ PAWB (People Against Wylfa B) question the Japanese firm's commitment and ability to deliver this project. ➤ Protestors claim nuclear to be "old fashioned, dangerous and dirty." (Wyn-Williams, 2016)

	<ul style="list-style-type: none"> ➤ Critics say that strike price is bad value in the current market as the wholesale price of energy has collapsed in the last 3 years or so, to around £45 per megawatt hour, as opposed to the £92.50 per megawatt hour strike price for Hinkley units. This potentially equals a controversial cost of up to £30 billion on the UK consumers backs (Chu, 2016) 	<p>comparing them to “ghetto camp[s]”(News&Star, 2016).</p>	
Complex	<ul style="list-style-type: none"> ➤ No EPR is yet in operation anywhere in the world. First reactors at Olkiluoto and Flamanville are hugely over-budget and delayed. HPC reactor design is untried and unproven (Morris, 2016) ➤ The first part of the complex construction process involves civil work and earthworks to prepare the site for construction; a total of 4 million square metres of earth needs to be moved before construction can even begin. In addition to this, 70 miles of engineering and fitted pipe systems are needed for each reactor. It has been said that 60% of the project is to be nuclear construction, the remaining 40% is additional work including the jetty and sea wall as well as drilling tunnels for cooling pipes that will go out to sea (Macalister, 2014). ➤ Huge governance issues on the project in particular the tension between political expediency and professional project management practices (Morris, 2016) 	<ul style="list-style-type: none"> ➤ Alongside the reactor and turbine buildings, support buildings including a substation and a circulating water system will be required. ➤ Earthworks needed for screening and noise reduction. Replacement habitats will also be required and flood plain compensation if necessary. ➤ Surface water, sewer drainage systems and fresh groundwater extraction facility required (NuGen, 2016) ➤ A transport access strategy is required for access to and from site; this strategy will include rail and sea via a marine off-loading facility, extensions to the existing railway line improvements to the local road network (NuGen, 2016) ➤ Requirement for new £2.8 billion, 164km partially underground power line to connect Moorside to the National Grid (WNN, 2017e) 	<ul style="list-style-type: none"> ➤ The development consent order (DCO) is scheduled for submission in 2017 following on from the generic design assessment (GDA) of the ABWR reactors which was submitted in 2014. ➤ Horizon has already conducted soil investigations, traffic and transport surveys and ecological studies on site. ➤ Enabling infrastructure projects are required such as the MOLF (marine off-loading facility), cooling structure, power transmission infrastructure and administration buildings (Power-Technology, 2017) ➤ Project also includes 3 radioactive waste storage buildings providing safe and secure storage for the waste onsite. When the waste can be “repackaged” it will be taken to a radioactive waste disposal facility currently in the planning stage (Kelsey, 2016).

Table 2: Challenges facing UK New Nuclear Build Projects

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Colossal	Captivating	Controversial	Costly	Complex
Allow sufficient time/effort for front end decisions and project scoping activities (provide alternative solutions to problems) (Mišić & Radujković, 2015; Priemus, Flyvbjerg, & Wee, 2008; T. Williams, 2009)	Assess what worked on previous nuclear projects (lessons learnt, site visits, consult experts) (Davies, Gann, & Macaulay, 2017)	Make project data as transparent and visible as possible to avoid contested information. Have a single point of truth for the project. (Klakegg, Williams, & Shiferaw, 2015; Priemus et al., 2008)	Make nuclear funding mechanisms transparent (avoid over-complex/opaque financing structures where possible) (Taylor, 2016)	Organise for the unseen (don't neglect the wait or do nothing option) (Davies et al., 2017) <u>Pay attention to the weakest links in the technology and the organisation – for instance impurities in reactor steel at Flamanville</u> (Ansar, Flyvbjerg, Budzier, & Lunn, 2016)
Establish effective project governance mechanisms (within and cross organisational) (Biesenthal, Clegg, Mahalingam, & Sankaran, 2017; Morris & Geraldi, 2011)	Deploy rigorous and transparent front end decision making.	Devote time/effort to active stakeholder management (Locatelli, Mikic, Kovacevic, Brookes, & Ivanisevic, 2017) <u>Prepare for conflict between "political goal setters and practical [nuclear project] professionals"</u> (Morris, 2016, p18)	Avoid one-size fits all contracts (fixed price more appropriate for low uncertainty areas, target-cost for more uncertain domains) (Davies et al., 2017)	Pay particular attention to the interfaces – technical and organisational. Try to build a project culture that cuts across different institutional or national cultures. (Davies & Mackenzie, 2014)
Implement rigorous project gateway review process (Klakegg et al., 2015)	Use reference class forecasting for costs, timescales, risks and benefits. Interrogate the business case closely.	<u>Organise regular, real and responsive community involvement (Locatelli et al., 2017) Engage early and often with communities close to the</u>	Foster early nuclear contractor involvement and relationship building (Saunders, Gale, & Sherry, 2016)	Where possible reduce technical complexity in the planning stage to reduce the level of uncertainty. (Giezen, 2012)

Field Code Changed

	<p>(Flyvbjerg, 2013). <u>Consider carefully what appropriate reference class for new nuclear build is</u> ((Morris, 2016)</p>	<p><u>new nuclear build</u>(Invernizzi, Locatelli, & Brookes, 2017)</p>		
<p>Set up process for inevitable design changes (whether technical, institutional or political) – Police this process closely. (Flyvbjerg, Bruzelius, & Rothengatter, 2003)</p>	<p>Make every effort to consciously avoid hubris/optimism bias. (Flyvbjerg, 2014)</p>	<p>Keep governmental communications channels wide open and two-way(Morris, 2016).</p>	<p>Generate realistic cost estimates, retain sufficient contingency funds and acknowledge <u>the uncertainties in nuclear projects</u>-rather than hide/ignore <u>them</u>it. (Flyvbjerg et al., 2003; Klakegg et al., 2015; Saunders, Sherry, & Gale, 2016)</p>	<p>Promote increasing professionalism of project organisations (Klakegg et al., 2015)</p>
<p>Establish and maintain good risk management discipline (covering design, construction, operation, labour, legal, political, contractual, financial and economic risks) (Brookes, Sage, Dainty, Locatelli, & Whyte, 2017; Sanchez-cazorla, Alfalla-luque, & Irimia-dieguez, 2017)</p>	<p>Consider new nuclear build as a portfolio of projects at governmental level (phase activities where possible to limit strain of resources)</p>			<p>Reduce reliance on bespoke <u>nuclear</u> solutions – use scalable/modular solutions and test/pilot new technology off site first. (Ansar et al., 2016; Davies et al., 2017)</p>

Table 23: Recommendations for policy makers, promoters and project managers for new nuclear build projects

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