IRREVERSIBLE NUCLEAR DISARMAMENT

UNIVERSITY of York

Illuminating the 'UK Nuclear Complex'

Implications of hidden links between military and civil nuclear activities for replacing negative with positive irreversibilities around nuclear technologies

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York IND Research Report#2

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Cover photo: Construction of the Hinkley Point C nuclear reactor, Somerset, UK.

Executive Summary

This report is for a project commissioned by the UK Foreign, Commonwealth and Development Office and coordinated by Dr Nick Ritchie at the University of York. The project examines the reversibility of UK commitments to questionable security strategies based around nuclear weapons. It also explores the more general irreversibility of wider steps towards nuclear disarmament in the event that these were to occur. The report was prepared for a workshop involving senior figures concerned with the steering of UK government policy around both military and civil nuclear technologies.

The report undertakes three main tasks:

1. First it analyses (as requested by the project), a range of different theoretical approaches in political science, the history of technology, innovation studies and sociology concerning how *technologies routinely obsolesce and so can become 'reversed' and effectively 'uninvented'.*
2. Second, it summarises the history of the development of military and civil nuclear technologies in the UK against the backdrop of world events – *attending equally in this to issues unfolding around nuclear weapons, submarine propulsion and civil nuclear power*.
3. Third, it undertakes an initial pioneering study of an important feature of the UK national economy that has hitherto been remarkably neglected: concerning overall flows of money, justification and other resources that deeply interlink supposedly separate civilian and military nuclear activities.

It is on the basis of these three elements that the report draws conclusions concerning general questions of *reversibility in nuclear technologies on both civil and military sides – as well as on implications for current energy, climate and security strategies and the wider UK economy.*

First, contrary to assertions by prevailing powerful vested interests, the report shows how *prospects for reversal in nuclear technologies are both historically routine and can be prospectively realistic – if such futures were to be collectively pursued.* These possibilities for alternative security and energy strategies can best be understood (and arguably achieved) by looking beyond narrow ideas of 'socio-technical systems' to think about how wider structures of power and privilege work in technology.

Second, the report documents the deep and intimate interlinkages between civil and military nuclear infrastructures in the UK – illuminating how these technologies form in this country (as more widely around the world) a single 'nuclear complex'. Dependencies run deeper than just flows of special nuclear materials – to include distinctive skills, supply chains, industrial capabilities, educational provision, research facilities, regulatory capacities and career incentives. *Commitments to supporting* *these nuclear-specific capabilities hold significant implications – and pose important but under-explored opportunity costs – for pursuit of alternative energy and security strategies in the UK.*

Until recently being urged by critical research to acknowledge these deep links, the UK has lagged far behind other democratic governments in admitting how they shape wider military strategies and climate/energy policies – and in providing transparency over impacts on the economy at large.

Third, the report navigates remarkable levels of official secrecy, obfuscation and obstruction, to provide an initial comprehensive estimate of the flows of money, justification and cultural attachment that keep the combined civil-military 'UK nuclear complex' in operation. In short (even under highly conservative assumptions), hitherto uncounted additional costs to the national economy (beyond stated budgets) of maintaining this UK nuclear complex (rather than adopting alternative security and energy strategies) amount to at least – likely well in excess of – five billion pounds per year.

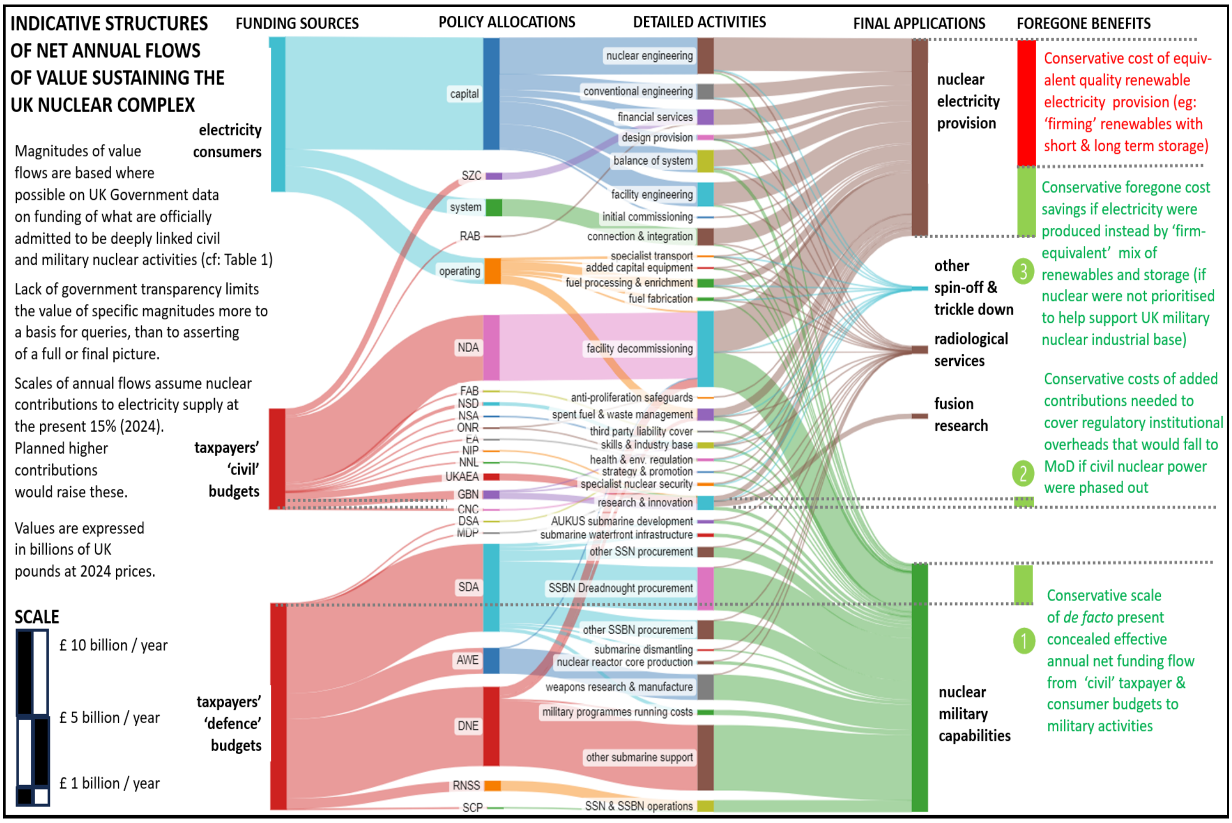
This latter provisional picture of additional costs is summarised in the infographic presented below. These avoidable extra nuclear burdens falling on UK electricity consumers and taxpayers arise from:

> *(1) requiring electricity consumers to purchase nuclear power rather than pursuing fully alternative zero carbon energy services offering superior levels of quality at lower costs;*
>
> *(2) covertly transferring revenues from supposedly 'civil' taxpayer and consumer budgets to cover costs of military nuclear activities that fall outside existing levels of defence spending;*
>
> *(3) committing the UK to support an expensive array of nuclear-specific policy, regulatory, research and industrial bodies that are unnecessary for non-nuclear strategies, but around which commitments can impede more productive jobs and investments in other sectors.*

The report concludes that reversal of commitments to nuclear technologies in the UK (as more widely) might be seen as a routine – indeed inevitable – consequence of the jointly emerging obsolescence on both the civil and military sides. In both areas, alternative challenges and options are increasingly eclipsing traditional forms of justification for nuclear-based strategies. Whilst diverse political perspectives certainly remain valid and legitimate, it is clear that rational and robust national policy making across these crucial policy domains is currently seriously curtailed in the UK by a lack of rigorous and accountable comparisons between alternative ways forward. In particular, deeply entrenched interests associated with the UK nuclear complex are – as with all previously obsolescing technologies – evidently currently actively resisting due consideration for alternatives.

The crucial – previously seriously neglected – questions addressed in this report apply equally strongly, irrespective of positions taken either for or against civil or military nuclear technologies.

Across all views, it is a matter equally of rigour and common-sense in policy making, as well as the quality of UK democracy, that these issues and possibilities be openly and thoroughly discussed.



1. EMERGING VIEWS OF 'LARGE TECHNOLOGICAL SYSTEMS' AROUND NUCLEAR TECHNOLOGIES

This report has been produced for a project commissioned by the UK Foreign, Commonwealth and Development Office and coordinated by Dr Nick Ritchie at the University of York. The project as a whole examines the reversibility of UK commitments to questionable security strategies based around nuclear weapons. It also explores the more general irreversibility of wider steps towards nuclear disarmament, in the event that these were to occur. The report is prepared for a workshop which will involve senior figures concerned with the steering of UK government policy around both military and civil nuclear technologies. Two central questions lie at the heart of this project [1].

(A) How '*reversible*' are current UK commitments to national nuclear weapons capabilities and the associated sociotechnical system? This is about possibilities for UK nuclear disarmament.

(B) How '*irreversible*' would such a UK nuclear disarmament process be, given dynamics of the wider civil/military nuclear complex within which this 'nuclear weapons system' is nested? This is about mutually reinforcing interlinkages between different kinds of nuclear activity.

These crucial issues of reversibility in current attachments to nuclear weapons and countervailing prospective moves towards nuclear disarmament have recently been very insightfully and usefully explored [2] using concepts of 'large technical' [3] [4] and 'sociotechnical' systems [5]. Analysing associated possibilities with this sociotechnical lens can help illuminate scientific, technological, economic, political and cultural factors driving strong forces of 'path dependence' [6], 'lock in' [7], entrenchment [8] and entrapment [9]. It is these powerful dynamics – not historical inevitability [10] – which help shape the currently prevalent 'spectrum of irreversibility' [2] around nuclear weapons. As in many preceding histories of technological obsolescence [11] and decline [12], it is these forces that must be reversed if meaningful nuclear disarmament is to be achieved in a feasible, just and peaceful fashion [13].

In recent years 'sociotechnical transitions' [14] perspectives have developed what were formerly sometimes slightly mechanistic 'systems' notions into more sociologically, politically and economically sophisticated *institutional* forms around 'sociotechnical regimes' [15]. From this, a variety of more detailed and nuanced ideas have developed around the unmaking [16], destabilising [17], exnovating [18], phasing out [19], disrupting [20], withdrawal [21] and discontinuing [22,23] of variously-characterised 'systems' or 'regimes'. Key insights arise concerning multiple factors that may potentially weaken this military 'nuclear lock-in' [24], helping to open 'windows of opportunity' [25] for deliberate policy and wider political interventions seeking to supersede what is conventionally identified as 'the nuclear weapons system' [26] or 'regime' [27].

While recognising the usefulness of these perspectives, our own more relational 'sociomaterial' approach [28] emerges from trying to navigate analytic difficulties that arise in this field from unduly taken-for-granted assumptions about pre-defined notions of 'systems' or 'regimes' [29]. In such conventional categorical views, much depends on what remains under-interrogated in constituting and bounding the sometimes idealised constructs in focus [30]. For instance, sociotechnical systems analysis typically concentrates attention on dimensions that are considered 'internal' to 'the system' [31]. Essentially the same characteristic can be identified with regard to 'regimes' [32]. This may inadvertently lead to relative neglect for formative factors acting from *outside* this focus.

So, mainstream approaches can often tend to address their envisaged sociotechnical systems or regimes primarily in terms of the social functions they are claimed to fulfil (like provision of energy, food, or mobility services) [33]. Where it is nuclear technologies that are in focus, two primary functions are relatively distinct from each other and from other kinds of societal purpose – security (notionally through projected threat of mass destruction) [34] and energy (through the releasing the intoxicating concentrated power of forces bound up in atomic nuclei) [35]. Whatever field they are applied to, such functional approaches can treat what is held to count as 'the system' with *"misplaced concreteness"* [36] – taking constituting elements, dimensions, structures and boundaries somewhat at face value. Despite protestations otherwise [37], such a style can also impair attention to more messy, complex, ambiguous or distributed formative factors that incumbent interests around the configurations in focus may find it expedient to conceal [38]. Examples here might include cross-cutting flows of resources, money, authority, power, influence, justification, privilege or other factors that transcend the notional boundaries of the system or regime in question [39].

The automobile, for instance, is seen in a 'systems view' mainly as a means to deliver the notionally clear-cut function of mobility [40]. Yet it is well known by advertisers incentivised to harness more deeply-embedded realities, that this sociomaterial configuration is also strongly oriented towards mediating the performance of social standing [41]. When cars are being sold, as much reference is typically made to identity affirmation and status envy as to mobility [42]. The deeper and more pervasive the rooting of any given sociomaterial configuration in underlying formations of politics and culture, the more serious can be this neglect for crucial constituting features that are under-represented in routine policy categories [43].

With nuclear weapons infrastructures arguably especially deeply rooted in contemporary geopolitical orders [44] – and the wider *'infraculture'* [45] of colonial modernity more generally [46] – these are weaknesses in systems and regime approaches, which (despite other strengths) are particularly salient in this field [47]. Assumptions around the social functions of particular sociotechnical systems has also meant that historical case studies of sociotechnical transitions [17] have neglected roles played by the military and war, that can fundamentally shape and imprint on ostensibly 'civil' systems rather than merely 'accelerating' or 'destabilising' them [48–50].

Other sometimes unduly neglected presumptions in thinking about sociotechnical systems or regimes, reflect influence of engineering ideas in innovation studies [51]. In envisaging temporalities of system change, for instance, it is often taken for granted that paths [52] pursued in historic developments will broadly follow set-piece categorical forms like logistical 'S curves' [53] or 'ballistic' [54] 'trajectories' [55], running relatively smoothly from 'niche creation' [56], through 'diffusion' [57] to 'regime formation' [58]. Despite lessons taught by manifestly more complex and unruly history [59], it is rather rare that more messy undulating modalities of change are even imagined as possibilities [29], let alone addressed. Reinforced by the policy expediency of simplicity [60], a core constituting commitment in colonial modernity [61] that technology will simply *"go forward"* in this way, can make even the possibility – and very meaning – of reversal more difficult to imagine [62,63 64].

On relatively rare occasions where it is acknowledged that real world dynamics of technology change at least imply a potential for reversal [65], emphasis still often lies in straightforward, presumptively regular, 'waves' [66] or 'life cycles' [67]. These again tend to be imagined in simple categorical stages, for instance from 'emergence' to 'decline' [68] – typically *reductively* envisaging reversal more in terms of circumscribed components of a system, than of more *holistic* dynamics across the total social, cultural and political-economic '*milieu*' [69] in which all regimes are set and conditioned [70]. This is especially so, where 'the system' is tacitly identified to be effectively synonymous with the presumptively constant function by which it is defined, whose material necessity reinforces notions of irreversibility. For as long as 'security' can be imagined to persist as a human need, then, such conventional imaginaries further impede the possibility of reversing the current prevalence of nuclear weapons.

This is where a more broadly and deeply relational 'sociomaterial' approach may become practical [28]. This expands attention from categorically-defined technological, institutional or functional systems/regimes and extends it to configurations that pervade an entire encompassing milieu – for instance of contemporary colonial modernity [61]. With change envisaged in this way more like the complex recombining patterns of a kaleidoscope [71] or kaleidocycle [72], a richer diversity of temporalities can be imagined than set-piece trajectories or waves [29]. Beyond the boundaries of specific industries, infrastructures or economic missions [73], this expands the scope to address wider relations of dependency and interaction permeating entire societies, economies and cultures as a whole [74]. What then comes to the fore are typically less explicit formative pressures arising in general structures and flows of power or privilege that conventional policy analysis may find it difficult fully to acknowledge, let alone engage with.

A sociomaterial approach thus avoids treating powerfully-favoured technologies and related institutions as if these were internal to some given bounded system that is historically hardwired or synonymous with delivery of crucial functions. Resisting pressures to treat change processes in such domesticated *policy* terms, this acknowledgement of more complex, pervasive and unruly dynamics recognises inherently more expansive *political* dimensions of sociomaterial reversibility – opening up possibilities to engage broader and deeper material dynamics, political motivations, historical understandings and cultural values. Perhaps most importantly, a grasp can be gained, on how the articulation of knowledge necessary for transformative action is not just about *'speaking truth to power'*[75], but also about how *'power shapes truth'*[76] – resisting how understandings even of strongly motivated critics can sometimes inadvertently be restricted in envisaging possible kinds of change [39].

In this way, for instance, relations between nuclear weapons capabilities and plural notions of human security can become more open to deeper kinds of questioning [77]. Whose security? What kind of security? According to whom? With what confidence? Under what circumstances and assumptions? Incurring which implications? Alongside erasures of these kinds of questions and their associated reasons, powerful hegemonic pressures shape truth in a number of other ways that reproduce the constituting storylines of encompassing colonial modernity. For instance, it becomes routinely alleged in favour of the reversibility of massive global military nuclear infrastructures – as if it were self evident – that *"the bomb can't be uninvented"*[78]. Notwithstanding the many associated complexities [79], this strikingly ignores the manifest fact as seen from nearly any view, that uninvention of politically and culturally (as well as technologically) obsolescing innovations has – since (for example) the stone axe, armoured knight or crucifix – been almost as much a norm, as the invention of new ones [80] [81].

Each in their day, ancient imperial 'pacification' [82], early feudal baronial 'protection' [83], high medieval 'noblesse oblige' [84] and supposed 'civilising' missions of European colonialism [85] all conditioned then-prevailing notions of 'security' [86]. Accordingly, it can readily be seen from many perspectives, how entrenched imaginaries broadly bearing on security, have in the past been circumscribed, impaired and expediently subverted by wider prevailing hegemonic structures of power and privilege operating at the time [87]. In such ways, what is obscured in the present can be more clear in the light of history. So, a broader and deeper sociomaterial understanding attempted here, may help with struggles against contemporary nuclear-based hegemonies of security. This may help more diverse potential *socialities* [88] and *materialities* [89] to be imagined, perhaps helping to open up [90] more fundamentally alternative possibilities for future unfoldings of history [91]. For a configuration that is as culturally and politically embedded as that around nuclear weapons, such approaches may offer particular benefits [92].

How this might be, can be illustrated by considering specific ways in which the notionally irreversible status of nuclear weapons technologies accrues legitimacy [93]. At both national and global levels, strongly asserted storylines frame highly specific nuclear infrastructures as if these were effectively synonymous with maintenance of more general functions of 'national security' [94] or a stable 'world order' [95]. Distinctive long-run security threats that even proponents must acknowledge to be posed by nuclear weapons technologies [96] – including to the polities who wield (and thus provoke) them [97] – make this idealised conflation self-evidently questionable across differing political perspectives [98].

In this way, the imaginations of even the most 'independent' analysts can be imprinted and bounded with ideas that 'the system' (whilst it may be objectionable) is somehow effectively synonymous with its stated purpose (rather than being contingently imposed) [99]. Even self-styled sceptics can thus find themselves obstructed by a degree of fatalism or even despair that *"there is no alternative"* [33]. So prospects for nuclear disarmament can become attenuated merely to incremental nuclear arms reduction [100] or anti-proliferation[101]. This is further reinforced where the historical, political and normative scope of relevant understandings are restricted in notions that 'the system' should be subject only to conventional evidence-based policy making – on the basis of analysis that is itself conditioned by the same limiting imaginations [102]. For instance, much security-related policy appraisal in nuclear weapons states fails even to contemplate the possibility of non-nuclear weapons security strategies, let alone systematically compare them [103]. Building on insights of sociotechnical approaches, it is these constrictions that a sociomaterial approach tries to help open up.

In the second section that follows, this report will first scrutinise in this broader light the detailed ways in which the unfolding UK 'nuclear weapons system' has historically been far more embedded than is typically recognised, in a broader physical, technological, political and cultural (i.e., sociomaterial) context. On this basis, the third section will attempt (in the face of severely constrained availability of information) a provisional sketch of the sociomaterial entanglements of supposedly separate 'civil' and 'military' nuclear activities in the UK – as exemplified in annual flows of resources through both public and market institutions. With prior constraints thus removed from analysis about what constitutes 'the system' in this setting, the picture that results is one of deep entrenchment of military interests in crucial wider fields of politics including foreign policy, energy security and climate action. The practical political implications are profound, both for these wider affected domains as well as for understandings concerning routinely assumed (and claimed) qualities of UK democracy.

2. GENERAL HISTORICAL INTERLINKAGES BETWEEN CIVIL AND MILITARY UK NUCLEAR ACTIVITIES

It is well established in wider literatures [104], that the historically-entrenched, currently-globalising political milieu in which nuclear technologies have so formatively developed, is distinctively characterised by the ubiquitous prevalence of imaginaries of control [105]. Encompassing different kinds of totalitarian communism and fascism as much as state and market capitalism, this formation is notably bigger than anything that 'policy making' is conventionally supposed to address. Thereby strikingly un-named as a focus – even where the ostensible policy aims are about 'transformation', this pervasive political-economic-cultural formation is perhaps best identified as 'colonial modernity' [61]. Whatever it is called, it is a notable feature of nuclear technologies of all kinds, that they arguably 'crystallise' [106] even more than any other area of contemporary culture, the metastasized imaginations of control that are arguably so centrally constituting of this contemporary globalising formation [107].

The point here is not that civil or military nuclear technologies actually do enable machine-like control over their respective energy or security challenges, but that the distinctive constituting infraculture [45] of colonial modernity persistently urges that this be imagined [108], even where such a view is repeatedly refuted by events. Across a variety of fields initially extending well beyond just military or energy applications, then, *'controlling the atom'* [109] has thereby been asserted as an imperative in its own right, spanning a diverse array of political aims [110] [111]. Even before consideration for material or societal efficacy, the prestige associated with credible claims to wield this power, have long led prowess in nuclear science and innovation to be treated as a symbolic of national status on the world stage [112].

The allure of such a proxy for global status is especially strong for national identities challenged by imperial decline [113]. As Ernest Bevin said of UK atom bomb aspirations in 1946, *"We've got to have this thing over here whatever it costs [and] we've got to have the bloody Union Jack on top of it"* [114] As Winston Churchill reportedly said when informed of the huge burdens that nuclear commitments would place on the country "[w]*e must do it. It's the price we pay to sit at the top table"* [115]. Right up to the present, this is a key reason why ministers can express such irrationally-unqualified sentiments as *"investing in nuclear is what this Government is all about for the next twenty years"* [116] or that *"there is no limit to how much new nuclear capacity the Conservative Party is prepared to build in the UK"* [117]. In any other field, treating a tool as if it were a self-evident end in itself would be recognised as irrational. It is arguably the 'missing mass' of colonial modern aspirations to superior status through assertions of imagined control, that helps stabilise this manifest fallacy of confusing means and ends in the nuclear field [46].

Entangled with these colonial modern fantasies, identities and national pride, more granular material interlinkages between civil and military applications of nuclear technology are a more complex matter [118]. These links have been widely recognised since the earliest pioneering efforts in nuclear science and technology [119], but the manner and degree to which they can be acknowledged in public are seriously constrained by geopolitical etiquettes [120] and international law [121]. For instance, with the UK being signatory to the 1967 Nuclear Non-Proliferation Treaty, the wider norms (if not codified law) around provisions concerning separation of civil and military activities make it highly sensitive to acknowledge any kind of link [122]. Idealised notions of 'law' may be acknowledged as a thin veneer cloaking underlying political realities, but 'civilising effects of hypocrisy' can still be recognised [123], in which there is a strong realpolitik in compliance with international norms. So, military pressures to maintain 'national nuclear capabilities' remain strong, but as the number of state signatories grows behind global moves to make nuclear weapons themselves illegal [124], the stigma attached to these terrorising rationales becomes ever more intense [125]. Perhaps most crucially, as resulting hostilities inevitably arise, the practical efficacy of any resulting imagined 'security' also steadily diminishes [126].

Nonetheless, a succession of twentieth century worldwide conflicts long helped ensure that military applications formed (albeit often covertly [127]) the strongest drivers of seminal research and innovation across the nuclear field in general [128129]. In the UK in particular, general underlying civil/military interlinkages are a pronounced feature of nuclear history as told from many sides [130 131]. Accordingly, despite diplomatic inhibitions, British official enthusiasm for nuclear technology has historically been as clear around military as ostensibly civilian applications [104]. Accordingly the 'dual use' [132] potential of these technologies has always been emphasised on many sides. This interconnected military/civil relevance is as intrinsic to early aspirations of nuclear proponents [133] around 'nuclear ploughshares' [134], as to the positions of nuclear critics over the years concerned about military ambitions concealed behind ostensibly civilian nuclear initiatives [135,136].

The most obvious aspect of this 'dual use' potential, lies in the unprecedented explosive power of fissile and fusile materials [137]. General civil/military nuclear linkages are further intensified, in that broadly related, but very distinctive, nuclear capabilities to produce electricity in highly concentrated ways are also regarded as crucial across a number of other military functions [138]. For instance, nuclear power has (despite its acknowledged relatively great expense [139]) come to be seen as a key means for naval propulsion [140], especially for the ballistic missile submarines that form the most strategically-favoured platforms for nuclear-armed ballistic missiles deployed by the most powerful nuclear-armed states (USA, Russia, China, UK and France) [141]. Indeed, so strong are these military preferences for nuclear electric naval propulsion [142], that they are recognised to have formed a major driver of early lock-in affecting not only military nuclear reactors, but also civilian designs [143].

As long ago as the 1940s [144], it was the especially high power density (and thus compactness) of light water reactor cores [145] that helped underpin selection of this type of reactor for naval propulsion [143]. Starting in the US, early nuclear investments in research, education, training, materials, regulatory, supply and career infrastructures became prioritised around particular configurations and materials necessary for military light water reactors [143]. From then on, cumulative effects of this specialised 'sunk investment' evidently helped shape the competitive position of light water designs on the civilian side as well. The result has been a largely military-driven lock-in to light water reactors that spans both sectors [143]. This is significant, because it is partly the high power density of light water designs that is often observed to help exacerbate problems for civilian applications [146]. Being relatively unforgiving in many accident scenarios, the high power density of light water reactors needs (all else being equal) more expensive safety engineering [147].

In the UK, a major milestone in this process of lock-in, was the acquisition in the early 1960s of US naval nuclear reactor technologies for use in the first British nuclear 'fleet' submarine *Dreadnought* [148]. With British 'Magnox' reactors designed (like Chernobyl-style Soviet RBMK designs [149]) largely around on-load refuelling to enable plutonium production for weapons [150], older British gas-graphite power reactors had also originally been optimised for this different military purpose. But with military demand on this count largely already addressed by the 1970s, new military priorities attached to submarine platforms for these weapons evidently helped shift the UK from one kind of military-driven civil nuclear lock-in to another. With British stockpiles of nuclear weapons materials relatively secured by the 1970s [151] and existing gas-graphite designs then recognised as uncompetitive in civilian markets [152], the developing naval reliance on light water reactors [153] helped lead the UK momentously to shift to this latter design also in the civil sector in the 1980s [154].

So, in the UK as elsewhere, it is arguable that 'spin off' conditioned by military pressures for the high power density of light water reactors helped to 'imprint' energy policy [49,155], aiding entrenchment of civilian reactors around particular designs that have been manifestly less effective than others might have been under similar development support, for the purpose of safe, cost-effective commercial power production [129] .

Also integrating civilian and military applications of nuclear science and technology in the UK are a range of longstanding large scale nuclear infrastructure and policy visions [156]. For instance, one internationally iconic family of concepts going back almost as far as nuclear activities of all kinds, are ideas about the "nuclear fuel cycle" [157]. Across various forms of this vision [158], a distinctive picture of nuclear technologies was strongly asserted in the past, holding that – uniquely among energy infrastructures– nuclear power might be used not only to generate electrical power, but also to produce its own primary energy feedstocks [159]. In principle this has (inaccurately [111]) sometimes been asserted to promise 'limitless energy' [160]. Less widely proclaimed openly – but at least equally formative in international affairs – is the fact that technological capabilities required to achieve this ostensibly civilian end, are also highly useful for producing nuclear weapons materials [161]. In hindsight, it is now widely accepted even by proponents of nuclear power, that this past strong commitment on the part of successive UK governments of different parties to the reprocessing of civilian nuclear fuels, was to a significant extent reflective of pressures to produce fissile explosives for weapons [161].

Among the distinctive militarily-valued capabilities for these ambitions to 'close the fuel cycle' [162], were 'fast reactors' [163] and 'nuclear fuel reprocessing plants" [164]. With a challenging – and even more extremely expensive – mix of plutonium fuels and potentially explosive liquid metal coolants [165], fast reactor variants could also be used to 'breed' [166] (as well as consume) fissile materials for power production (and potentially for military purposes [167]). Again at far greater expense than required in more routine 'once through' nuclear fuel management [168], 'reprocessing plants' enabled the recovery of these militarily useful materials from irradiated fuels of many kinds [169]. However as the 1970s and 1980s unfolded, economic difficulties were added to by concerns about enhanced waste volumes [170] and aggravated environmental and safety risks [171] attached to this 'plutonium economy' [172].

Especially in the US (a large enough economic power to maintain a virtually entirely separate military fissile material production system [173]), international momentum behind the 'nuclear fuel cycle' began to be seen in the 1970s as a growing driver of horizontal nuclear proliferation [174]. The fear in Washington was that spurious legitimation was being provided to nations less favoured in US strategy, by states like the UK and France wishing to integrate their civilian and military nuclear infrastructures in order to reduce necessity for the even greater expense of dedicated military fissile material production facilities [175]. So, US diplomatic pressures added through the 1980s to growing technical, economic, environmental and wider political difficulties around reprocessing and fast reactors [156]. Having prided itself on being a world leader in these extremely expensive technologies [176] the UK began to close its investments in this field in the 1990s [177] and shelve plans for further development [178]. Ending an era whose extraordinarily negative long run economic legacy remains strikingly under-interrogated, the final residual form of claimed 'commercial' British reprocessing came to an end at the renamed Sellafield plant in 2022 [179].

This history of strong civil/military interlinkages impacting on major nuclear infrastructure choices with large scale economic, safety, environmental and wider political implications is recognised across a diverse range of academic and more widely independent commentaries [127,133,180–183]. Yet the formal public position of successive UK Governments of contrasting political persuasions has persistently insisted that national infrastructures for civilian nuclear power production are effectively entirely separate from those required to sustain military nuclear capabilities. For instance, in response to an article that highlighted the present authors research on the linkages between the UK's civil and military programme a civil servant from the Department of Business, Energy and Industrial Strategy (BEIS) stated that "*The civil nuclear sector is separate from the defence nuclear programme, and any suggestions otherwise are simply untrue*"[122]. It is especially remarkable that this official position has been maintained in such unqualified ways over so many years, because incontrovertible evidence to the contrary is now accepted even by governmental bodies [184]. As a result, it is a significant factor in gauging present continuing claims about the supposed separation of the two sectors – especially in international policy arenas – that past UK Government statements to this effect can now be recognised as manifestly false [185].

For instance, it was prominently officially claimed throughout the Magnox reactor programme of the 1960s right up to the 1980s, that the UK civilian power industry was not involved in any way in assisting the production of fissile materials for military nuclear purposes [186]. Authoritatively substantiated refutations of these claims were repeatedly outright denied. Yet it became widely known in the 1980s [118] – and officially accepted by the 1990s – that particular ostensibly civilian Magnox stations were specifically operated in such ways as to optimise the isotopic profiles of fissile plutonium for reprocessing from irradiated fuel at the Windscale plant (as it was then named) in order to supply materials for UK nuclear weapons production.

A major shift of context occurred to these historic dynamics in links between civil and military nuclear activities in the aftermath of the dissolution of the Soviet Union in 1991. Institutionalised in a series of strategic arms reduction treaties [187], associated perceptions of 'the end of the Cold War' led to significant reductions in superpower nuclear weapons stockpiles [188]. Correspondingly diminished pressures on the size of the UK nuclear arsenal reduced requirements for inputs of fissile materials to weapons production [189] including civilian nuclear electricity production, began to be recognised as sufficient for foreseeable needs [190]. So, hitherto strong material interlinkages between civilian and military aspects of UK nuclear activities began to decline in importance – with the pinchpoint shifting between fissile and fusile nuclear explosives from plutonium to tritium [191]. From the 1980s, the UK obtained its tritium supply from the 'civil' nuclear reactors at Chapelcross [192] however this plant ceased operations in 2004. Since then (although obscured by secrecy), it is thought likely that the UK obtains its tritium from the USA under the Mutual Defence Agreement [193] where it is also produced in 'civil' nuclear reactors [191].

In the UK as elsewhere, the 'nuclear peace dividend' [194] at first seemed to give an impression that the long falsely-claimed separation between civil and military might be taken more seriously. But as time went by through the 1990s and into the 2000s, various factors slowly revealed the continuing importance of the particular civil/military dependencies beyond the flows of special nuclear materials . This new set of dependencies were embedded instead in highly distinctive nuclear-specialised scientific knowledge, research capacities, engineering skills, design capabilities, supply chains, manufacturing facilities and regulatory infrastructures distinctively necessary for naval nuclear propulsion [195–197]. Accordingly (in the UK as elsewhere [198], light water reactor designs remain prominent even among current 'fourth generation' and 'small modular' nuclear reactor concepts [194]. But, although often downplayed in the public domain, this imprint of military priorities on the shape of civilian industry is also reflected behind the scenes in wider contemporary reactor designs. For instance, emerging military uses for powering space-based radars [199] or directed energy weapons [200] are among key drivers of currently burgeoning new concepts around compact 'solid state' [201] and 'micro scale' reactors [200].

So, a growing body of work is documenting the detailed effects on UK civil nuclear policy, of these military pressures to maintain a national military 'nuclear industrial base' [201]. In short, the rapidly declining competitiveness over the past twenty years of civil nuclear power compared with other low carbon alternatives (like renewable energy [202] and storage technologies [203]) has increasingly highlighted the importance of this kind of civil / military nuclear connection. Despite especially strong efforts in the UK to conceal their implications for government policy and public expenditure [204], these intimately shared 'industrial interdependencies' between civil and military nuclear activities are becoming obvious as an even more important connection than the historically better-known 'material links' [153]. The fact that these industrial dependencies previously remained unduly neglected in academic policy and even critical commentary, led them to be so virtually invisible in policy debates by the early 2000s, that even the UK Government itself evidently effectively forgot about them [205].

Although not noticed in public at the time, however, UK Government recognition for these industrial interdependencies did begin to properly dawn in 2005. It had previously already become recognised in military circles, that procurement of nuclear propelled submarines needs to maintain a steady 'drumbeat' in order to maintain in operation between submarine manufacturing orders, a hugely costly national 'submarine industrial base' [206,207]. It is for this reason that the UK was forced to forego alternative far cheaper options for 'SSN' attack submarines that do not necessarily require nuclear propulsion [208], in order to maintain its committed fleet of four 'SSBN' ballistic missile boats, for which nuclear propulsion was judged – uniquely – to be a strategic necessity [90]. In this way as in others, 'lock in' around nuclear weapons had already exported huge expenses to other areas of military activity [209]. What was first privately recognised by government in 2005, was that these wider economic impacts of commitments to nuclear weapons capabilities also extend to civilian industry.

With the continued existence of a national civil nuclear industry simply taken for granted up to then, the unprecedentedly detailed, comprehensive and high quality Energy White Paper of 2003 ushered in a sea change [210]. This analysis substantiated in detail that has also been unsurpassed since, that nuclear power had become an *"unattractive"* contributor to UK energy strategy. Previously unsuspected by an elite mindset that nuclear technologies are somehow self-evidently superior, this for the first time opened the prospect that the UK might be on a path towards entirely withdrawing from its civil nuclear commitments [211]. As only became public later, a major 2005 report to the MoD from the RAND Corporation [212] was followed by a "secret process" [213] through 2006 that led Prime Minister Blair to undergo a remarkable policy u-turn, reversing the earlier white paper and announcing in 2007 that *"nuclear is back with a vengeance"* [214]. Strikingly (albeit not publicly noted at the time), this defiant slogan from the top of government highlighted the name of the most recently commissioned of the UK's nuclear-propelled ballistic missile submarines. Since then, the same broad military pressures evidently drove persistent efforts over the past two decades to deny the ever-deteriorating attractiveness of civil nuclear energy strategy [215–218].

Details of how this dynamic unfolded over the past twenty years are published in detail elsewhere [207,219,220]. In short, multiple official policy and parliamentary documents on the military side [221] and occasional insights from grey literature on the energy side [222], all serve to underscore this picture of further intimate interconnectedness [223]. A 2007 report by an executive from submarine-makers BAE Systems called for these military costs to be *"masked"* behind civil programmes [224]. A secret MoD report in 2014 [225] (later released by freedom of information [226]) showed starkly how declining nuclear power erodes military nuclear skills. In repeated parliamentary hearings [227], academics [193], engineering organisations [228], research centres [227], industry bodies [215] and trade unions [194] urged continuing civil nuclear investments as a means to support military capabilities [220]. In 2017, submarine reactor manufacturer Rolls Royce even issued a dedicated report, marshalling the case for expensive *"small modular reactors"* to *"relieve the Ministry of Defence of the burden of developing and retaining skills and capability"* [218].

For its part, the UK government remained coy about acknowledging this pressure to *"mask"* military costs behind civilian programmes [224]. Yet the logic was nonetheless clear in repeated emphasis on the supposedly self-evident imperative to *"keep the nuclear option open"* – as if this were an end in itself, no matter what the cost [229]. Energy ministers have occasionally been more candid, with one calling civil-military distinctions *"artificial"* and quietly saying: *"I want to include the MoD more in everything we do"* [217]. Even more clear, was oral evidence given in 2017 [219] to a parliamentary public accounts committee investigation of the deal to build Hinkley Point C power plant [230] by the former chief civil servant of the Department of Energy and Climate Change [231].

Earlier appointed from the nuclear industry [232] amid unusual controversy over then-unexplained prime ministerial interference [233] (then sir, now lord) Stephen Lovegrove was asked a telling question by the Committee. This was prompted by evidence submitted by the present authors about pressures from the military side to secure what the National Audit Office recognised as *"lock in"* of consumers to a *"risky and expensive deal"* for civil nuclear electricity from Hinkley Point C [234]. Defending the need to join up action spanning civil and military nuclear fields, Stephen Lovegrove responded that *"We are completing the build of the nuclear submarines which carry conventional weaponry. We have at some point to renew the warheads, so there is very definitely an opportunity here for the nation to grasp in terms of building up its nuclear skills. I do not think that that is going to happen by accident; it is going to require concerted government action to make it happen"* [235] Significantly, (now) Lord Lovegrove had at the time of this evidence already moved back out of the energy ministry to head the civil service at the Ministry of Defence. His strikingly short tenure from an initially controversial appointment to the completion of the civil nuclear contracts was just three years [236].

Despite such rare acknowledgements in grey literature, the importance of this cross-linkage has remained remarkably neglected in wider UK policy and media debates [237]. Intermittent attention occurs in sporadic mainstream news articles focusing on work by very few researchers [238]. And it is only in devolved parliaments of the UK with no decision-making powers over nuclear policy, where these issues have even been mentioned [239]. But – surprisingly given the topicality and high stakes – the issues also remain otherwise almost entirely neglected even by some organisations that define themselves as critical in their attention respectively to 'civil' and 'military' nuclear technologies [240]. So, the evidently tight connection between UK civil and military nuclear activities remains more evident in actions than words.

Up to the present day, many hundreds of millions of pounds are prioritised for nuclear innovation programmes [241] and nuclear sector deals *"committed to increasing the opportunities for transferability between civil and defense industries"* [215] . Yet even when a 'civil' nuclear roadmap [182] for the first time on the energy side in 2024 explicitly highlights the crucial inter-dependencies between civil and military nuclear activities [153], policy debates in the UK remain strikingly muted about the huge economic costs and burdens that this implies in relation to foregone benefits from more viable alternative energy strategies. It seems beyond 'systems' functionally concerned with provision of 'nuclear weapons' and 'civil energy' then, that powerful forces behind UK 'nuclear lock-in' extend also to Parliament [242], wider policy making bodies [243], agencies charged with formal scrutiny of budgeting [234], as well as the mainstream UK media [244].

It is only by recognising this remarkable power of sociomaterial incumbency evidently in play in the UK, that it can be understood how it has been possible to (just about) maintain a national nuclear industrial base [245] in a country with such an internationally comparatively weak commercial nuclear industry [246]. This is again where the present sociomaterial framework can help to explain crucial aspects – looking beyond the dynamics of particular 'systems' (like that concerned with energy). In particular, this approach helps explain why it should be that Germany – with such a relatively strong domestic reliance on such a comparatively internationally successful civil nuclear industry [247] – has in the national *Energiewende* [248] been able more readily to recognise the momentous reversal in the currently growing competitiveness of nuclear power and renewable energy [249]? By invoking ‘resistance’ on the part of a ‘civil nuclear regime’ [250], conventional systems approaches would predict that it would be Germany more than the UK, which should display the strongest lock-in to this obsolescing technology [43]. Only by considering factors external to the energy system – like military drivers and relatively low quality democracy – can it be satisfactorily understood why it should be Germany and not the UK that is phasing out civil nuclear power [43].

3. SCOPING THE POLITICAL ECONOMY OF THE COMBINED CIVIL/MILITARY 'UK NUCLEAR COMPLEX'

It was explained in the first section of this report how adoption of a relational sociomaterial approach (rather than a more categorical systems-based understanding) [72] can have significant implications for understanding nuclear disarmament and associated policy interventions. Questions arise in terms of the assumed delineations of what constitutes the UK's nuclear weapons 'system'. The separation of civil and military nuclear activities are all too often taken for granted not just in policy making but also critical communities in both disarmament and civil nuclear circles. While pre-fixed notions of systems and the dimensions that constitute them may offer expedient means for policy recommendations and operational interventions, these approaches may also end up even inadvertently reinforcing the hegemonic structures and incumbent interests that make nuclear disarmament so challenging [251].

What the second section of this report showed, is that an alternative starting point (that does not prioritise particular internal dimensions or apply fixed or bounded notions for the focal 'system') is to further interrogate the shared 'industrial interdependencies' of a UK nuclear complex that spans civil and military activities [153]. Such an approach challenges conventional delineations of a 'nuclear weapons system' and raises significant questions about a wider context for sustaining crucial flows of money, materials, capabilities, careers, justification and legitimacy. Accordingly, what emerges more holistically under the present relational 'sociomaterial' framework for understanding internal workings of nuclear activities in the UK, is – despite continued protestations otherwise [120] – a tightly integrated technological, industrial, infrastructural, institutional and cultural 'UK nuclear complex' [207]. Without recognising associated deep interlinkages between areas of activity long officially insisted to be effectively entirely separate 'civil' and 'military' nuclear capabilities, it seems impossible to explain a range of high stakes formative characteristics and dynamics of this complex as a whole.

For instance, discussion in the last section shows how it is impossible reasonably to account in other ways for a variety of junctures in the history of notionally 'civil nuclear' initiatives in the UK. Examples include the original choice of gas-graphite power reactors in the 1950s (developed from designs optimised for on-load refuelling to obtain military supplies of fissile materials) [148]. Also potentially relevant is the subsequent move in the 1970s to a light water reactor design (originally configured to make use of high core power densities for confined spaces of submarines) [141]. Massively uneconomic investments made since the 1960s in efforts to 'close the fuel cycle' with fast breeder reactors and reprocessing were significantly aimed at securing long term military supplies of fissile materials [167].

The seemingly unshakeable intensity of UK government support for civil nuclear power despite its already near hopeless and rapidly further deteriorating competitive position, likewise reflects military imperatives to maintain the 'military nuclear industrial base' [212]. With hidden cross subsidies from taxpayer expenditures and consumer revenues lavished on unnecessarily costly electricity from nuclear power, the associated expensive military skills, infrastructures and supply chains are maintained outside the defence budget, off the public books and away from critical scrutiny [252]. As summarised above and published in detail elsewhere [207,219,220], official policy and parliamentary documents on the military side [216,253] and occasional insights from grey literature on the energy side [222], all serve to underscore this picture of intimate interconnectedness.

What arises from all this, is a crucial question that should be central to UK nuclear policy making as much on the civil as on the military side – and whose salience is equally obvious across a full diversity of political perspectives on associated issues. *What is the overall structure and magnitude of the total flow of value – including both state and market resources – across the full range of interlinked activities that sustain the UK nuclear complex taken as a whole?*

What is remarkable about this question is not only that it remains virtually entirely unanswered, but that throughout the long history of UK nuclear policy making reviewed above, it has not in the public domain (in any duly full form), even ever been seriously posed [237]. Divided as constituencies are on these issues across policy bodies, civil society and academia, this neglect has been similarly evident on both the civil and military sides. Remarkably, it has in both regards been avoided almost as much by critics of nuclear activities as (more understandably) by their proponents [254].

Government secrecy compounds the difficulties in raising these issues [255]. For instance, even a body as respected for its independence as the National Audit Office has allowed its own opportunities to interrogate these interlinkages to be obfuscated in opaque footnote disclaimers [256]. Budget scrutiny on the military side notes that the 'submarine industrial base' is assumed to remain available outside the scope of analysis [256]. Scrutiny of rationales for accepting unattractive costs on the civil side acknowledges the salience of "other strategic factors" [234], but does not say what these are. As a result, the implications are as major for governance as for expenditure [219]. If such wilfully obstructed official representations are not to block democratic accountability, attention must seek actively to pierce these barriers.

So: how to negotiate these kinds of seriously misleading obfuscations? How to identify flows of expenditure between activities concealed behind headline budget items? How to disentangle named allocations that overlap in highly complex ways, such as the groupings of organisations and activities they encompass, or the misaligned periods that they address? How to correct for confusing effects of frequent re-namings of initiatives and budgets? How to estimate magnitudes of spending streams that remain entirely invisible behind official secrecy? How to reconcile resulting highly uncertain patterns, such that they are comparable with other kinds of expenditure on an annualised basis?

In the absence (at least in the public domain) of any official attempts at systematic or fully comprehensive accounting, it is difficult to map the combined huge and complex webs of long term value flow associated with nuclear facility and project financing on both civil and military sides. Perhaps the most pragmatic approach is to begin with the small subset of annual dedicated allocations to nuclear-specific organisations or activities that happen to be made officially explicit and snowball from this? If so, a key starting point lies in straightforward taxpayer budget allocations and consumer market expenditures, with onward additions and complexities addressed from there.

Accordingly, Table 1 (below) refers to a wide range of official documents in order to summarise (on the left hand side) the key primary *funding sources* underpinning civil and military nuclear-related services in the UK. As a first approximation, these comprise two key inputs. First, there are expenditures on nuclear electricity across the full range of UK electricity consumers. Second, there is UK taxpayer funded public spending on nuclear-related 'civil' and 'defence' budgets. As a working baseline, the reference year is 2024. Where possible, this picture also accounts for various relevant fluctuations, including major multi-year allocations that are not explicitly annualised. In order to partly address (and help be accountable for), such large uncertainties, the figures are given as ranges.

The primary source of funding to cover the vast array of activities associated with the operations of civil nuclear power, lies in revenues from wholesale market contracts for consumer electricity. Here an overall figure can be estimated by means of Government data for the aggregate value of wholesale electricity sales in the UK [257]. As contracted from generators prior to addition of transmission and distribution costs, these are projected for 2024 at around £60 billion [258]. With the proportional contribution of nuclear electricity to the supply mix projected for 2024 at 15% [259], this gives a rough annual consumer spend specifically on wholesale nuclear electricity of some £9 billion. Below this, explicit public expenditures are quantified by aggregating individual agency and project budgets. The stated figures allow for various uncertainties about out-turns and ambiguities of interpretation.

The second column of Table 1 then shows (as well as can be determined), the *principal allocations* from these sources that are well distinguished in the public domain – either as widely-recognised proportions of business revenues allocated to major aspects of nuclear-related commercial activity [260 261 262 263], or as stated budgets to named organisations or programmes. Here, it is sometimes necessary to articulate together officially published annual budgets and flows of revenue together with more intermittent announcements of further policy allocations. Although contrasting conventions for calculating costs can lead to great variability, this same diversity of sources does provide a useful basis for triangulating the likely proportional scales of the rough streams of revenue to different kinds of activity. In the case of public bodies and programmes with explicit formal accounts, the overall annual flows in the first column have been corrected such as to be consistent with these. Again, stated figures allow for various interpretive ambiguities and uncertainties about out-turns.

More speculatively, the third column in Table 1 lists more concrete nuclear-related *detailed activities* that are variously distinguished in the literature. This provisionally estimates the indicative magnitudes of associated flows of value from the better documented sources and allocations shown to the left. These figures are obviously subject to correction, but the scope for error is at least bounded in broad terms, by the overall magnitudes of the better-documented principal allocations. This provides a basis for reasonable confidence that – although the fine grain structure is uncertain – the overall magnitudes remain broadly meaningful. Across all three columns, the cited references are not necessarily definitive in themselves with regard to the stated ranges of values, nor are they necessarily all individually in agreement. They are identified instead for the sake of accountability, as being broadly relevant as part of the evidence base used to arrive at the stated range in each case.

Table 1: indicative annual value flows to diverse UK civil & military nuclear-related activities (2024)

FUNDING SOURCES	£/y billion	refs	PRINCIPAL ALLOCATIONS	£/y billion	refs	DETAILED ACTIVITIES	£/y billion	refs
electricity consumers	8.5 – 9.5	258	capital costs (including during construction)	6.3 – 6.8	260 261 262 263	financial services	0.8 – 1.0	260 261 262 263
			fixed operations, maintenance, backend	1.4 – 1.7	260 261 262 263	nuclear engineering	2.0 – 2.2	260 261 262 263
			variable operations, maintenance, backend	0.8 – 1.0	260 261 262 263	design provision	0.25 – 0.35	260 261 262 263
						conventional engineering	0.85 – 0.95	260 261 262 263
						balance of system	1.2 – 1.4	260 261 262 263
						facility engineering	1.3 – 1.5	260 261 262 263
						initial commissioning	0.05 – 0.15	260 261 262 263
taxpayers' 'civil' budgets	5.4 – 6.4		direct capital support for construction (SZC)	0.3 – 0.5	264,265	specialised transport	0.05 – 0.15	260 261 262 263
			regulated asset base policy (RAB)	0.05 – 0.15	266	connection & integration	0.9 – 1.1	260 261 262 263
			Nuclear Decommissioning Authority (NDA)	3.3 – 4.2	267	added capital equipment	0.09 - 0.11	260 261 262 263
			Environment Agency (nuclear)	0.015 – 0.025	268	fuel mining, processing, enrichment	0.45 – 0.55	260 261 262 263
			Nuclear Liabilities Financing Assurance Board (FAB)	0.5 – 1.5	269	fuel fabrication	0.15 – 0.25	260 261 262 263
			Nuclear Sector Deal Policy (NSD)	0.15 – 0.25	270	spent fuel & waste management	0.45 – 0.55	260 261 262 263

			nuclear skills allocations (NSA)	0.05 – 0.15	271–276	facility decommissioning	4.3 – 4.5	267
			Nuclear Innovation Programme (NIP)	0.03 – 0,05	277	third party liability cover	0.05 – 0.15	278
			National Nuclear Laboratory (NNL)	0.005 – 0.015	279	skills, industry base, supply chains	0.3 – 0.4	277,279–282
			UK Atomic Energy Authority (UKAEA)	0.35 – 0.45	283,284	safety, health, environmental regulation	0.16 – 0.18	268,281
			Great British Nuclear (GBN)	0.45 – 0.55	285,286	anti-proliferation safeguards	0.06 – 0.08	287
			Office of Nuclear Regulation (ONR)	0.085 – 0.095	281	strategy & promotion	0.07 – 0.09	288
			Civil Nuclear Constabulary (CNC)	0.05 – 0.15	289	specialist nuclear security	0.17 – 0.19	290
						general research & innovation	0.75 – 0.8	284,286
						military programmes running costs	0.25 – 0.35	290,291
						submarine waterfront infrastructure	0.15 – 0.25	290,292
						AUKUS submarine development	0.15 – 0.25	292
taxpayers' 'defence' budgets	11 – 12	293	MoD Police (nuclear) (MDP)	0.07 – 0.09	290	other SSN procurement & support	0.55 – 0.65	290,291
			Defence Nuclear Safety Regulator (DNSR)	0.05-0.09	281,282	SSBN Dreadnought procurement & support	2.4 – 2.6	292
			Submarine Delivery Agency (SDA)	4.0 – 4.8	294	other SSBN procurement & support	1.0 – 1.2	253
			Atomic Weapons Establishment (AWE)	1.2 – 1.8	290,295	nuclear reactor core production	0.15 – 0.25	292
			Royal Navy Submarine Service (RNSS)	0.5 – 0.7	290,291	weapons research & manufacture	1.4 – 1.6	291,295
			Strategic Command programmes (SCP)	0.03 – 0.05	290,291	SSN & SSBN operations	0.55 – 0.65	290,291
			Other Defence Nuclear Enterprise (DNE)	5.0 – 5.5	293	submarine dismantling	0.05 – 0.15	290

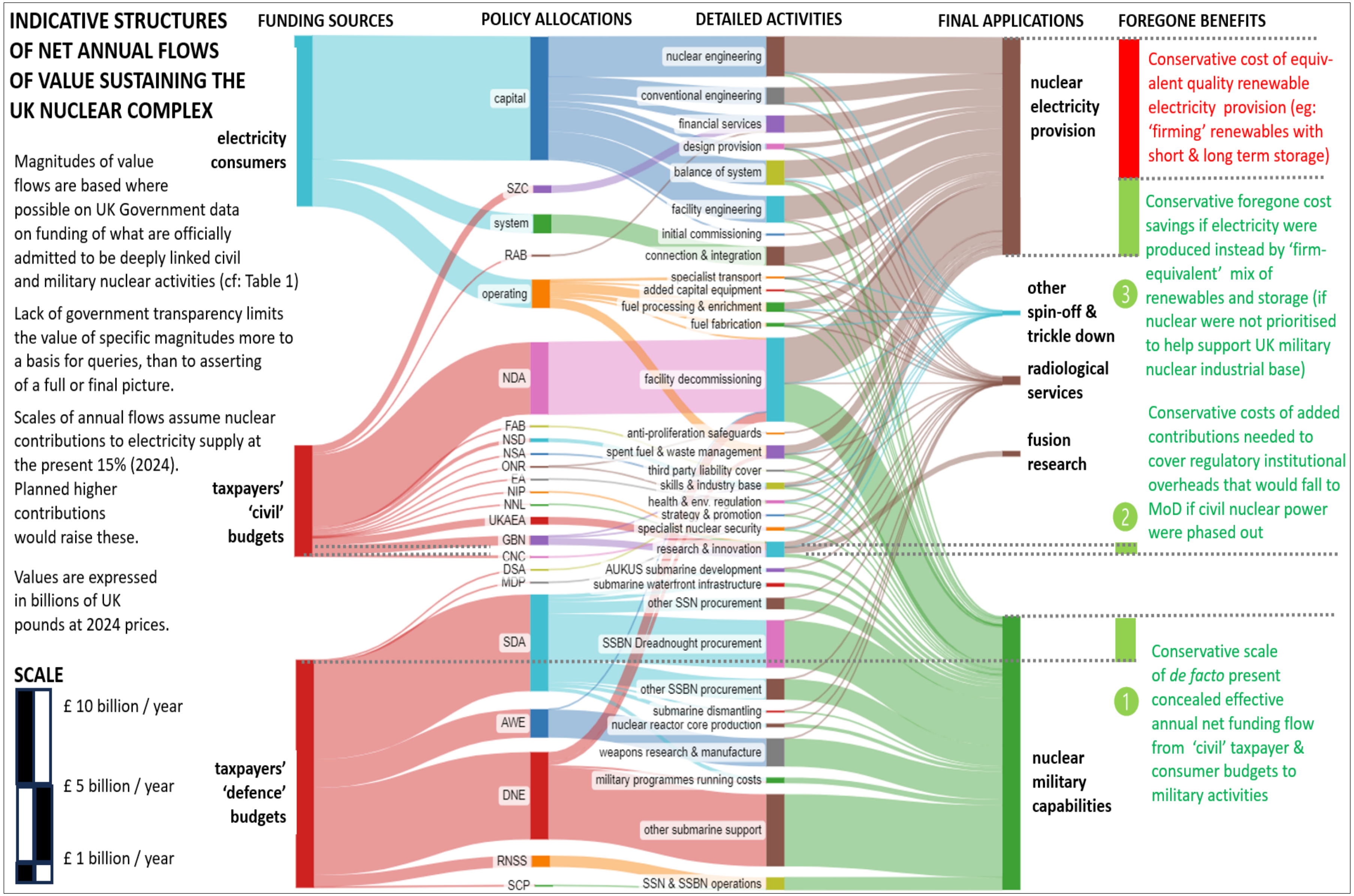
It has to be emphasised that difficulties discussed above and scarcity of official candour concerning the full scope or basic structure of the flows summarised in Table 1, mean that the details presented here must be regarded more as provisional and indicative starting points, than as settled findings. As such, this data is more a cue for further queries about the broad scale and shape of the combined UK civil/military nuclear industrial complex, than a source of confident answers. If there is disagreement concerning the accuracy of particular features, the open transparency of this picture at least allows a rigorous basis for correction. By this means, further derived work may hopefully yield more robust results than can – rather remarkably – be obtained from the presently consulted official UK sources. This said, every effort has been taken here to render the picture conservative with respect to the hypothesis under scrutiny – concerning the entanglement of civil and military fields of activity.

A few further notes are also necessary on the particular means by which this picture has been arrived at in Table 1. One major issue, for instance, is that the lifetimes of many nuclear projects (both civil and military) typically extend over many decades and (in the case of waste management facilities) centuries [296]. Over the course of this time many budget shifts often take place (typically increases [297] [298]). Aside from this tendency to steady escalation, these flows tend to vary relatively little over the years compared to fluctuations in project-specific budgets. In this sense, for instance, the massive financing requirements of civil nuclear power stations are ultimately all underwritten by anticipated accumulations of revenues either from future electricity consumption and/or by support from public budgets. Operational costs and profits taken by various players at every stage in these complex processes, are all in the end underwritten by these originating taxpayer or consumer expenditures.

A similar situation applies to other commercial or administrative operations. Complexities associated with accounting for long run initiatives (like research projects or investment programmes) running over many variously-overlapping periods can all be addressed to a first approximation, by quantifying the original annual expenditures from public or private sources that are variously aggregated or dispersed in order to meet these cost profiles. So, the central question then shifts, to asking what expenditures can be accounted for from either private or public sources, that unambiguously under-write the many diverse arrays of functions necessary to sustain the UK Nuclear Complex. It is in answer to this form of the question that Table 1 provides – insofar as limited available data allow – a provisional first-order answer that is serviceable at least for raising onward more detailed questions.

Based on this picture – and subject to all the given caveats – attention can then finally turn to the central question concerning the emerging overall structure of the combined UK civil-military nuclear complex. A start can be made in scoping out the approximate magnitudes of any net flows of value that may exist from the civil to the military side or *vice versa*. To this end, the most clear-cut way to represent the structure of associated flows is by means of a Sankey diagram [299]. Accordingly, Figure 1 below takes the data from the sources given in Table 1, but conservatively mediates out uncertainties to arrive at a rough schematic picture of the overall structure of the approximate annualised flows of value through the range of activities that distinctively constitute the UK Nuclear Complex as a whole.

Figure 1: initial picture of indicative net annual flows of value sustaining the UK Nuclear Complex


INDICATIVE STRUCTURES OF NET ANNUAL FLOWS OF VALUE SUSTAINING THE UK NUCLEAR COMPLEX
Magnitudes of value flows are based where possible on UK Government data on funding of what are officially admitted to be deeply linked civil and military nuclear activities (cf: Table 1)
Lack of government transparency limits the value of specific magnitudes more to a basis for queries, than to asserting of a full or final picture.
Scales of annual flows assume nuclear contributions to electricity supply at the present 15% (2024). Planned higher contributions would raise these.
Values are expressed in billions of UK pounds at 2024 prices.
SCALE
£ 10 billion / year
£ 5 billion / year
£ 1 billion / year
FUNDING SOURCES
electricity consumers
taxpayers' 'civil' budgets
taxpayers' 'defence' budgets
POLICY ALLOCATIONS
capital
SZC
system
RAB
operating
NDA
FAB
NSD
NSA
ONR
EA
NIP
NNL
UKAEA
GBN
CNC
DSA
MDP
SDA
AWE
DNE
RNSS
SCP
DETAILED ACTIVITIES
nuclear engineering
conventional engineering
financial services
design provision
balance of system
facility engineering
initial commissioning
connection & integration
specialist transport
added capital equipment
fuel processing & enrichment
fuel fabrication
facility decommissioning
anti-proliferation safeguards
spent fuel & waste management
third party liability cover
skills & industry base
health & env. regulation
strategy & promotion
specialist nuclear security
research & innovation
AUKUS submarine development
submarine waterfront infrastructure
other SSN procurement
SSBN Dreadnought procurement
other SSBN procurement
submarine dismantling
nuclear reactor core production
weapons research & manufacture
military programmes running costs
other submarine support
SSN & SSBN operations
FINAL APPLICATIONS
nuclear electricity provision
other spin-off & trickle down
radiological services
fusion research
nuclear military capabilities
FOREGONE BENEFITS
Conservative cost of equivalent quality renewable electricity provision (eg: 'firming' renewables with short & long term storage)
Conservative foregone cost savings if electricity were produced instead by 'firm-equivalent' mix of renewables and storage (if nuclear were not prioritised to help support UK military nuclear industrial base)
3
Conservative costs of added contributions needed to cover regulatory institutional overheads that would fall to MoD if civil nuclear power were phased out
2
Conservative scale of *de facto* present concealed effective annual net funding flow from 'civil' taxpayer & consumer budgets to military activities
1

What Figure 1 adds to Table 1 in its further column on the right hand side, is an initial schematic model of indicative flows of value from each detailed activity to broad *final applications* that can generally be distinguished as 'civil' or 'military' in nature. Some activities– like costs of naval operations involving 'attack' (SSN) or ballistic missile (SSBN) submarines – are effectively exclusively military in their purpose. Other activities – like direct capital investment or regulatory asset base accounting policies for the prospective Sizewell C nuclear power plant – are likewise effectively civil in their immediate effects. In such cases, though, it has to be recalled that even the most generalised of support for civil military activities does involve a *de facto* indirect benefit to parallel military nuclear activities, through helping to sustain the national nuclear industrial base as a whole. By excluding these most generalised of benefits and addressing only more direct annual value flows, the present analysis is again conservative with respect to a hypothesis of civil / military interconnection.

Even in narrower terms of direct value flows, a large proportion of the activities shown in the fourth column in Figure 1 involve some tangible benefit both to civil and military purposes, for instance including value accrued on both civil and military sides from national reactor design capabilities, specialised nuclear engineering and welding skills, general nuclear science education and research capacities, specialised material supply chains, facility dismantling and decommissioning expertise, environmental and safety regulatory infrastructures and cross civil-military industry strategy and promotional activities. In these cases, Figure 1 offers an initial estimate of the rough division of value that might be associated with each specific function. Once again, care is taken in these allocations to be conservative with respect to any residual flow of value that might be implicated beyond the default stated 'civil' or 'military' purpose at hand in each case. For instance, the military utility of currently large higher education and academic nuclear-related research budgets is not included at all.

The final element of the picture summarised in Figure 1, is a tentative representation of the general implications of this initial analysis for the question at the heart of this report, concerning the overall structure and magnitude of the total flow of value – including both public and consumer resources – across the full range of interlinked activities that sustain the UK nuclear complex taken as a whole. Here there are three main potentially salient aspects, each involving a form of hidden *de facto* net transfer of value from some notionally 'civil' to some predominantly 'military' purpose.

Before looking at this question, it is first necessary to address an important issue that necessarily accompanies any enquiry into flows of value from civil to military nuclear purposes. This is, that activities associated with the UK nuclear complex may also be expected to yield benefits of other kinds to the UK economy. In other words, it is not just military applications that benefit from taxpayer and consumer funding of the skills, industrial base and supply chains needed for nuclear power. Although nuclear-specific expertise, materials and technology are all relatively specialised, there are other kinds of potential application, spin-off and trickle down, like radiological services and fusion development. Indicative flows to these applications are shown in the centre of the further column of Figure 1. Each of these is also entangled in various ways with military applications. This is shown, for example by naval interest in fusion power for maritime propulsion and directed energy weapons [300]. With details beyond the current scope, a conservative approach for present purposes is to indicate these other kinds of trickle down and spin off as separate to a main focus here on relations between civilian fission power and military nuclear applications in naval propulsion and weapons production.

Specifically concerning relations between value flow to civil nuclear fission power and military nuclear applications, attention might turn first to the green vertical interval and text in the lower right hand corner of Figure 1 1. This employs the same scale as other flows of value shown in this diagram. Using thin black dotted lines traversing from right to left, this indicates the approximate scale of the difference between revenue flows from taxpayer budgets explicitly labelled as concerned with 'defence' (on the left hand side) and the actual real-world overall magnitude of the flow of value from taxpayers and consumers as a whole in support of these military activities (on the right hand side). Despite the caution built into this analysis as noted above, Figure 1 suggests an initial estimate of this presently concealed *de facto* flow of value from civil allocations to military purposes, is conservatively more than at least £2 billion per year.

The second effectively independent salient point to make from Figure 1 for the picture of overall flows of value between civil and military, is represented in the second green vertical interval in the centre right hand side of the diagram 2. Again using thin black dotted lines extending to primary funding sources on the left, this shows the rough indicative proportions of taxpayer-funded budgets for combined civil-military nuclear agencies and programmes, that comprise managerial overheads for these organisations. These also underwrite organisational functions necessary on the military nuclear side, including those dedicated to education, research, regulation, skills, decommissioning and waste management. It is these costs that would have to fall to national 'defence' budgets if the UK civil nuclear programme were phased out in favour of alternative low carbon energy options.

In other words – as a separate matter to specific programme budgets shown in the flows of Figure 1 – this suggests the approximate scale of the administrative overheads for associated organisations and initiatives presently labelled primarily as 'civil' in their responsibilities, that would attach to military costs if there were no civil nuclear power. Again taking a cautious view, the magnitude of this item is estimated here to be roughly of the order of some £ 0.5 billion per year.

The third and final way in which Figure 1 indicates the broad scale of difference in flows of value that would be associated with a UK nuclear complex with and without civil nuclear power, is shown by the vertical green interval in the top right of the diagram 3. Again using thin black dotted lines, this shows using the latest available official data concerning 'enhanced levelized costs of electricity' from renewables (i.e., including energy storage) [203,301,302], how costs of providing renewable electricity at equivalent quality to nuclear output compare with overall costs of nuclear electricity provision in the UK. Despite the rapid reductions in these costs, this data has not been updated for several years [303], so is again conservative with respect to the conclusions being drawn here. In short, the red vertical line under 'foregone benefits' shows the costs according to official sources, of producing as much firm-equivalent power through renewables, as is anticipated to be produced in 2024 from nuclear power.

At the same scale as other flows shown in Figure 1, then, the green interval 3 suggests the rough foregone savings that arise from a choice to keep the civil nuclear programme in operation, rather than shift to renewable alternatives (in the event that nuclear power was not prioritised to help support the overall UK military nuclear industrial base). As the diagram shows, a conservative estimate of these foregone benefits of a non-nuclear UK energy strategy is more than £3 billion pounds per year. With the gap growing rapidly between nuclear power costs on the one hand and costs of renewables and short and long term energy storage on the other, this estimate becomes increasingly likely to be on the low side as the time horizon extends into the future.

Subject to all the qualifications, complexities and caveats detailed above, then (and more as a prompt to further research than definitive findings at this stage), a *prima facie* case is substantiated by this analysis that the overall excess costs to the UK economy of military pressures to maintain civil nuclear power to keep the national nuclear complex in operation, may confidently be estimated conservatively to be significantly greater than £5 billion per year.

CONCLUSIONS: IMPLICATIONS FOR REVERSIBILITY OF UK COMMITMENTS TO NUCLEAR WEAPONS CAPABILITIES

As set out in the first paragraphs of this report, Two central questions lie at the heart of the project within which this work was commissioned [1].

(A) How '*reversible*' are current UK commitments to national nuclear weapons capabilities and the associated sociotechnical system? This is about possibilities for UK nuclear disarmament.
(B) How '*irreversible*' would such a UK nuclear disarmament process be, given dynamics of the wider civil/military nuclear complex within which this 'nuclear weapons system' is nested? This is about mutually reinforcing interlinkages between different kinds of nuclear activity.

What has been substantiated in the preceding three sections of this report are three broad issues that bear significantly on both these questions. Neither conclusive nor complete in themselves, these issues relate to the nature and strength of commitments bearing on (A) that arise in currently under-recognised entanglements between military and civil nuclear activities. These are constituted in flows of economic value – and associated forces of political justification and cultural attachment – that also bear on (B). Implications for these two core questions will be returned to after summarising findings.

The first significant issue arises in Section 1. This is, that the degree to which UK military nuclear commitments are reversible cannot confidently be assumed (at least *a priori*) to be best understood exclusively in terms of any particular notion of a '*sociotechnical system*' narrowly delineated just around nuclear weapons capabilities themselves, or the wider nuclear military infrastructures and imagined security functions associated with their delivery. For there to be due confidence that analytic artefacts have been avoided, scope of enquiry should broaden to include proper attention to potential linkages between civil and military nuclear activities. Also possibly relevant, are less visible but highly formative effects from distinctive features in generally overarching global political-cultural formations [153], as well as from more specific national elite imaginaries within this [112].

Broader and deeper then, than is usual in policy, academic or even conventional critical civil society discourse, it is this unusual scope that has been attempted in the present initial 'sociomaterial approach' [29] – expanding attention to encompass a UK 'civil-military nuclear complex' [207] as a whole and addressing this in the even wider prevailing hegemonic context of 'colonial modernity' [61]. This scope helps avoid restrictive assumptions about simple one-to-one mappings of imagined 'systems' onto notionally singular, separable or otherwise-bounded societal 'functions' around energy or security [304]. It questions many performative mainstream positions – as for instance institutionalised in the statutes of the International Atomic Energy Agency [305] – that imply it to be more reasonable for nuclear arms control efforts to actively support civil nuclear technology [187], than for this side of the nuclear complex to also be allowed to possibly decline [118]. It helps avoid capture by partisan interests seeking to deploy justification based on one side of the complex for supporting activities on the other.

The key significance of this scope, however, is not that adopting such wider analytic breadth *compels* conclusions that commitments to nuclear weapons are necessarily deeply entangled on the civil side. It is still perfectly possible to identify within this analytic frame, that key drivers and opportunities are after all largely circumscribed around military institutions and infrastructures. The main point is rather that, if the adopted analytic frame itself in some way circumscribes consideration for such broader possibilities, then it becomes more likely that important wider implications will be missed.

A second important issue arises from the history of UK nuclear activities summarised in Section 2. This account seeks to attend in a balanced way to both civil and military areas together. As a result, it becomes more visible that some key junctures in the development of UK nuclear infrastructures and institutions in each field become more satisfactorily explicable by reference also to the other field, than in exclusive terms of notionally more circumscribed and divided 'systems', each centred around an assumed singular, separable policy-delineated societal function like energy or security.

In this more material historical sense then, it can also be seen how reversal of pre-existing military-driven UK commitments to gas-graphite civil power reactors in the 1970s may be understood better if shifts on the military side towards light water designs for naval propulsion are also attended to [306]. Likewise, reversal from the early 1990s of massively entrenched official UK commitments to ostensibly civil nuclear fuel reprocessing emerges as less easy to fully understand without also noting the concurrent military and geopolitical shifts brought about by 'the end of the cold war' [187]. Again, developments in one notionally function-specific 'system' can be seen significantly to help shift an otherwise seeming irreversible commitment in another. Once more, appreciation for the conditions bearing on reversibility must attend to formative dynamics that transcend notionally specific systems.

A third significant issue arises in the third section of this report, offering an initial indication of the broad magnitudes of currently largely concealed flows of value that interlink otherwise notionally separate 'civil' and 'military' aspects of this integrated 'nuclear complex' in the UK. Here, official secrecy (sometimes reinforced by active denial [120] and misinformation [307]) makes the picture difficult to represent with full confidence. But by adopting cautious assumptions (with respect to testing the present hypothesis of interlinkage), it can nonetheless be seen quite clearly, that undeniably significant flows of value are currently in play across these two fields in the UK. As an indicative cue for further exploration, these flows are conservatively estimated here to amount to more than £ 5 billion per year. *This avoidable additional economic burden falling on UK taxpayers and electricity consumers results from under-scrutinised commitments to the national civil/military nuclear complex – and evidently constitutes a major adverse challenge for the UK economy as a whole.*

An important feature of this scale of interlinkage, is that it mediates cross-dependencies that act both ways. Where a net flow of resources runs from notionally largely civil towards partly military activities, a result is that the military activities become more difficult to reverse without action to also curb the sustaining support – or at least illuminate this for public scrutiny. Yet such flows also obstruct efforts at reversal acting the other way. If support given to military capabilities becomes a key (if covert) justification for civil activities, it also becomes harder to reverse commitments to civil nuclear power as well. The same would in principle be true in an opposite fashion, if it were flows of resources from military applications that supported civilian commitments. Either way, *an integrated UK nuclear civil/military complex, is as a whole less reversible than the sum of it's separate parts*

It is in these ways that such cross-dependencies between notionally-specific civil and military activities would constitute a major and under-explored obstacle to reversal of commitments to nuclear technologies on either side. Where these technologies are each judged to be relatively cost-effective in their respective fields (as compared with alternative means for provision either of security or energy), then such a driver of irreversibility might be judged to be of only hypothetical interest. But where it begins to become even only partly realised under at least some informed perspectives in just one field, that political-economic trends are beginning to raise questions about obsolescence in nuclear technologies, then implications of cross-dependencies become more policy relevant [24]. *Even where obsolescence is seen to arise only by some on one side, major issues of irreversibility follow.*

Adding weight to this point, is the wider observation that – as is also discussed in Section 1 above – obsolescence is a near-ubiquitous general characteristic in innovation history [308] [309] [310]. Timeframes of course vary. But – especially as military and civil nuclear technologies approach a century of existence (in the coming period for infrastructure investment) [311] – it becomes *more readily recognisable as irrational to ignore questions of potential obsolescence than to highlight them*.

Whatever perspectives are adopted on either military or civil rationales for nuclear technology, then, it is manifestly unreasonable in either regard to neglect this general routine possibility of obsolescence [312]. And this becomes even more difficult to deny, when specialist debates in their respective fields, are increasingly raising questions over the relative efficacy of nuclear technologies as compared with alternative means to provide both national security [313] or deliver zero carbon energy [314]. In the case of military nuclear capabilities, this competition arises from contending security threats [315] and possible defence capabilities [316], as well as detection systems [317], countermeasures [318] and alternative means to submarine propulsion [319]. In the case of civil nuclear power, it lies in rapidly improving options for zero carbon renewable power [320], energy storage [203] and service efficiency [321].

Crucially, it does not need to be agreed that such prospective kinds of obsolescence are already occurring in either respect, for such potentialities to be recognised as salient in relation to approaching long-run infrastructure investment windows. *Even just the mere possibility of such 'cascading obsolescence' spanning civil and military sides of the nuclear complex, is – under any view – a potentiality whose stakes make it at least worthy of consideration.*

In such a context, recognition for the possibility of interlinkage-driven irreversibilities become even more important. And this is so under any rational view – even those that are favourable to nuclear technologies in some specific setting or both. This is because large-scale cross-dependencies would – if they exist – mean that normal processes for mediating technological obsolescence throughout the wider culture and economy might not be able to operate fully, properly – or even be visible – because pressures for irreversibility arising from concealed cross-dependency would obscure this. *So, even for views under which obsolescence is not recognised to be occurring, it becomes uncontroversial to argue in favour of at least some 'institutional vigilance'* [322] *about the possible future relevance of such interlinkages for the governance of reversibility.*

The present report is not an appropriate place to seek definitively to adjudicate pros or cons bearing on details around cases for or against emerging obsolescence in nuclear technologies on either the civil or military sides. What is most relevant to the current remit concerning reversibility is that a strong *prima facie* case emerges for at least asking the question. Accordingly, rather than taking a position, the analysis here has instead been based on much more general and neutral parameters.

(1) First, the 'sociomaterial' frame adopted here for understanding complex socio-technical entanglements, is indifferent with respect to cases for or against nuclear technologies.
(2) Second, the history summarised here of unfolding developments in UK nuclear activities is also independent of any positive or negative position on rationales for these commitments.
(3) Third, the official data (insofar as is publicly available) analysed here concerning real-world flows of resources across notional civil/military divides, is also neutral with respect to diverse rationales as to why these flows might variously be considered justified or contestable.

So recognising the importance of vigilance for mere possibilities of future obsolescence in military or civilian nuclear technologies, is a conclusion that is independent of any position on either side.

In this light, what is crucial about recognition of this need for institutional vigilance concerning reversibility-obstructing interlinkages between civil and military nuclear technologies, is associated recognition that *provision for this policy quality is virtually absent in contemporary UK governance, equally on either side of these links, as well as across related functions of government in general.*

(i) Crucial features in this regard are discussed above, for instance, in relation to how the government body most relevant to such vigilance – the National Audit Office [234] – has failed fully to deliver on responsibilities to interrogate openly and comprehensively, issues of nuclear cross-dependency that it acknowledges privately and in footnotes [256].

(ii) Compelling high stakes evidence for formative nuclear military pressures on civil energy strategies has been submitted to numerous parliamentary enquiries with related remits over the years (including by the authors). This has also never been explicitly refuted – yet remains oddly almost entirely neglected in continuing policy deliberations [219,220,323].

(iii) Despite strong initial journalistic interest, patronage pressures have left editorial desks and specialist correspondents in national news media notably diffident about exploring these issues [324], despite the fact that investigative journalism has repeatedly raised them (again without refutation or even substantive response) in the same news outlets [325].

(iv) Although responsible departments of government continue (when pushed hard), actively to reject the significance of these interconnections, such specific denials are asserted without substantiation [120]. At the same time, other official documentation paradoxically increasingly highlights in more general terms that civil and military nuclear commitments are indeed interconnected [182,216,326]. But the obvious cue is still not taken to pose basic questions about the *magnitudes* of associated interdependencies.

(v) Across UK governance of civil and military nuclear activities as a whole, then, the mainstream default in ruling parties [327], parliament at large [326], the civil service [213,328] and wider policy debates [244,329] remains simply one of assuming without significant question (and contrary to prevailing and growing evidence), the continuing indefinite future necessity of both military and civil nuclear technologies [244].

(vi) Where it occurs at all in any systematically critical fashion, formal official policy appraisal is restricted to simply asking how to deliver this assumed commitment [330,331], rather than about whether or not there might be more viable alternatives [332].

(vii) For the past twenty years, there has as a result been no serious substantive official effort on either the civil or military sides in the UK, rigorously to assess in a balanced way, the comparative cost-effectiveness of nuclear options with respect to their most viable non-nuclear alternatives [207,333]. For instance, it is remarkable that UK government energy white papers no longer publish comparative costs for nuclear power compared with alternative zero carbon energy options, in a way that was once routine [334] [335].

(viii) Although, despite continuing official denials [120], civil/military nuclear cross-connections are in places becoming more prominently formally acknowledged in principle [182,253], the *magnitudes* of associated interdependencies – and therefore associated irreversibilities – remain resolutely publicly unacknowledged and unexplored.

Bearing most broadly on the resulting imperatives that emerge for institutional vigilance concerning obsolescence and irreversibility, the authors know of no UK government document in the past twenty years (even in grey literatures), that has sought in any detailed, comprehensive, or balanced way to quantify the relative pros, cons and opportunity costs that arise around:

a) Nuclear weapons compared with other claimed means to further national security;
b) Nuclear propulsion as one means among others to deploy various kinds military capability;
c) Nuclear power as one strategy among many alternatives for delivering zero carbon energy;
d) Possible pursuit of *either* civil or military UK capabilities in the absence of a case for the other.

A key implication of this analysis is thus that it is essential in the interests of rigour and democratic accountability in UK policy making around civil and military nuclear strategies, that these crucial issues must be addressed. Returning on this basis to the core questions reviewed above (A and B – that anchor the project of which this report is part), it becomes possible confidently to conclude that:

A1) The *reversibility* of current UK military commitments depends strongly on entanglements detailed here to constitute the UK nuclear complex as a whole. As is shown, these comprise significant flows of monetised value, as well as associated forces of political justification and cultural attachment. The larger these previously hidden flows of support become recognised to be, the more reversible nuclear weapons commitments become. Other factors also bear on these questions. But – all else being equal – *as the growing visibility of these hidden de facto cross-subsidies makes it ever more clear that military nuclear activities impose a greater burden on the national economy than has been recognised before, then it becomes easier to reverse the associated military commitments than it otherwise would have been*.

A2) A further significant point bearing on the *reversibility* of UK military nuclear commitments arises on the civil side of the UK nuclear complex. Relevant here are current global trends for nuclear electricity to grow rapidly less attractive by comparison with other zero carbon energy strategies. If these trends continue, then (again, all else being equal) continued *withdrawal from obsolescing civil nuclear power may be expected to significantly reduce flows of money, justification and attachment to military nuclear capabilities. This again makes it* *more likely that commitments to UK nuclear weapons systems might be reversed.*

B1) The *irreversibility* of any hypothetical future UK nuclear disarmament process also depends at least partly on the dynamics of the wider civil/military nuclear complex within which nuclear weapons related activities are nested. The greater the flows of value (and associated justification and attachment) from the civil nuclear activities that are necessary to sustain the military side of this combined complex, the more difficult it becomes in economic or political terms to re-establish weakening military commitments. *All else being equal, then, recognition for the presently-documented expansive flows of support running from the civil to the military side, helps make any prospective process of national nuclear disarmament significantly more irreversible.*

B2) A final important specific point also bears on the *irreversibility* of any envisaged process for UK (or – by extension – wider international) nuclear disarmament. This again relates to the rapidly internationally declining competitiveness of civil nuclear power by comparison with other zero carbon energy alternatives. As civil nuclear power declines further in relative terms, it becomes progressively more difficult to conceal the full magnitude of the costs associated with nuclear-specific infrastructures and industrial functions that are essential for maintaining military nuclear capabilities. *The great the recognition for this evidently coming global era of obsolescence in civil nuclear power – and the less that pressures for military-related justifications are able to obscure this – then the more plausible it becomes to recognise important potential irreversibilities in international nuclear disarmament.*

The core aim of this report, however, is not to seek comprehensively or definitively to refute the nuclear case in any (let alone all) of these regards. Much remains to be said, in particular, about the conventionally-presumed (but highly questionable) association made between projection of military nuclear capabilities and notionally increased national security [96,97,100,336–338]. What can presently be concluded from these findings under any view, however, is that UK governance across civil and military nuclear fields has fallen into a habit of under-scrutinising some important associated issues – certainly with due openness, transparency, accountability or rigour. With nuclear activities on each side individually counting as recipients of some of the most massive long-run allocations of public spending [291,339–341], the stakes across the two areas together are even greater [290,341,342].

Whatever view is taken on the credibility of justifications for either civil or military nuclear activities, then, there can be agreement that it is quite normal for all technologies at some point to start to obsolesce. In the event that this becomes widely recognised to be at least foreseeable in principle for either or both civil or military nuclear technologies, then the findings of this analysis become crucial for all sides – that *scales of commitment to either side of the combined nuclear complex as a* *whole, make attachments to the other less reversible*. It is in this recognition that the evidence in this report becomes most broadly relevant, for currently-hidden, large scale, irreversibility-fostering interlinkages between UK civil and military nuclear activities. This is the basis on which it may be agreed across all perspectives, that *the most rational response is to make these links visible and to talk about them.*

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