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We Need to Talk About Engineering Policy

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Abstract

The governance of engineering, unlike science, is rarely discussed in the academy. We analyse this issue in relation to the prevalence of the term 'engineering policy' in contrast to 'science policy' as a means of demonstrating the nature of the different treatment of these concepts inside the academy and outside. We show that 'engineering policy' as a term has almost no academic inquiry relative to science policy, and that even 'engineering' is marginalised in critical social science domains like Science and Technology Studies, as others have noted. Further, we extend this exploration with regard to the visibility of engineering policy in practice communities where it ought to be visible but isn't. Specifically, we use the UK government and governance communities as a space to show how engineering and policy for engineering remain side-lined in policy practice. Given how central engineering is to society, the obscurity of its governance mechanisms and the absence of critical scrutiny of engineering policy, we propose a research and action agenda as a means of stimulating action and coalescing a community of stakeholders to redress this situation with some urgency.

Keywords: engineering; policy; science policy; governance; research agenda;

1. Engineering on the margins

Engineering holds a strange place in the academy. It is at once the disciplinary cluster where the skills and practices are developed for making society what it is, and transforming it fundamentally [1,2], yet at the same time – as we aim to show in this paper – it remains mostly outside of either direct governmental oversight or critical academic inquiry. This latter point was perhaps first identified by Downey and Lucena [3] nearly 30 years ago, and attributed the marginalisation of engineering in critical social studies to the liminal nature of engineering: it can be seen to exist on the boundary of labour and capital. This difficulty in separating issues of labour (the social practices engineers participate in as part of their work) and capital (the contents and outputs of engineering work) leading to it being overlooked in Science and Technology Studies (STS) at least, which tends to focus either on labour (scientists) or capital (technology).

Whatever the reason, this marginalisation persists today, despite there being no single global – or local – challenge for which engineering insight, skills or processes cannot be usefully applied, whether it is fixing problems that engineering itself generated (e.g., microplastic pollution and the climate crisis) or new challenges that it is creating (e.g., so-called 'autonomous vehicles' or 'artificial intelligence'). Our broader argument rests on the notion that given how central engineering is to society, the lack of critical oversight either academic or political may itself be causal in reproducing a mode of engineering practice (the engineering we have) that continues to generate highly problematic solutions. As such, creating structures and programmes of critical inquiry and public governance of engineering may present an opportunity to create new modes of engineering (the engineering we need). This claim therefore rests on understanding the concept of 'engineering policy': the ways in which engineering itself is governed, and what makes for 'good' engineering in society.

Therefore, it is necessary to actively focus intellectual and research resources to understand, assess and critique 'engineering policy' in a similar way as is done for 'science policy'. This paper then is an attempt to lay the foundations for such a programme, and to do so in an evidence-based way. We break this foundation-building into three interconnected claims:

1. That 'engineering policy' as a concept equivalent to 'science policy' has been historically marginalised or otherwise overlooked by the academy. That is, there is an identifiable gap.
2. That 'engineering policy' is not conceptually captured either by the idea of 'applied science' or 'technology policy'. That is, the gap is not an artefact of topical nomenclature, but a real gap.
3. That the generation of a body of knowledge to build out an understanding of how better to deploy engineering policy will lead to better societal outcomes. That is, this real gap is important, such that research investment is urgent if we are to address it, and reap the rewards of doing so.

The term 'engineering policy' – at once recognisable and unusual – is sometimes seen in academic works, just as in policy circles, referring to policies which carry with it some obvious need for engineering e.g. infrastructure development involving transport, energy, water and so on. But here we want to claim the term as a corollary to 'science policy'. This of course begs the question of what 'science policy' is. Like many academic jargon terms, there is rarely clear consensus on their definition, so we take a pragmatic approach to understanding it: finding the highest-cited academic paper referencing the term in its title and either using any definition deployed there or inferring one from its content. A short search of the Scopus database for "science policy" in the title of any record, identifies a clearly "science policy"-focused paper third on the citation count, which is sufficient for our purposes: 'The neglected heart of science policy: reconciling supply of and demand for science' by Dan Sarewitz and Roger Pielke from 2007. The paper by Sarewitz and Pielke [4] mentions "science policy" 49 times, but doesn't at any point explicitly define it. The closest they get is to ask:

> *In pursuing a particular societal goal or set of goals, how do we know if a given research portfolio is more potentially effective than another portfolio?*
>
> [4]

They claim that this question "lies at the heart of science policy". Implicitly, and aligned with the other content in the paper one definition could therefore be "any actions which aim to set the goals [cf. 'a particular societal goal or set of goals'], provide the resources for undertaking or applying knowledge from science [cf. 'a given research portfolio'], and the processes, structures and standards by which those actions are chosen and judged [cf. 'more potentially effective than another portfolio']".

Such a definition of science policy echoes Harvey Brooks' [5] differentiation between 'policy for science' (here: "goals…and resources for undertaking…science, and the processes, structures and standards by which those actions are chosen and judged") and 'science for

policy' (here: "actions…applying knowledge from science, and the processes, structures and standards by which those actions are chosen and judged"). Interestingly, this distinction and definition is not limited to science policy studies scholars like Sarewitz and Pielke (and even more recently Gluckman [6,7]) but echoes earlier work by STS scholars like Jasanoff [8] and Hilgartner [9].

If this definition of science policy holds then it can usefully serve as a template for engineering policy, with the simple act of switching the word 'science' for 'engineering':

> Any actions which aim to set the goals, provide the resources for undertaking or applying knowledge from *engineering*, and the processes, structures and standards by which those actions are chosen and judged.

This then places engineering at the centre of a novel area of academic inquiry, one clearly linked to 'science policy' on account of the same kinds of questions being at the 'heart of the matter' (here: "In pursuing a particular societal goal or set of goals, how do we know if a given engineering portfolio is more potentially effective than another portfolio?") but focused topically on an area that is related to, but also clearly distinct from 'science'. Our next step then is to demonstrate how 'engineering policy' has been marginalised from the fora where such discussions and research ought to happen, and that investment is needed to address that. We turn now to showing the difference in treatment between these two concepts both in reference to the academic literature but also in the UK policy practice setting, as an example case. In doing so we build on the groundwork laid by Mitcham and Kang where they use n-grams, and explorations of Wikipedia and major texts to illustrate how 'engineering policy' has been marginalised or subsumed under other terms such as science policy, and industrial policy [10].

2. 'Engineering policy' vs 'science policy' in academic publications

The claim that 'engineering policy' has been side-lined or otherwise overlooked in academic research is not a contentious one (as outlined above), so demonstrating it empirically needn't require exhaustive searches. Rather a simple comparison between the prevalence of 'science policy' and 'engineering policy' should not only demonstrate support for this claim but also reveal other important aspects related to it.

2.1 'Engineering policy' vs science policy in academic journal articles

A simple way to establish the status of 'engineering policy' as a concept in relation to 'science policy' is to undertake simple, systematic searches of major abstracting databases covering millions of records of academic output. The two major such databases covering the social and policy sciences as well as engineering and physical sciences are the Elsevier-owned Scopus, and Clarivate's Web of Science (WoS). Two simple searches were undertaken in both (so four in total) comparing the number of returns for "engineering policy" as an exact phrase in the title of records. No other limits were set For Scopus the search term was TITLE ({engineering policy}) which rules out combinations of engineering and policy with intervening punctuation. For WoS, the search term was TI=("engineering policy") with the advanced option for 'exact search' switched on. This search does not filter

out instances with intervening punctuation, so they needed to be identified manually. Identical searches were carried out across the two databases for the phrase "science policy".

For both WoS and Scopus the difference in the number of returns between "engineering policy" and "science policy" was enormous. WoS returned 2275 hits and Scopus 1083 searching for "science policy". This compared with 25 and 17 for each for "engineering policy", so nearly a factor of 10 difference within each database. Despite the twofold difference in "science policy" hits between WoS and Scopus, they agreed closely on some broad indicators for the literature: timespan of citations, and top 5 publications hosting records with "science policy" in the title. That is, the first record in each was data 1947 with 1 citation, and 2022 the most recent with 31 on WoS and 8 in Scopus. The top 5 publication titles were *Science*, *Nature*, *Chemical and Engineering News* (ironically), *Minerva* and either *Science and Public Policy* (Scopus) or *Environmental Science and Policy* (WoS).

By contrast, the date range for "engineering policy" was much narrower: 1982-2021 for both databases. They agreed on 3 publication titles within the top 5: *Nature Biotechnology*, the *13th IEEE Annual Consumer Communications & Network Conference 2016*, and *Boston Studies in the Philosophy and History of Science*. WoS had *Insight* – the journal of the National Academies in the US, that Scopus did not have. As an aside, a brief check of the titles returned under the "science policy" search within the *Chemical and Engineering News* noted above, did not reveal any mention of 'engineering' in the titles of these papers. Finally, note that these numerical citation hits comparisons between engineering and science policy searchers are made on unvalidated, unfiltered analysis of returns. We turn now to a more detailed look at the 'engineering policy' searches to combine across the two databases, remove duplicates and out-of-scope returns, to give a final number of papers with "engineering policy" in the title.

The WoS returns were reviewed for any instances of the exclusions that would occur in the Scopus search, i.e., presence of intermediate commas etc. In addition, for both, instances of engineering associated with a specific field or where engineering was used as a name for a technology were excluded: e.g., 'genetic engineering', 'climate engineering'. Finally, any general uses of engineering to mean 'shaping' or 'designing' where it was clear a pun was intended (i.e., the papers were not about engineering) were also excluded. In the WoS search, the 25 hits resulted in 10 final includes (3 with intermediate punctuation, and the remaining 12 instances of types of engineering: germline, climate, systems, wind, genetic). One citation with intermediate punctuation was not excluded as it was a hyphen in "Understanding Challenges at the Engineering-Policy Interface" which was understood to be close enough in meaning to 'engineering policy' (particularly the 'engineering for policy' form) as to warrant inclusion. In the Scopus search the 17 hits, there were no punctuation exclusions but 10 exclusions in total (9 for types of engineering: clinical, germline, genetic, climate, traffic, maintenance, software and one for 'design' use). This left 17 citations in total across the two databases. Four of these were duplicates of one type or another, leaving 13 unique references across the two databases.

These 13 citations split into two temporal groups: pre 2002 and post 2002. 2002 was chosen as a date that roughly sits in the middle of the range of publication years, but also sits

roughly halfway between two of Downey's publications on 'Engineering Studies', which reiterate the same issues, 20 years apart [3,11]. The pre-2002 (4 citations) 3 are in journals, one of which no longer publishes, and one is in an engineering institutional publication. Post-2002 (9 citations) comprise 4 chapters from one-off volumes or 3 citations from Institution publications and 2 from conference proceedings. Within these recent 9 publications, 2 of them describe the creation of the 'National Engineering Policy Centre' (which we discuss below). Three of them cover directly the perspective we are taking here, a chapter by [10], and two chapters by [12,13] in related volumes concerning the philosophy of engineering. Also of potential interest is a paper titled 'Russia's new engineering policy' [14]. However, on inspection this is not about 'engineering policy' as meant here and so was excluded. We will return to examine the three texts noted above in order to build the case for an agenda in the academy for greater focus on research to support the development of 'engineering policy'.

2.2 'Engineering' in STS

The other way of determining the marginalisation of 'engineering policy' in critical academic debates is to search in key places where such debates about the role of engineering in society *should* be happening. The most obvious place for this is in the critical social theory domain of Science and Technology Studies (STS). The top 3 most cited textbooks on STS according to Google Scholar are by Sismondo [15], Jasanoff [16] and Hackett *et al* [17]. We conducted content searches for mentions of 'engineering' specifically in these texts to see what proportion of pages dealt with 'engineering' in its disciplinary sense, as a proportion of the overall book. We excluded mentions of 'engineering' when part of a phrase 'science and engineering' or equivalent, or as part of a list of disciplines – that is, they are not talking about engineering *per se*. To be conservative we included mentions of engineering that could ambiguously understood as about a technology as much as about a disciplinary practice (e.g. genetic engineering). Across all three the results are consistent with the story in the published, indexed academic journal articles. For Sismondo, 'engineering' is mentioned 8 out of 207 pages of text (4%), in Hackett, 1 chapter out of 38 is focused on 'engineering ethics' (3% of chapters) while engineering is mentioned on 26 of the roughly 785 pages of text, excluding references, notes and the chapter on Engineering Ethics, which again is 3% of the included text. Similarly, for the Jasanoff text, 1 chapter out of 28 focuses 'engineering' (4%) – a key chapter referenced above on 'Engineering Studies' by [3]. Excluding the 14 pages of that chapter from the textbook, 'engineering' appears on 44 pages of the remaining 378 pages. This represents 12% of the written volume, around 3-4x more than in the more recent works by Hackett and Sismondo. The upshot is that despite Downey and Lucena's eloquent call to arms, engineering studies and the related empirical research investment has yet to take off.

2.3 'Engineering' in Technology in Society

Finally, and for the purposes of completeness given where we are publishing this paper, we undertook simple searches in Scopus of the indexed articles for *Technology in Society*. There are 2367 papers indexed in Scopus for the journal at the time of writing (August 2022), from 1979 to today. This represents a reasonably substantial body of literature focused largely on the conceptual space with which 'engineering policy' might reasonably feature. A search for

'engineer*' in the titles, abstract or keywords of the records (a broader search than before, given the narrower frame) resulted in only 235 hits (10%) of the papers (with only ~30% of those using 'engineer*' in the title, suggesting only around 3% centring on engineering per se), and *not a single hit* for {engineering policy}. This contrasts with 693 for 'scien*' (30%, with 37% in the title) which features 3x as frequently.

The evidence to date suggests that the marginalisation of social studies of engineering and related work on engineering policy visible to Downey and Lucena in 1995 remains. It may well be that the failure of STS to focus on engineering practice is due (as noted earlier) to the liminal status of engineering compared with science or technology [18]. However, this doesn't explain the lack of development of a corpus of academic literature emerging via other routes.

We speculate that this may be due to the nature of engineering itself – its epistemology, its ontology, and the common mode of practice. The epistemology of engineering typically focuses on answering practical problems [19], using tools rooted in mathematics and physics developed through formal education [13,20]. Such tools are unsurprisingly not suited to reflect on engineering practice. This is reinforced by an ontology focused on the physical that doesn't necessarily 'see' the socially-rooted practice(s) of engineers and engineering as an object of inquiry – it is not a 'problem' as such [21]. Finally, the private sector context of much engineering practice lends itself not to critical reflection on what is good, but more often to risk aversion from indefensible (i.e., non-standard) practice, and avoidance of litigation. This therefore privileges a practice tasked with designing (and implementing) physical solutions often with limited critical reflection, self-reflection, and reflexivity. Although potentially reasonable, such explanations for the lack of progress on this topic are limited by a severe lack of empirical data. This absence of data is one reason for us to write the article here and make the case for a research agenda on engineering policy.

Having established a lack of published research naming the concept of 'engineering policy' either generally in academic research or specifically within core areas of relevant social science research, we ask the question: that gap real? We turn next to address this question in two ways: first, whether other related policy concepts can arguably be said to cover the territory implied by the term 'engineering policy'; and second, to explore possible implications on the policy practice community which might derive from the absence of a research programme around 'engineering policy'.

3. Engineering policy: aka Applied Science or Technology / Innovation policy?

Do we need to introduce the term 'engineering policy'? Or, is the notion of adding 'applied' to science, and therefore assuming that 'science policy' has it covered, sufficient? Or can we assume that the obviously related concepts like 'technology' or 'innovation' policy have it covered? The argument might run: since engineers are part of the development of technology, surely a new concept of 'engineering policy' is unnecessary? Others have addressed this issue previously in different ways. [3] argue that engineering studies cannot be seen as a simple linear extension either forwards from the study of science or backwards from the study of technology. In large part this argument rests on the well-established

critiques of the linear model of innovation. We see a direct corollary of this argument from engineering studies to engineering policy.

3.1 Engineering policy vs science policy

To deal with the distinction between science policy and engineering policy first. The relationship between science and engineering is not a linear 'science discovers law, engineering applies it' since many of the instruments used by scientists to explore reality are built by engineers (e.g. the large hadron collider, telescopes, computer-aided personal interviews) and engineers have the capacity to create objects that have not been subject to (or the subject of) empirical scientific study (e.g. a solar-powered car). Further, engineers do more than simply 'apply science' in the process of innovation or design. Significant amounts of engineering is about managing and maintaining systems, ensuring safety and resilience and optimising processes in place. Additionally, scientists differ considerably in their likely workplace setting: many scientists work in publicly funded academic research institutions, while most engineers work in private sector companies [11]. Fundamentally, assumptions and concepts from science do not apply equally to engineering [22–24], meaning a distinction between the two, in policy terms, is important if both are to be governed effectively.

3.2 Engineering policy vs technology or innovation policy

We can further extend the argument for distinction by drawing on other elements of what a focus on 'engineering' vs technology or innovation brings. The focus on technology foregrounds objects, the focus on innovation foregrounds process. In Landon Winner's seminal work on the philosophy of technology, *The Whale and the Reactor* [25] he states:

> *The basic task for a philosophy of technology is to examine critically the nature and significance of artificial aids to human activity. That is its appropriate domain of inquiry, one that sets it apart from, say, the philosophy of science.*
>
> (p.4)

The focus on the 'artificial aids' actively backgrounds those that bring such artificial aids into existence, or who hold them there, or indeed might oversee their disposal: engineers. In much the same way, but more brusquely, he notes in relation to the void in a philosophy of technology that he aims to fill "[e]ngineers have shown little interest in filling [it]'. At the same time, his position tends to imply that a philosophy of technology and a philosophy of engineering are one and the same, at times asking, of engineering colleagues "What are the founding principles of your discipline?", as if the questions of technology and the questions of engineering are an identity. Suffice to say that his inquiries are reportedly met with 'puzzlement' from his engineering colleagues.

We therefore might agree with Winner's implied identity, that a philosophy (and, perhaps therefore a policy) of technology equals a philosophy of engineering. It would certainly make this paper shorter, but it is – perhaps not surprisingly – one we don't share. One piece of circumstantial evidence for differentiating between technology and engineering – at least at the philosophical level, is the emergence of several volumes focused on the philosophy of

engineering published some 3 decades after Winner's book first arrived [20,26–29]. One has to imagine that if there were no real distinction to make between technology and engineering, there would be no room to publish so many volumes. But while such evidence is useful in support of a distinction, it doesn't get to the heart of the distinction between technology and engineering, which is perhaps one of perspective and frame of analysis.

A focus on technologies is necessarily rooted in particular objects, with the engineers in orbit. Whereas a focus on engineers and engineering is necessarily rooted on their skills, knowledge and practices, often with technologies in orbit. Exploring engineering practice surfaces how engineers draw on existing and new knowledge, how they communicate amongst themselves and with others in a way that exploring technology does not.

3.3 Brief case example: solar geoengineering

Further, we can even find instances where technologies are being imagined in contexts where few or no engineers are present. Solar geoengineering, the field focused on developing techniques to increase the amount of solar rays reflected into space as way to reduce global warming, serves as a prime example [30]. Indeed, even though the discipline's name contains the term 'engineering', engineers occupy a peripheral place in the field.

Solar geoengineering research takes places mainly at universities and institutes where scientists (not engineers) are leading projects [31]. Typically, when solar geoengineering priorities and challenges are defined, natural scientists are the ones who tend to be called on first [32]. This is not to say engineers are completely absent but rather that they are normally brought in by scientists to demonstrate technical feasibility [33,34], cost-effectiveness [35,36] or design architecture for field experiments [37]. The science leads to candidate technology designs (here, for instance, stratospheric aerosol injection) which engineers are brought in to make real: solar geoengineering technologies are being imagined in a space where engineers are not central [38]. In this instance, the design phase is shared space where scientists are in the driving seat with engineers in support, problem-solving on a case-by-case basis. Fundamentally, the technology is not an identity with the engineer or engineering, supporting the case for a real and important demarcations between science, technology and engineering policy.

4. 'Engineering policy' in UK practice

The case for distinguishing between engineering and either technology or science is further made in relation to policy practice. It is to that area we now turn our attention with specific focus on the emergence of 'engineering policy' in policy and practice communities, with reference to the UK, largely because it is known directly to us, and data on other jurisdictions is not easily available (which of course, further illustrates our main point). Our intention here is to show how the limited emergence of 'engineering policy' in government settings could be a corollary of the limited focus on 'engineering policy' (and engineering studies more generally) in academic settings. If this causal link is a real one, it would lend weight to the argument that establishing a higher profile and robust programme of critical,

interdisciplinary (or even transdisciplinary) academic research on engineering policy is essential to getting change at the governmental level.

4.1 Engineering in central government

When looking for 'engineering policy' in practice, what are we looking for? Obvious signs of 'engineering policy' being a central and foregrounded concern of policy practitioners is surely the existence of a government ministry with a portfolio focused explicitly on engineering. In the UK, there is currently no such ministry nor ministerial portfolio where 'engineering' is directly visible. The most obvious place for such a portfolio is in the UK's ministry responsible for science, technology and innovation policy: the Department for Business, Energy and Industrial Strategy. But there, the portfolios of the current ministerial team (as at 8 Aug 2022) comprise the Secretary of State whose portfolio includes "ensuring the UK remains at the leading edge of science, research and innovation" (followed by a listing of several organisations, none of whom mention engineering explicitly) and has responsibility for "steel and metals, critical minerals and the maritime, automotive and aerospace sectors". Which is a very circumspect way of naming a large portion of the UK engineering community, while not actually naming the 'engineering community' as such. This clearly has implications for engineering policy, but one which is *ad hoc* rather than strategic.

The other 4 ministers have portfolios which are mainly business or energy/climate focused. Notably, the ministerial post which is nominally closest to engineering – the Parliamentary Under Secretary of State (Minister for Science, Research and Innovation) is currently vacant since the minister resigned earlier in the year. Much like the Secretary of State's portfolio, the responsibilities include tiptoe around various technologies (fusion, artificial intelligence) as well as just mentioning 'technology' itself, without ever mentioning engineering *per se*. Similarly, in the UK Parliament, where scrutiny of government policy reaches its apotheosis via the 'committee' structure, a search for 'engineering' in the names any of the 262 current committees brings up no hits[*]. By contrast, a search for 'science', returns 6 committees, and 'technology', 7.

4.2 Engineering in public bodies

This absence of 'engineering' from the national policy landscape extends through to the range of bodies that represent 'engineering' interests in government. A search of the UK's governmental departments, agencies and public bodies[†] for 'engineering' in their names reveals 4 organisations (out of a possible 587) referring to engineering, compared with 16 for 'science', and 6 for 'technology'. A closer look at the 4 'engineering' bodies is instructive at this point:

[*] Search conducted here: https://committees.parliament.uk/committees/ by entering the word 'engineering' into the box labelled 'Name, abbreviation or keyword(s), 'House' and 'Status' options set to 'any'. Last accessed 8 August 2022.

[†] https://www.gov.uk/government/organisations. Accessed 8 Aug 2022. Simple searches in the text box labelled 'Search for a department, agency or public body'.

- the **Engineering and Physical Sciences Research Council** (EPSRC) a national body, funded via taxpayer income, that distributes research grants on topics rooted in their definition of engineering, largely to universities and similar eligible research institutes. This is clearly a manifestation of 'policy for engineering' but is also not exclusively 'engineering' and is mainly about research in universities.
- the **Government Science and Engineering Profession**, which sets the standards for recruitment and progression of civil servants occupying posts with an explicit requirement of science of engineering training. This is clearly a manifestation of 'engineering for policy' (which also has implications for policy for engineering). Again, this is not exclusively engineering.
- The **Engineering Construction Industry Training Board** has a role to ensure sufficient skills supply in the construction industry, and is sponsored by the UK Department for Education. This is clearly a manifestation of 'policy for engineering' (which has implications for 'engineering for policy'). This is exclusively engineering, but is one sub-domain of engineering, and a workforce-focused body – so *ad hoc* in a way similar to the ministerial portfolio discussed earlier.
- **Military Engineering Experiment Establishment** which appears to have been untied from central government funding as an independent, not-for-profit, that provides 'pro bono support to the Armed Forces, [Ministry of Defence] and its agencies, and other government departments'[‡]. This is clearly a manifestation of 'engineering for policy'. While this is clearly mainly engineering body (though some of the members are 'scientists'), it is also a very niche area.

It is clear that 2 of the 4 bodies are not exclusive focused on engineering, and one of them is very narrowly focused, so not strategically important for 'engineering policy'. This indicates that the profile of engineering in the UK government is extremely low or narrow, and capacity for any of them to represent or channel wider policy or public interests in engineering as a form of governance is likely nil.

4.3 Engineering policy in non-governmental bodies

Outside of central government, the only other obvious place where 'engineering policy' manifests explicitly in policy practice settings is via the relatively recently established Royal Academy of Engineering-led *National Engineering Policy Centre* (NEPC). This Centre enable the sector, as embodied by 42 UK engineering bodies (often called 'institutions') to provide engineering advice to government – so represents another form of 'engineering for policy. The '42 engineering bodies' arguably represent the main way that 'engineering policy' in the UK manifests, particularly the 'policy for engineering', alongside the EPSRC identified above. These comprise the Royal Academy of Engineering – a charity with similar status to the Royal Society, independent of government funding. The 39 UK institutions of engineering that are licensed by the UK Engineering Council. These licences allow the institutions to assess professional practice standards important for accreditation – and so is clearly a governing body and structure for engineering policy. The Engineering Council is a fee-

[‡] https://mexe.org.uk accessed 8 Aug 2022. Site was being developed at the time of access so the landing text may well have changed.

funded, membership organisation, which gains income via another body, Engineering UK – not-for-profit, limited by guarantee charitable-status company.

These institutions of engineering are clearly an extremely important feature of the UK engineering policy landscape, such as it exists. They clearly play an important role in establishing the nature and quality of engineering in their disciplinary or institutional clusters, but how those standards get determined is less clear. The main focus seems to be on establishing the intellectual and practical value of engineering to policy (via the advisory functions like the NEPC) rather than on considering what might make engineering fit for the 21st century. To be clear, these institutions do consider such questions – an undated document (likely from around 2010) is available on the UK Engineering Council's website called "Engineering the future – a vision for the future of engineering"[§]. Yet even this document is very much about engineering for policy (and delivery), including a section specifically about 'engineering advice'. There is nothing at all on policy for engineering, which is clearly a significant and strategic issue in determining whether we get the engineering we need in society.

5. An agenda for (critical) engineering policy research

It is clear that engineering is both fundamental the nature of our society now and fundamental to how we shape society in the future, including addressing the existential crisis of climate and ecological breakdown. Yet, understand, scrutiny and governance of engineering remains largely beyond academic critical inquiry, research programmes and public policy. This paper is an attempt to address this fundamental gap, picking up the baton from Downey's papers in 1995, and 2015 and seek to establish research on engineering policy and practice as a key plank in the global research architecture alongside science innovation and technology policy, and science and technology studies. We now turn our attention to setting out a provisional agenda for how to build the foundations of this enterprise as an entry point into a wider debate.

Some of the key elements for future research into this area need to take account of the recent developments. These include the ongoing work published by the journal *Engineering Studies*, and the various volumes, most recently the *Routledge Handbook on the Philosophy of Engineering.* These sources reveal two major foci of recent work relevant to engineering policy: a focus on engineering education and a focus on engineering ethics. Both such areas are essential for any programme of research related to engineering policy, but neither cover the topic directly. Any research on engineering policy must interrogate, integrate and build on work in these areas as well as open up new questions about curriculum, chartering standards and issues of philosophy around ethics in public governance, epistemology, ontology and methodology.

Three papers directly focused on engineering policy are also worth reflecting on. Brian Collin's section Engineering Policy in *The Future of Scientific Advice in Whitehall* [39] tends to focus on the 'engineering for policy' side of the equation, like most of the commentary and

[§] Available here: https://www.engc.org.uk/EngCDocuments/Internet/Website/Engineering%20the%20future%20-%20Manifesto.pdf Accessed 8 September 2022.

analysis in this nascent field. This includes a call for more and better use of systems thinking and better links between policy design and execution. Natasha McCarthy's focus is also on 'engineering for policy' [13]. She does reflect briefly on 'policy for engineering' but moves on quickly to engineering advice. Her analysis is insightful not least in the use of narrative form to understand engineering advice, which is important for comparing with other sources of advice in science, economics, modelling and social research. The other significant development in McCarthy's work is the foregrounding of qualitative data to support analysis – something we have seen very little. Much of the literature (excluding the significant work of Bucciarelli [40]) is lacking empirical data, informed either by personal experience (e.g. Collins, Petroski) or philosophical argument or theoretical insight (e.g. Mitcham and Kang, Pitt, Downey). Further, the emphasis in general is on engineering advice and more generally, engineering education, ethics and philosophy.

5.1 Understanding Policy for Engineering – developing comparative data

A major gap in the research identified as here as real and distinct, and supported by argument and analysis elsewhere, is the understanding of policy for engineering. The key issue here is simply observing how engineering is governed in different contexts and to develop the mechanisms of data collection and comparative analysis to explore it. What seems important here is that different states have different approaches to governing engineering, and different engineering disciplines approach their own governance in a variety of ways. Being able to see and understand these differences will be a major leap forward. Extending this to understand how different governing regimes gives rise to different societal outcomes is over course the major goal of such an enterprise. Part of this about the relation of standards applied in education (accreditation) and in ongoing professional training and standards (including the role, process and importance of chartering). Also, of interest here will be the relationship between engineering and science – and whether lessons from one can be drawn for the other, or indeed whether some co-ordination between the two is necessary to reap benefits otherwise inaccessible.

5.2 Extending our understanding of engineering for policy – developing thick description

As noted above, and as developed by Cooper [41], Lioté [42] and McCarthy building on the emerging qualitative empirical corpus of data on engineering advice will be key in understanding how it functions, where the opportunities and risks are for policy. From this author's perspective who has had significant government experience as a social researcher, the absence of engineering in social policy (e.g., education, justice) is as problematic as their dominant presence in 'technical' policy areas such as transport and energy. Understanding where engineers are, whether they aren't and how they wield influence (or not) and to what societal benefit, should be central concerns. Exploring how this happens in other settings such as the private sector, international governmental organisations and in different countries will be key.

5.3 Building on recent work in education, practice, diversity as well as philosophy and ethics

The focus of research in the journal *Engineering Studies* and the emergence of several volumes focused on the philosophy and ethics of engineering [20,28,29,43,44] gives rise to several topics that can be built on and connected to a wider enterprise of research on engineering policy. A rapid content analysis of the title, abstracts and keywords from 144 articles published in *Engineering Studies* since 2009, shows that the topics of *education* (searched as 'educat*', ca. 50%, or 78 papers mentioning), *practice* (practic* or profession*, 70 and 73 mentioning, respectively) dominate. After that, gender and related topics (around 25) before philosophy, ethics or policy (philosoph*, ethic* and policy, around 10 each). Connecting these topics will be key to understanding the mechanisms of change in engineering itself, which is a central concern for any engineering policy. A key idea here is to develop an international, longitudinal cohort to follow through the life outcomes and experiences of engineers in different settings, providing a backbone for critical and ethnographic approaches. Central to this would be a greater focus on inclusion, meaning not just a stronger focus on the topics of gender and racial justice but also inclusion of research in the Global South, beyond US and European borders.

5.4 *Creating a focal point for engineering policy research*

Engineering policy is understood as so central to delivering fair and effective outcomes in society (and implicitly, the lack of a critical approach to engineering policy is a partial cause of engineering policy failures) that any such research programme needs to consolidate research carried out under 5.1-3 above, and provide a neutral arena for open debate across the communities of interest in engineers. Crucially, such an arena cannot be owned by engineering (so current institutions cannot play that role) as that prevents the neutrality required for open, critical debate. It needs to connect the academic community, the wider engineering practice community (including institutions but also businesses) and policy communities. The need for such an arena is necessitated by the fact that neither business nor policy communities access journal articles, and if they did, would regularly fail to recognise the concepts or jargon necessary to develop ideas. But instead, a dynamic, open arena would enable the kind of transdisciplinarity necessary for success in this enterprise, and to connect the views and insights from practice into research programmes and vice versa. We propose therefore that an Institute of Engineering Policy as a necessary development, one which might even oversee a dedicated open access journal, and related conferences. It is worth noting that the journal *Technology in Society* represents the closest the engineering community has to *Nature* or *Science* as a platform for debating and sharing strategically important ideas about engineering.

6. Conclusions

We recognise that much of what we have said repeats ideas and issues developed elsewhere. The notion that engineering is marginalised is not new. The notion that engineering has so far avoided critical inquiry from a large proportion of the social science community has been noted. We have extended this into the notion of 'engineering policy' to highlight key governance concerns over a central mechanism of societal reproduction and maintenance. We have attempted to reinforce the claims in this area made by others with regard to bibliometric data and explorations into the case of solar geoengineering and the practice of engineering policy in the UK government. In so doing, we have attempted to

draw together a number of threads, and with it an emerging swell in the ocean of the academy and beyond that seeks to explore whether the engineering we have is the engineering we need. For us these are central defining questions of our age, and where others cannot see that, we hope the research community becomes convinced by the work of those who can.

We hope this paper ignites a wider debate in this critical community, alongside work the authors are doing to bring engineering communities and their work in this area together for mutually beneficial exchange and development of ideas.

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Highlights

- Engineering policy has rarely been recognised or scrutinised by the academy
- This contrasts with science policy which is the subject of significant research
- The absence of engineering policy in public governance is a major issue
- An agenda of research and debate on engineering policy is proposed