Doctoral Thesis

How is engineering advice deployed in energy policy practice? An ethnographic look at BEIS, the UK government's department for energy

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Declaration of Authorship

I, Laurent-Olivier Lioté, confirm that the work presented in this doctoral thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in this thesis.

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The following work of the author is partially integrated into this thesis and was undertaken throughout the time that the author was registered at UCL working towards the completion of this thesis.

- Lioté, L. (2023) 'Towards a framework for understanding transdisciplinary engineering in policy practice: Insights from the UK's energy ministry'. In P. Koomsap, A.C.G. Cooper, J. Stjepandić (Eds.), *Leveraging Transdisciplinary Engineering in a Changing and Connected World*. Amsterdam, Netherlands: IOS Press. https://dx.doi.org/10.3233/ATDE230671

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- Cooper, A.C.G., Lioté, L. & Colomer, C. (2023) 'We Need to Talk About Engineering Policy'. *Technology in Society.* https://dx.doi.org/10.1016/j.techsoc.2023.102196

- Lioté, L. (2022) ‘Modelling for the UK’s utility-scale solar regulation change: Lessons for transdisciplinary engineering in policy practice’. In B. R. Moser, P. Koomsap, J. Stjepandić (Eds.), *Transdisciplinarity and the Future of Engineering.* Amsterdam, Netherlands: IOS Press. https://dx.doi.org/10.3233/ATDE220646

Full UCL research paper declaration forms can be found in appendix L.

Laurent-Olivier Lioté

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Abstract

Given their involvement in the development and construction of built-systems, engineers have a crucial role to play in tackling the grand challenges faced by our societies. For example, developing new modes of transportation and energy production to tackle climate change. However, seeing that engineering has such a key role to play in policy making, the fact that no significant academic corpus explores engineering advice for policy is surprising. This thesis therefore aims to fill this void by looking at engineering advice deployment in UK policy making.

As academic literature on this topic is limited, this thesis starts by building a theoretical framework by looking at three adjacent fields of study. The review of science advice, engineering studies and UK intra-ministerial policy advice literature generates three questions to be empirically answered:

- How does engineering advice work in a UK government department?
- What is the difference between science and engineering advice in a UK ministerial context?
- What are the impacts of the UK government structure and civil service culture on engineering advice?

To answer these questions, this thesis takes an underused but called-for methodological approach to study policymaking: ethnography. This ethnographic study focuses on a team of trained engineers that advises other policy teams within the UK government's Department for Business, Energy, and Industrial Strategy (BEIS). The research looks at how the engineers interface with policy officers, how the engineering team compares to BEIS' climate science team and how the civil service culture shapes engineering advice.

By combining concepts from the theoretical framework and the data collected, this thesis provides insights into engineering advice deployment in policy along three axes. It starts a conversation about the epistemology of engineering advisers and its impact on policy. It compares engineering and science advice to show what makes engineering advice unique and

how it should be conceptualised. And it highlights how political vision influences engineering advice development. This thesis ends by suggesting avenues for future research to further improve the understanding of engineering advice in policy practice.

Impact Statement

Academic impact. This thesis ethnographically investigates engineering advice deployment in energy policy practice and has multiple academic impacts. It explores a topic, engineering advice for policy, that has never been systematically examined in the academic literature. This study therefore opens a new research area but also contributes to three adjacent fields. It explores whether science advice literature concepts can be applied to engineering advice as assumed by science advice scholars. It looks at whether engineers advising policy makers share the same practices and identity as engineers in the private sector, as observed by engineering studies authors. It complements UK intra-ministerial advice literature by adding the relationship between engineering advisers and policy officers to this body of work. This thesis does all this by adopting an ethnographic approach, an underused but called-for methodology to study policy making. This research recommends the further investigation of engineering advice deployment in policy along three axes: the epistemology of engineering advisers in policy, the uniqueness of engineering advice and the institutional context in which advisers operate. Future research could therefore build on this work and consider these three points in different contexts: different policy organisations, different policy areas and different countries.

This research has already generated several academic outputs. Four publications have been written using empirical and theoretical insights from this study, all of which cater to the academic engineering and academic policy communities and create a space for anyone in between. Three of these articles have been presented at international conferences, one of them earning a 'best student paper' award at the Massachusetts Institute of Technology (MIT) for the *29th Conference on Transdisciplinary Engineering*. By April 2024, this thesis will generate two additional publications in the following journals: *Engineering Studies* and *Policy Sciences.*

Policy impact. This thesis also yields two sets of policy insights. First, continuing professional development courses and higher education programmes are needed to help engineers and policy makers collaborate. Such training should be developed with experienced engineering advisers and policy makers to leverage the best practices they acquired with experience. Some are presented in this thesis. Second, to fully leverage engineering advice, policy organisations need to think about how to organise their engineering capacity. This research offers insights into how engineering and policy teams can be arranged to best benefit policy making. Future research should share best practices and insights from this thesis with other organisations and find new organisational strategies to improve engineering advice deployment in policy.

This research has already generated several policy outputs. Insights from this research have been shared with the UK Department for Energy and the UK Department for Transport. This enabled cross-governmental sharing of engineering advice best practices. Findings from this thesis have also served as the basis for developing an Engineering in Policy Network to connect professionals interested in the role engineering can play in policy making. In the future, this study could be used to foster more cross-governmental initiatives to improve the deployment of engineering advice in policy.

Acknowledgments

First and foremost, I would like to thank both my supervisors, Dr. Adam Cooper and Pr. Neil Strachan for all their help and support during these last four years. I would also like to mention the PhD students, academic and professional services staff at STEaPP, my home department, for their guidance and the stimulating conversations. I am lucky to share an office with PhD students from Security and Crime Science and the Cyber Security CDT who have kept me sane through the pandemic and beyond. Additional professional acknowledgments go to all other PhD students and academics I met at UCL, conferences and workshops, thank you for your input. I would also like to thank the EPSRC for funding my research (grant #2264956) and all the civil servants who participated in my study.

On a more personal note, I would like to thank all my friends from over the years, who have shaped my personal and professional journey more than they might know. This includes my childhood friends from Paris and the U.S. and their growing families, my London friends from my undergraduate, masters and now PhD, my former colleagues, and my running and football friends. Thank you for being there, I have learned so much from you all.

Finally, I would like to thank my family, without whom I would not be here. Your unwavering love and support mean everything. *Merci pour tout!*

Table of Contents

List of Figures

List of Tables

List of Acronyms

AC	Alternative Current
B-SEN	BEIS Science and Engineering Network
BEIS	UK Government Department for Business, Energy and Industrial Strategy
BERR	Department for Business, Enterprise and Regulatory Reform
BIS	UK Government Department for Business Innovation and Skills
BSE	Bovine Spongiform Encephalopathy
CAD	Computer-Aided Design
CPD	Continuing Professional Development
CS-N0W	Climate Services for a Net-Zero (resilient) World
CSA	Chief Scientific Adviser
DBT	Department for Business and Trade
DfT	Department for Transport
DC	Direct Current
DCMS	Department for Digital, Culture, Media and Sport
DECC	UK Government Department for Energy and Climate Change
DEFRA	UK Government Department for Environment, Food and Rural Affairs
DESNZ	UK Government Department for Energy Security and Net-Zero
DIUS	Department for Innovation, Universities and Skills
DSIT	Department for Science, Innovation and Technology
DSR	Demand Side Response
EBPM	Evidence-Based Policy Making
EPA	Environment Protection Agency
EU	European Union
EV	Electric Vehicle
FDA	Food and Drug Administration
GCSA	Government Chief Scientific Adviser
GO-Science	Government Office For Science
GRAINN	Genetics, Robotics, Artificial Intelligence, Neuroscience and Nanotech
GSE	Government Science and Engineering profession

HEO	Higher Executive Officers
IEEE	Institute of Electrical and Electronics Engineers
IGEM	Institution of Gas Engineers and Managers
IPCC	Intergovernmental Panel on Climate Change
ITT	Invitation To Tender
MW	Megawatt
MoG	Machinery of Government
NAS	National Academy of Science
NSIP	Nationally Significant Infrastructure Project
PM	Prime Minister
PV	Photovoltaic Panel
RQ	Research Question
SCS	Senior Civil Service
SEO	Senior Executive Officers
SICE	Science and Innovation for Climate and Energy
STS	Science and Technology Studies
UCL	University College London
UK	United Kingdom
UKRI	UK Research and Innovation
UN	United Nations
US	United States of America

How is engineering advice deployed in energy policy practice? An ethnographic look at BEIS, the UK government's department for energy

1 Introduction

1.1 Problem context and aim of the thesis

> *"If you are reading this on a screen, the specific set of electrical impulses that creates the characters that appear before you was standardized by a recent international committee of engineers, as were the software languages that make it possible for your e-reader to generate this text. Other such committees established the standards for the battery your device uses and for every switch and junction, transmission line and tower, between your battery charger and the power plants that provide its electricity" –* ***Yates and Murphy*** *(2019, p.1)*

Engineers are behind all the objects we use, the machines that build these objects and the infrastructure that allows them to work. In fact, in one of its broader definitions, engineering refers to the practices of design and construction of any artifact that meets some recognised need (Vincenti, 1993; Mitcham, 2020). Engineers are therefore involved in designing and building objects and ensembles of objects, i.e. systems, that transform the world around us. Given their involvement in the development, construction and operation of built-systems, engineers have a crucial role to play in tackling the grand challenges faced by our societies. This includes, for instance, working with policy makers to develop new modes of transportation and energy production to tackle climate change.

Seeing that engineering and engineers have such a key role to play in policy making, the limited attention it gets in academia is surprising. Only a few attempts at exploring what engineering advice for policy looks like have been made and serve as the basis for this research. As detailed below, McCarthy (2017, 2021) and Cooper (2020) both offer insights into engineering advice deployment in UK policy practice and conclude that further research is needed to fully understand the engineering-policy interface. As Cooper (ibid) points out, besides isolated efforts like these studies, there is no significant academic field or corpus specifically examining engineering advice for policy.

Considering the importance of engineering in tackling many of the policy challenges we currently face and the lack of academic literature on this topic, this thesis aims to fill this void by investigating how engineering advice is deployed in policy practice. This research therefore builds on McCarthy and particularly Cooper's work to improve the academic and policy conceptualisation of engineering advice. This thesis explores engineering advice in the UK to more easily build on the aforementioned studies that share the same national focus. Concentrating on the UK also facilitates policy access as this research is funded by a UK research council and carried out by a UK national in a UK university.

1.2 Academic literature and research questions

Given that there is no academic corpus that systematically examines engineering advice for policy, the theoretical framework for this research had to be derived from adjacent fields of study and McCarthy and Cooper's work.

The most obvious starting point with engineering advice is the academic literature on science advice. Indeed, the science advice literature shares similarities with this research's focus as it examines the relationship between a technically trained group (scientists) and policy officials in a policymaking setting. A common misconception visible in this literature however is that science advice incorporates engineering advice. As the literature review shows, engineering and science are different disciplines with different goals and ways of thinking, raising questions around the applicability of science advice concepts to engineering advice.

To explore this further, the literature review draws on authors who looked at the difference between science and engineering. Their work pioneered the field of engineering studies which ethnographically explores engineers' skills and practices in industry. Engineering studies however does not consider these practices in policy, requiring us to use McCarthy and Cooper's work on engineering advice to extrapolate engineering studies authors' findings.

McCarthy's work (2017), based on policy document analysis and personal experience, looks at communication issues at the engineering-policy interface and how they can be improved. A second study (2021) analyses the narrative of engineering advice in policy, drawing on philosophical reflections on the nature of engineering and academic literature on narrative explanation. Working with more empirical data, Cooper (2020) explores policy officials' narratives of working with internal engineer officers in the UK Government Department for Energy and Climate Change (DECC) in 2012. Based on interviews of policy officials, Cooper examines the nature of engineering advice for policy and how it might differ from science advice. Possible differences are drawn from the language used by policy officials when discussing engineering advice compared to selected concepts in the science advice literature, rather an empirical comparison between science and engineering advice in that context. Cooper ends by hypothesising that, given engineering advice is about "problem-solving in the physical world", it can be particularly valuable for policy officials "aiming to make policy that works" (ibid, 501). Alternatively, ministerial engineering experts could clash with policy officers who are also trying to solve a policy problem in a different way.

Linking engineering studies authors' findings and McCarthy and Cooper's work starts to generate a theoretical narrative of engineering advice in policy. This includes insights into the focus and narrative of engineering advice and hypotheses on the skills and practices of engineering advisers in policy. McCarthy and Cooper's studies combined with literature on the difference between science and engineering also highlight theoretical differences between engineering and science advice. This also generates hypotheses on which science advice concepts might be transferable (or not) from the science advice literature.

This leaves one last theoretical angle unexplored: the impact of policy setting on engineering advice. In the UK, a lot of policy making is done at ministerial level (Page and Jenkins, 2005; Page 2006, 2010, 2012), making government departments appropriate sites to explore engineering advice for policy. Cooper's study acknowledges this point and looks inside a UK government department; however it does not delve into the impacts of the UK civil service or department's structure on engineering advice. The science advice literature is of no use here either as it focuses on advice in organisations that advise yet sit outside of central government. And engineering studies literature, as mentioned, does not consider engineering practice in a policy setting. The last part of the theoretical framework therefore looks at literature that ethnographically explores the impact of the UK's civil service culture and structure on policy advice in government departments. Working those insights into our theoretical narrative of engineering advice prompts a reflection on the knowledge and skills of engineering advisers and their relationship with policy officers in UK ministries.

The framework created by combining science advice, engineering studies, and policy literature generates a theoretical picture of engineering advice deployment in UK government departments. This theoretical narrative however remains to be empirically tested and this can be done by answering the following three research questions:

1. How does engineering advice work in a UK government department?
2. What is the difference between science and engineering advice in a UK ministerial context?
3. What are the impacts of the UK government structure and civil service culture on engineering advice?

1.3 Methodology and research setting

The three research questions are underpinned by literature focused on how science advisers, engineers, and UK policy officers understand their role, practices, and identity. This implies that an understanding of engineering advice in policy can be found by analysing the day-to-day activities of engineering advisers and their collaborators and how they interpret what they do. The research questions also suggest that special attention should be paid to the structural context in which the actors operate as it shapes their role and practices. An ethnographic approach, whose objective is to understand the activities and interpretations of actors in a given setting or structure (Malinowski, 1978), therefore seems like an appropriate methodological choice.

Adopting an ethnographic approach to engineering advice in policy practice is not only an appropriate way to get the data needed to answer the research questions, but also an underused approach to study policy making. Science advice authors (Hiltgartner, 2004; Spruijt et al., 2014) and UK policy advice scholars (Stevens, 2011; Page, 2012) noted that their respective fields would benefit from more ethnographic studies exploring how policy advice is constructed from the point of view of those who give and receive it. Engineering studies authors use ethnographic methods but have never applied them to engineers working in policy. Ethnographically exploring engineering advice in policy therefore presents a double contribution: it fills in a content gap by looking into an understudied domain and a methodological gap by using an underused (but called-for) approach.

The selection of the ethnographic site was influenced by Cooper's work (2020). As mentioned above, the study rests on interviews of 18 policy officers at DECC and explores their narratives of working with internal engineering advisers. In line with Page's point, Cooper explains that the UK's energy ministry is a good place to look at engineering advice because, in the UK, a lot of policy is made at ministerial level and because energy is clearly an engineering-dependent policy area. Cooper also mentions that DECC had an internal engineering advice team and a science advice team although he only interviews the policy officers that work with them. The UK's energy ministry therefore seemed like an appropriate setting for this research for multiple reasons. First, based on Cooper's study and his retained network as an ex-civil servant, we knew we would find engineering advice there. Second, it would enable us to answer our first two research questions and build on Cooper's work by focusing on the engineering advisers and science advisers rather than just the policy officers they collaborate with. And finally, it would provide answers to our third research question on the impacts of the UK civil service structure and culture on engineering advice.

Since Cooper's study, DECC merged with another department to become the Department for Business, Energy and Industrial Strategy (BEIS). The internal engineering advice team mentioned in Cooper's work however is still active and formally called BEIS' 'technical energy specialist team'. The team is made up of trained engineers and its remit is to "provide engineering advice to other policy units sitting within BEIS to deliver decarbonisation of energy at an acceptable cost"[1]. The engineering advice team therefore seemed like a good place to start investigating the engineering-policy interface and became the focus if this study. To be clear, BEIS has engineering advice capacity in other teams, as well as other ways of bringing engineering expertise into the department. However, given the amount of time it takes to undertake an ethnographic study and the amount of data it generates, we decided to limit our focus to this one space.

Data collection and analysis was subsequently divided into three research phases, each phase mapping on to a research question. The first phase, designed to explore how engineering advice works in a UK government department, focused on the engineering advice team. It consisted of document analysis and ethnographic interviews of engineering advisers and the policy officers they work with. This generated insights into the engineering-policy interface by following the same projects from the engineering advisers and policy officers' point of view. Document and interview data were thematically analysed.

The second phase of research aimed to answer our research question on the difference between science and engineering advice in a UK ministerial context. To explore this, we looked at BEIS' climate science team that "looks after the UK's climate science capability and provides scientific advice to other policy teams within the ministry"[2]. This team is based in the same directorate as the engineering advice team, allowing for a direct comparison of science and engineering advice in this context. This phase consisted of observation, document analysis, a community-based workshop and ethnographic interviews of engineering advisers, science advisers and the policy officers they work with. All the data was thematically analysed, reusing as many themes from phase 1 as possible to make the comparison between science and engineering easier. As highlighted throughout this thesis, please note that the comparison here is between engineering advice and climate science advice in the context of those two teams at BEIS. As explored in the conclusion, further research would be needed to see if the findings in this thesis apply to other types of science advice, in health or medicine for instance.

[1] Description taken from the letter sent by BEIS to UCL to approve my fieldwork.
[2] Quote from the head of the climate science team

The last phase of research looked at the impacts of the UK civil service's institutional structure and culture on engineering advice. This consisted of document analysis and interviews of senior civil servants who currently supervise the engineering advice team, its directorate, and the policy teams that work with the engineering team. To take a more historical perspective, ex- senior civil servants who oversaw the science and engineering capacity of the ministry during its transition from DECC to BEIS were also interviewed. Data gathered were thematically analysed, again, re-using themes from phases 1 and 2 where applicable.

1.4 Findings and contribution

Each research phase surfaces different insights. Phase one shows how engineers and policy officers' interface at each stage of the policy advice process. Phase two highlights the similarities and differences in work process and content between the engineering and science advice team. Phase three explores how changes in ministerial vision have shaped the role of engineering advisers at BEIS and the impact of the civil service's generalist ethos on engineering advice.

Combining these empirical insights with points from the literature review answers our three research questions. The analysis of the engineering-policy interface (phase 1) nuances and adds to two bodies of literature: engineering studies and UK intra-ministerial advice literature. This opens up a discussion about the epistemology of engineers in an intra-ministerial setting and its implications for policy. The comparison of engineering and science advice at BEIS (phase 2) links back to the literature on science and engineering epistemology and science advice literature. This starts a conversation about what makes engineering advice unique and what it means for its role in policy and academic conceptualisation. And finally, results on the impact of the civil service culture and structure on engineering advice echo arguments from the intra-ministerial advice literature. This shows how political vision, ministerial team arrangement and turnover reinforce certain issues at the engineering-policy interface.

The findings and analysis mentioned above contribute to a better understanding of engineering advice deployment in policy practice. This thesis adds to McCarthy and Cooper's work by reinforcing and refining theoretical points made in these studies with additional empirical data. This work also contributes to three adjacent academic fields. It explores whether science advice literature concepts can be applied to engineering advice as assumed by science advice scholars. It looks at whether engineers advising policy makers share the same practices and identity as engineers in the private sector, as observed by engineering studies authors. And it complements UK intra-ministerial advice literature by adding the relationship between engineering advisers and policy officers to this body of work.

This thesis concludes with two sets of policy insights to best leverage engineering advice. One relates to education and training for current and future staff working at the engineering-policy interface. The other is connected to organisational structure and how ministerial team can be arranged to improve engineering advice deployment. We end by proposing avenues for future research for scholars wishing to build on this study and further contribute to the understanding of engineering advice in policy practice.

1.5 Thesis outline

The remainder of this thesis is structured as follows:

Chapter 2: Literature Review. This chapter creates a theoretical framework for our research using concepts from three adjacent fields of inquiry: science advice, engineering studies and intra-ministerial policy advice. We outline the strengths and gaps of each field in relation to our research aim. We also triangulate findings from each field with insights from the few studies on engineering advice available to generate three research questions to be empirically tested.

Chapter 3: Methodology. This chapter outlines why an ethnographic approach is justified to gather the empirical data needed to answer our three research questions. We also show how we designed three research phases, centred on BEIS' engineering advice team, to collect and analyse the data needed. This chapter ends with a section reflecting on the limitations of the methods, the issues encountered during the research process and how they were dealt with.

Chapters 4 to 6: Results. These three chapters present, in-turn, results from the three phases of research and include fragments of raw data (i.e. participant quotes and extracts from policy documents). Chapter 4 explores how engineers and policy officers interface at each stage of the policy advice process. Chapter 5 explores the similarities and differences in work process and content between the engineering and science advice team. Chapter 6 explores how changes in ministerial vision have shaped the role of engineering advisers at BEIS and the impact of the civil service's generalist ethos on engineering advice.

Chapter 7: Discussion. This chapter creates a dialogue between my empirical findings and concepts introduced in the literature review. This chapter is organised around my three research questions and answers each of them in-turn to improve how engineering advice deployment is understood academically and in policy. It introduces the concept of 'the generalist engineer' to describe the epistemology of engineering advisers and its impact on policy. It looks at difference between engineering and science based on the ethnographic data collected and therefore what concepts from science advice apply to engineering advice. It shows how political vision, ministerial team arrangement and turnover reinforce certain issues at the engineering-policy interface. And finally, it presents potential policy and educational strategies to alleviate these issues and facilitate engineering advice deployment in policy practice.

Chapter 8: Conclusion. The chapter summarises academic and policy insights from the discussion, highlighting key elements to look out for when conceptualising engineering advice deployment in policy practice. It also outlines the limitations of the study, pointing out that insights from the discussion have been developed in a specific context. This chapter proposes avenues for future research to further understand engineering advice deployment in policy practice.

2 Literature Review

As established in the introduction, engineering advice for policy has never been systematically examined in the academic literature. This chapter therefore looks for useful theoretical concepts in three adjacent fields of inquiry: science advice, engineering studies and intra-ministerial policy advice. The relationship between these three fields and the focus of this thesis are captured in figure 2.1 below.

The most obvious starting point with engineering advice is the extant literature on science advice. The science advice literature shares similarities with our research in that it explores the relationship between a technically trained group (scientists) and a typically non-technically trained group (policy officials) in the context of policymaking. A common misconception visible in this literature however, as we will see, is that science advice incorporates engineering advice. Upon closer inspection this turns out to be wrong and reflects a wider misunderstanding of engineering.

The science advice literature covers a similar conceptual space to our research, but important differences are notable. It tends to overlook intra-ministerial advice and focuses almost exclusively on science and not engineering. The latter point is due the fields' broad definition of science which gives the impression that science advice concepts can be applied to science and any other type of technical advice for policy, including engineering. We point out however that engineering and science are two different but inter-related disciplines with different goals and ways of thinking, raising questions around how well insights from science advice can be applied to engineering advice.

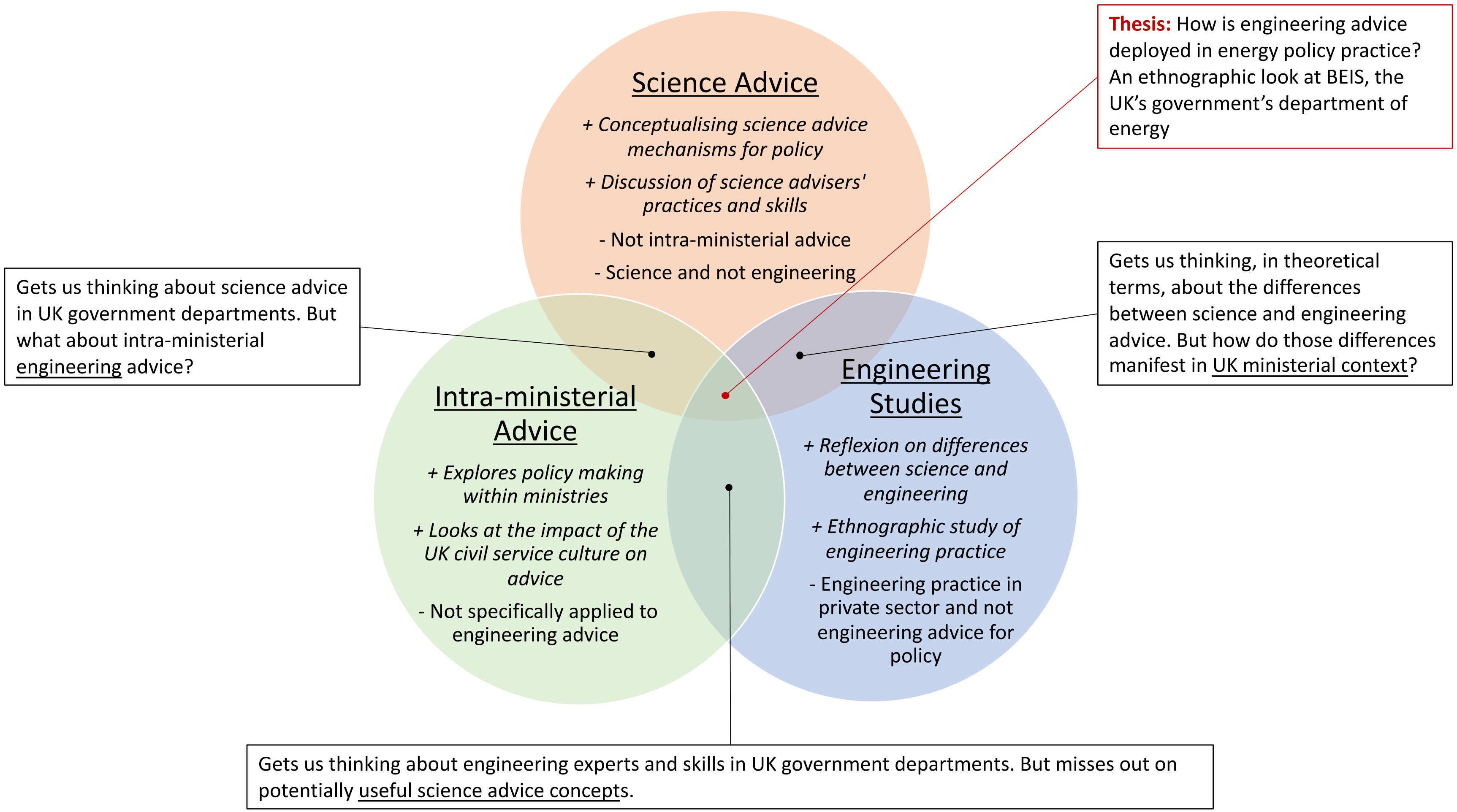
To explore this further, we turn our attention to authors who looked at the differences between science and engineering. Their work pioneered the field of engineering studies which ethnographically explores engineers' skills and practices in industry. Engineering studies however does not consider these skills and practices in policy practice, requiring us to use the very few articles available on engineering advice in policy to extrapolate engineering studies authors' findings. This starts to generate a theoretical narrative of engineering advice in policy practice and how it might differ from science advice, highlighting which concepts might be (or not) transferable from the science advice literature.

This leaves us with one final gap, none of the literature covered so far looks at policy advice within ministries, which is key to our research as a lot of policy making in the UK is done at ministerial level. We specifically focus on literature that ethnographically explores the impact of the UK's civil service culture and structure on policy advice in government departments. Working those insights into our theoretical narrative of engineering advice prompts a reflexion on engineers, their knowledge and skills in a UK government department while considering useful concepts from the science advice literature.

We conclude our review by emphasising that the assumptions, questions, and hypotheses raised in our combination of science advice, engineering studies and policy literature remain to be tested in practice. We end with three questions encapsulating all our theoretical points so far. Once empirically answered these questions will refine and develop our understanding of how engineering advice is deployed in policy practice.

Figure 2.1 illustrates the outline of our literature review presented above. It shows the three fields adjacent to intra-ministerial engineering advice: science advice, engineering studies and intra-ministerial policy advice. The figure summarises the useful lines of inquiry (show as +) and gaps (shown as -) of each of field in relation to our research focus. Combining any two of the fields fills in some of gaps of both fields and informs our thinking on intra-ministerial engineering advice. However, overlapping only two fields always misses out on useful arguments presented in the third, non-selected, field. It is only by combining all three fields, as we do in this chapter, that we can start painting a full theoretical picture of intra-ministerial engineering advice.

Figure 2.1: Literature review diagram showing the three fields adjacent to intra-ministerial engineering advice and their relationship with our research focus.



2.1 The Science Advice Literature

2.1.1 The Fifth Branch: An entry point into the science advice literature

Jasanoff's The Fifth Branch, first published in 1990, is credited with having brought the concept of science advice into the light and thus provides a great entry point into the field (Jasanoff, 2009; Lentsch and Weingart, 2011). Jasanoff's book, still one of the most cited works in this field, introduced the different themes covered in the science advice academic literature.

The Fifth Branch's aim was to bring the "modern scientific advice process out of the shadows to be scrutinised by public policy professionals and scholars" (Jasanoff, 2009, preface). The book was written in response to a crisis of confidence surrounding both political and scientific authority, breaking away from two pre-existing paradigms for analysing the use of science by regulatory agencies: the technocratic and democratic approaches. The technocratic approach conceptualised scientists as validators of policies whereas the democratic approach saw public participation as the antidote to the abuse of expert authority. In the Fifth Branch, Jasanoff argues that neither paradigm adequately understands nor describes the nature of science and politics. Instead, the book argues for an empirically richer and more realistic account of scientific expertise in public discussions drawing on US (United States of America) case studies.

The case studies centre around the US Environmental Protection Agency (EPA) and the US Food and Drug Administration (FDA). Worth noting here that part of both agencies' role is to advise the White House and Congress yet the agencies are not fully integrated parts of the US federal executive and legislative arrangements[3]. Jasanoff's focus is on the agencies' scientific

[3] The EPA is a fully independent agency, i.e. not part of the White House or Congress. The FDA is part of the US Department of Health and Human Services, so it is part of the executive branch. However, as Jasanoff points out (p.1), the FDA scientific advisory boards are made up of experts external to the agency, providing the boards with a certain degree of independence vis-a-vis the institutions they advise. As such, FDA science advisory boards can be said to advise yet sit on the margins of the executive (FDA, White House) and legislative (Congress) branches of the US government (Jasanoff, p.236).

advisory boards composed of "up-to-date practitioners in relevant scientific and technical fields" (p.1) responsible for advising on the scientific basis of any document under the authority of the agency's Administrator. The "fifth branch"[4] in the title of the book refers to these "technical experts" working on the agencies' boards (p.3), thirty of whom were interviewed to corroborate document analysis of past EPA and FDA cases. After a detailed explanation of a few cases, Jasanoff analyses how the behaviours and roles of these experts are responsible for the successes and failures of the agencies' relations with the White House and Congress.

It is worthwhile, at this point, to reflect briefly on Jasanoff's use of the terms "scientific" and "technical". It is clear from my introduction to the book above that Jasanoff uses the terms scientific and technical interchangeably: "practitioners in scientific and technical fields", the "fifth branch" referring to "technical experts" yet the book's subtitle explicitly referring to "scientific advisers" and its introduction to "scientific expertise", and so on. Based on this loose definition of science, "science advice" seems implicitly to incorporate all types of technical advice, including engineering advice (Cooper et al., 2020; Cooper, Lioté and Colomer, 2023). This broad, but misleading, definition of science advice is shared by most of the subsequent work done in this field, a point we will come back to in detail in this literature review (section 2.1.9).

With this in mind, The Fifth Branch's main conceptual contributions start with Jasanoff's summary of the distinction between what she terms "research science" and "mandated" or "regulatory science" (p.80). "Research science" refers to science generated in pure research settings like university labs, and mostly concerned with the extension of knowledge with limited regards for practical implications. By contrast, "mandated" or "regulatory science", is science used for the purpose of policy making with scientific and policy considerations integrated at every step of its production and use (Barnes and Edge, 1982; Rushefsky, 1988; Salter, Leiss and Levy, 1988; Jasanoff, 2009). Scientific advisers involved in creating or

[4] The first four branches are: the executive branch, the legislative branch, the judicial branch and the press/public interest groups (Jasanoff, 2009)

evaluating regulatory science therefore become part of a “hybrid socio-technical process” where “policy (socio-)” is mixed with “science (technical)” (Jasanoff, 2009, p.9).

Jasanoff’s case studies show that the advisers themselves are oftentimes aware that what they are doing is not science in a research science sense but a hybrid activity that combines scientific evidence with social and political judgements. In fact, when drafting their advice, science advisers on the EPA and FDA boards negotiate between scientific claims and data and socio-political values and context, between scientific communities, political decision-makers and the lay public. Once the advisers reach a consensus and give their recommendations to the White House and Congress however, scientific boards reconstruct sharp boundaries between science and policy, re-classifying their advice as “science” to prevent non-scientists from challenging it. This is known as “boundary work”, a concept initially coined by sociologist Thomas Gieryn (Gieryn, 1983). When this boundary holds, the public, executive and legislative institutions accept the scientific boards’ designation and their recommendation is “invested with unshakable authority” (Jasanoff, 2009, p.236).

Jasanoff concludes The Fifth Branch by looking at the implications of “socio-technical processes” of negotiation and boundary work for the experts on the EPA and FDA boards. Given the importance of negotiation and consensus building, the “ideal adviser needs to be more than just a technical expert” (p.243). Indeed, the most valued expert on the scientific boards is one that can transcend disciplines and summarise knowledge from different fields while also understanding the issues facing the agency. In other words, the best scientific advisers have two defining characteristics: they are comfortable with interdisciplinarity in that they can interact with experts in fields peripheral to their own, and they have a deep understanding of the agency’s own research policy agenda.

As explored below (sections 2.1.2 to 2.1.6), Jasanoff’s observations and concepts have been taken forward by subsequent works in this field. This has created two gaps in the context of my research focused on intra-ministerial engineering advice. First, the science advice literature has mostly kept Jasanoff’s focus on organisations that sit outside (or on the margins like FDA scientific advisory boards) yet advise the legislative and executive branches. This neglects an important part of the government science advice system which sits within ministries or government departments. Second, science advice literature has followed Jasanoff's definition of science advice which equates scientific expertise with technical expertise – including engineering expertise. Science and engineering, however, are different disciplines with different goals and practices meaning that one should not assume concepts of negotiation and boundary work apply in the same way to science and engineering advice for policy. These two gaps are explored in more detail in sections 2.1.8 and 2.1.9 below, after a discussion of the science advice literature in the wake of The Fifth Branch.

2.1.2 Science advice literature in the wake of The Fifth Branch

The Fifth Branch started an academic debate around the role of scientific advisers, with many scholars approaching science advice and discussing Jasanoff's conclusions from different angles. To explore how Jasanoff's concepts have been taken forward, I will follow Spruijt *et al.* sub-division of the science advice field, based on co-citation and content analysis (Spruijt *et al.*, 2014). After clustering, and based on the author group's self-proclaimed research approaches, the following strands of science advice literature were identified: post-normal science, science and technology studies, politics of expertise and science policy studies. I will now look at each strand in turn, highlighting how each approach built on concepts introduced in the Fifth Branch.

2.1.3 Post-normal science: Distinguishing between modes of scientific knowledge production and their implication for policy

The term "post-normal science" was introduced to describe knowledge produced in a context of strong political pressures where "facts are uncertain, values are in dispute, stakes are high and decisions are urgent" (Funtowicz and Ravetz, 1993). As Ravetz explains (Ravetz 2006), this includes worldwide attempts at policy and regulation of GRAINN (Genetics, Robotics, Artificial Intelligence, Neuroscience and Nanotech). Again, post-normal *science* seems to incorporate *engineering* elements, like robotics and nanotech, a point picked-up in section 2.1.9. Much like Jasanoff's concept of regulatory science, post-normal science highlights the growing academic attention paid to policy-related modes of knowledge production where science and policy considerations are intertwined (Funtowicz and Ravetz, 1993; Lentsch and

Weingart, 2011). Post-normal science rests on the idea that solving many complex policy problems requires drawing on scientific knowledge that is “uncertain” in that it was created in a value-laden context and therefore does not represent an objective, constant truth (Petersen *et al.*, 2011). Openly discussing the risks and implications of uncertain scientific knowledge requires an “extension of the peer community” to include the perspectives of representatives from social, political and economic domains. (Ravetz, 2006; Petersen *et al.*, 2011). In other words, for post-normal science scholars, solutions to complex policy problems can only be found through teamwork involving the scientific, business, political communities, and society.

Worth noting that, in addition to regulatory and post-normal science, a third similar concept called “mode 2 science” was coined in the early 1990s, further highlighting the need of science advice scholars to distinguish between modes of scientific knowledge production and their implication for policy (Gibbons *et al.*, 1994; Lentsch and Weingart, 2011). Gibbons et al, argue that another form of scientific knowledge production happens besides curiosity-driven disciplinary science – labelled “mode 1 science” (Gibbons *et al.*, 1994; Jasanoff, 2011). The other form of knowledge production, “mode 2 science”, is found in policy making and is concerned with the “application of science to answer social needs” (Nowotny, Scott and Gibbons, 2013). Mode 2 science, like regulatory and post-normal science, refers to the knowledge combining scientific and socio-political evidence produced during policymaking by scientific actors aware of the social implications of their work.

Beyond echoing Jasanoff’s distinction between research and regulatory science, post-normal and mode 2 science support two science advice concepts explored in The Fifth Branch: negotiation and boundary work. As a reminder, Jasanoff stressed that the science advice process for policymaking includes negotiation between scientific claims and facts and political values and concepts; a point also made by post-normal and mode 2 science under the idea of interdisciplinary teamwork for policymaking. As part of this negotiation, boundaries between disciplines are drawn to define who is seen as competent in specific areas of a policy problem – boundaries that are subject to contestation by scientists, policy and society (Petersen *et al.*, 2011). Jasanoff, post-normal science and mode 2 science scholars agree that a policy decision is seen as legitimate by all stakeholders only when the boundaries hold, and consensus is reached.

2.1.4 Science and technology studies: Refining the concept of boundary work

Science and technology studies (STS) scholars have actively built on concepts introduced in The Fifth Branch, in fact, Jasanoff belongs to this strand of the science advice literature (Jasanoff *et al.*, 1995; Spruijt *et al.*, 2014). STS authors focus on how science advice is constructed to understand science advisers' role and their relationships with policy decision makers. The most striking attempt at further exploring how negotiation and boundary-work work in practice came from adapting Goffman's framework – which treats advice as a dramaturgic performance – to science advisory bodies (Goffman, 1990; Hilgartner, 2000, 2004; Bijker *et al.*, 2009; Felt *et al.*, 2017).

Goffman's framework was first applied to science advice by STS scholar Hilgartner in his book Science on Stage (Hilgartner, 2000). The book examines the struggles over the credibility of science advice using the metaphor of performance and focusing on the US National Academy of Science (NAS). Although NAS is not a government agency, Hilgartner writes that it carries "quasi regulatory force" on many issues ranging from "strategies to explore Mars to the future of genetic engineering" (p.3). Taking The Fifth Branch as its starting point, the author agrees that contemporary policy problems are hybrids of the scientific and the political however he argues that science advice literature has done little to explain how the boundary work performed by science advisers to defend their credibility works in operational terms. To open up the "black box" of advising, Hilgartner analyses science advice as a form of drama, exploring how it is produced, performed and subject to critique.

The main contribution of Science on Stage is to highlight the importance of "stage management" in creating the science advisers' authority. Stage management here refers to the work advisers put in to maintain a division between "front and back stage", between what information is deliberately displayed and what is carefully concealed when a recommendation is given. This means fitting science and political facts and judgements into a narrative structure that that separates advisers from the vested interests that might seek to influence their advice. The stories created paint advisers as knowledgeable and objective and therefore competent and credible. Hilgartner concludes that science advisers are involved in boundary work which heavily relies on the enclosure and disclosure of information, a fact previously overlooked or missed by the science advice literature.

Building on Jasanoff and Hilgartner, STS scholars Bijker *et al.* ethnographic study of the Netherland's Health Council, is particularly relevant for this review. The book aims to "extend the sociology of scientific knowledge into the analyses of the political domain" by examining "interactions among scientists, engineers, policy makers and citizens" (Bijker *et al.*, 2009, p.4). The authors explain that the Dutch Health Council's setup is similar to that of the NAS in its advisory role and as a result their conclusions match points made in Science on Stage. Their analysis however shows something additional to Hilgartner and Jasanoff: advisory institutions not only emphasize boundaries when making reports but also bridge these boundaries. The Health Council achieves its authority by making distinctions between what counts as scientific and non-scientific and then bridging the two. Bijker *et al*, drawing on Star and Griesemer and Halffman, label this double movement "coordination work" (Star and Griesemer, 1989; Halffman, 2003).

A review of the STS approach to science advice would not be whole without at least mentioning Jasanoff's further works. In 2005, Jasanoff wrote Designs on Nature in which she introduces the concept of "civic epistemologies", the stylized and culturally specific ways the public expects a state's knowledge to be produced and tested (Jasanoff, 2005a). States of Knowledge was published a year later, introducing the notion of "co-production" showing how scientific ideas evolve together with the discourses that give practical meaning to these ideas (Jasanoff, 2006). In her latest book Dreamscapes of Modernity, Jasanoff explores "socio-technical imaginaries", that is how visions of scientific progress implicitly carry ideas about public purpose and the common good (Jasanoff and Kim, 2015). All three concepts mark a step away from the Fifth Branch's discussion of science advisers' relationship with political decision makers and take a much wider look at the relationship between science and society. Although civic epistemologies, co-production and socio-technical imaginaries still have indirect implications for science advice, they are not directly relevant for the purpose of my research exploring interactions between scientists, engineers, and policy advisers within government. It therefore seems logical to stay focused on the concepts of negotiation and boundary work in the rest of this review of the science advice field.

2.1.5 Politics of expertise: Boundary-spanning skills at the science-policy interface

Politics of expertise, the third approach listed by Spruijt *et al*, supports the idea of boundary and coordination work put forward by STS but argue that additional attention should be paid to the skills scientific advisers develop in their role. Authors in this group argue that, regardless of the institutional design of scientific advisory bodies, i.e. their intended function and relation to the executive and legislative branches of government, scientific advisers always act as brokers at the science-policy interface. As a result of the coordination work they perform between science and policy, scientific or technical advisers need and develop a specific set of boundary-spanning skills (Hoppe, 2005; Kropp and Wagner, 2010; Lentsch and Weingart, 2011; Spruijt *et al.*, 2014; Gluckman, Bardsley and Kaiser, 2021).

Lentsch and Weingart in their edited volume on "The Politics of Science Advice" state that, drawing on cases from the UK, Germany, the Netherlands, and the European Union (EU), there are three basic kinds of scientific advisory organisations. These are: collegial bodies (such as various forms of councils and committees, e.g. the EPA scientific board), research-based organisations (mostly policy-oriented think tanks) and academies (e.g. the NAS) (Lentsch and Weingart, 2011). Worth noting that intra-ministerial scientific advisory capacity is absent from this typology, a point picked up below in section 2.1.8. According to Lentsch and Weingart collegial bodies, research-based organisations and academies serve different purposes and have different links to government. Yet, regardless of institutional arrangement, scientific advisers are always involved in "knowledge brokerage". Science advisers act as knowledge brokers at the science-policy interface meaning they gather and synthesise information from the scientific and policy communities and align needs with outputs to formulate policy recommendations (Gluckman, Bardsley and Kaiser, 2021). Science advisers bridge science-policy boundaries by translating the different languages of the scientific and policy communities and matching or reconciling their arguments and interests to advise decision-makers.

In practice, this includes listening to a variety of knowledge sources and their approach to the policy problem, evaluating the options implied by these knowledge sources, and assessing how effective they will be in answering the policy question (Gluckman, Bardsley and Kaiser, 2021). As a result, science advisers should be able to mediate between disciplines to mobilize the best available knowledge, scientific or socio-political, and ensure it is at the disposal of the right audience at the right time (Hoppe, 1999; Kropp and Wagner, 2010; Lentsch and Weingart, 2011). Echoing The Fifth Branch, politics of expertise scholars argue that science advisers, as successful boundary spanners, need to be comfortable with interdisciplinarity and understand the timing and priorities of the policy cycle (Hoppe, 2009; Kropp and Wagner, 2010).

2.1.6 Science policy studies: Science advisers and transparency

Science policy studies, the fourth approach identified by Spruijt *et al,* agrees with the concepts of boundary work and brokerage presented in the rest of the science advice literature. Going a step beyond describing and conceptualizing the science advisers' role, science policy studies takes a more prescriptive approach, arguing that scientific experts should be transparent about their and alternative viewpoints when they interact with policy-decision makers (Spruijt *et al.*, 2014).

Science policy scholars agree with Jasanoff that in policy making, science and political values and judgements are intertwined, leading to struggles over how to frame a policy problem, what type of research should be pursued and whose research results are reliable (Souren *et al.*, 2007; Oreskes, 2011; Sarewitz, 2011). They argue that when advising policy decision-makers, science advisers should not try to obscure the complex negotiation process that precedes the recommendation but instead act with "professional humility" (Beck, 2011). The term was coined by Beck, based on a concept developed by Jasanoff, and refers to the transparency science advisers should adopt when engaging with decision-makers on complex and uncertain issues (Jasanoff, 2005b; Beck, 2011). Acting with professional humility means making transparent the limits of one's knowledge, the extent of uncertainty it is based on and, as a result, the different policy paths that might exist. Disclosing this information helps decision makers appreciate the complexity of certain policy issues and make more informed decisions.

The most famous articulation of this point can be found in science policy author Pielke's book The Honest Broker (Pielke, Jr, 2007). Pielke, using examples from the US, creates a typology of the different indirect and direct roles "scientific and technical" experts can play in policy (p.154). The author first mentions the "pure scientists" that produces research with no consideration for its use or utility, like Jasanoff's concept of research science. Still at the margins of policy, the second type of expert identified is the "science arbiter" that seeks to stay away from policy but recognizes that decision-makers may have specific questions that require expert scientific judgement. Within policy Pielke identifies two types of roles: "the issue advocate" and the "honest broker". The issue advocate aligns with a group seeking to advance its interest through politics. The honest broker however engages in decision-making by clarifying and expanding the scope of choice available to decision-makers. Pielke argues that science advice has a notable shortage of honest brokers, science advisers who are transparent about their viewpoints, how they reached them and what policy alternatives exists. The book concludes that, when directly engaging with policy makers, science advisers should strive to be honest brokers of policy alternatives.

Table 2.1: Science advice literature approaches and concepts (adapted from Spruijt et al., 2014)

	Science advice approach	Description of approach	Main unit of analysis	Approach said to include	Concepts & conclusions
Initial	The Fifth Branch	Provide a realistic account of scientific expertise in public policy	US EPA and FDA	Scientific and technical expertise	**Negotiation** and **boundary work**
After The Fifth Branch	Post-normal science	Explore knowledge production under conditions of uncertainty and disputed values	High-level, general view	Scientific and engineering knowledge for policy	Supports **negotiation** and **boundary work**
	Science and technology studies	Focus on science advisers' role and their relationships with policy decision makers	US/Europe collegial bodies and academies	Interactions between scientists, engineers and policy makers	Refines boundary work by adding **information enclosure/disclosure** and **coordination work**
	Politics of expertise	Describe science advisers' skills across scientific advisory bodies internationally	Worldwide collegial bodies, research-based organisations and academies	Scientific and technical advisers	Supports negotiation and coordination work, conceptualising science advisers as **spanning the science-policy interface**
	Science policy studies	Propose best practice rules for science adviser – policy maker collaboration	US/Europe collegial bodies and academies	Scientific and technical experts	To best bridge the science-policy interface, advisers need to act with **professional humility**

2.1.7 Science advice literature gaps: Going all the way back to The Fifth Branch

Despite introducing interesting concepts to understand science advice for policy, the science advice literature has two gaps of importance to this research which can be traced all the way back to The Fifth Branch. First, concepts of negotiation and boundary work were initially developed in a specific institutional context: US organisations that sit outside of yet advise the legislative and executive branches. Although there has been attempts to study science advice mechanisms outside of the US and within parliament as we will see below, the science advice literature has neglected science advice within ministries or government departments.

Secondly, the science advice literature has operated, since the Fifth Branch, with a definition of science which equates scientific expertise with technical expertise – including engineering expertise. Science and engineering, however, are different disciplines with different goals and practices meaning that one should not assume concepts of negotiation and boundary work apply in the same way to science and engineering advice for policy. In the following sections I will expand on both gaps in turn, highlighting their importance and implications for this research.

2.1.8 Science advice literature gap: Neglecting intra-ministerial advice

Jasanoff created concepts of negotiation and boundary work based on a specific institutional arrangement, that of the EPA and FDA, US agencies that advise the White House and Congress but sit outside of the US federal and legislative arrangement. In the wake of Fifth Branch, although some authors refined the concept using additional US data (Hilgartner, 2000; Pielke, Jr, 2007), all agreed that data on science advice mechanisms beyond the US was necessary to fully understand, test and refine science advice concepts (Hilgartner, 2000; Halffman, 2005; Bijker *et al.*, 2009; Jasanoff, 2011; Lentsch and Weingart, 2011). As Jasanoff explained, science advice "is a deeply social undertaking and it follows that its analysis should take cultural specificity into account" (Jasanoff, 2011, p.29). Authors took a more international outlook, looking at science advisory organisations, i.e. collegial bodies, academies and research-based organisations, in different countries (Lentsch and Weingart, 2011). As we saw, this included a worldwide perspective in post-normal science and case studies from the Netherlands, the UK, Germany and the EU in science and technology studies and politics of expertise approaches. This contributed to the expansion of the concept of boundary work to include coordination work and generally a better understanding of boundary spanning skills at the science policy interface.

A few points made throughout the science advice literature about the specificity of the UK policy culture are particularly relevant to this research. Drawing on data from UK non-departmental public bodies and the Royal Society (the UK's National Academy of Sciences), authors point out that the UK and US policy cultures are different (Collins, 2011; Jasanoff, 2011; Owens, 2011). Again, please note the specificity in institutional arrangements where the advisory organisations in question are not an integrated part of the executive or legislative branch of the government. All three case studies highlight that UK science advisers achieve credibility through demonstrated balanced judgement as opposed to the US where science advisers achieve credibility through legal challenge and review. This has an impact on boundary work where in the US science advisers focus more on creating boundaries between science and policy to protect themselves from challenges (Jasanoff, 2009) whereas science advisers in the UK are more involved in cooperative coordination work (Bijker *et al.*, 2009).

Having refined concepts introduced in the Fifth Branch using non-US data, including UK specific cases, some science advice authors turned to another limitation of Jasanoff initial concepts: the lack of data on legislative science advice. Indeed, as Kenny *et al* point out, most of the literature until 2015 had largely ignored science advice mechanisms within parliament (Kenny *et al.*, 2017). Since then a small corpus has looked at the systems that provide scientific information to European legislatures including legislative research services, committee support systems and lobbyists (Akerlof *et al.*, 2019, 2020, 2022). Conclusions of this corpus align with that of politics of expertise scholars, noting that science advisers in parliaments are involved in boundary spanning, mediating between disciplines to mobilize the appropriate knowledge and ensure it is available to the right audience at the right time.

This leaves us with an additional limitation or gap in the science advice literature: the lack of data on science advice within ministries or government department – a key part of the executive branch. As we highlighted, science advice concepts were developed and refined based on case studies from the US and Europe that focused on organisations that advise yet sit outside of government departments (US EPA, US FDA, US NAS, Dutch Health Council, UK Non-departmental public bodies, UK Royal Society). This is particularly problematic in the UK where a lot of the policy making is done by middle ranking officials in government departments (Page and Jenkins, 2005; Stevens, 2011; Page, 2012; Cooper *et al.*, 2020). I am not the first one to point this out, yet to this date there has been no specific empirical attempts to understand how concepts like negotiation, boundary work and coordination work hold up in an intra-ministerial context (Spruijt *et al.*, 2014; Kenny *et al.*, 2017; Christensen, 2021). Looking inside ministries might surface additional relationships like that of the science advisers to policy advisors to senior civil servants or ministers which could add to the literature's current understanding of boundary drawing and brokerage at the science-policy interface (Halffman, 2005; Kenny *et al.*, 2017). The few authors that have highlighted this gap have called for ethnographic studies of this space to understand how advice is constructed, how advisers understand their role and their relationship to other officials and decision-makers (Hilgartner, 2004; Spruijt *et al.*, 2014; Rhodes, 2019; Christensen, 2021).

2.1.9 Science advice literature gap: Conflating science and engineering

The second gap in the science advice literature is linked to the authors' broad definition of scientific expertise which is said to include any type of technical expertise, including engineering. Going back to the Fifth Branch, we pointed out Jasanoff's interchangeable use of 'scientific' and 'technical', a trend that has persisted throughout the literature. Post-normal science for instance includes the regulation of issues that involve engineers like "robotics, artificial intelligence and nanotech" (Ravetz, 2006). STS focuses on agencies that are involved in engineering-heavy projects like "the exploration of Mars" (Hilgartner, 2000) and aim to "extend the sociology of scientific knowledge" by examining interactions amongst "scientists, engineers and policy makers" (Bijker *et al.*, 2009). The science policy studies approach is no different, with Pielke stating that his typology includes "scientific and technical roles in policy" but subsequently only referring to the experts "scientific judgement", "pure scientists" or "science arbiter" (Pielke, Jr, 2007). Using such a broad definition of science, science advice authors conflate science and engineering, or at least give the impression that the concepts they developed can be applied to science and other types of technical advice for policy (Downey and Lucena, 1995; Downey, 2015; Cooper *et al.*, 2020; Cooper, Lioté and Colomer, 2023).

Engineering and science however are two different disciplines, with different goals, ways of thinking and practices, and this has potential implications for the transposability of science advice concepts. I will briefly outline what those differences might be now to highlight why this is an important gap in the science advice literature but will come back to this idea in a lot more depth in the next section of this review. Science focuses on studying the natural world as is, to comprehend its inner workings and therefore strives to develop a neutral stance towards the question under consideration (Kant, 2018; Kant and Kerr, 2019; Cooper *et al.*, 2020). Engineering on the other hand is concerned with designing and building tangible artefacts and systems to change the issue under consideration (Sarewitz, 2011; Kant and Kerr, 2019; Cooper *et al.*, 2020). Engineers are therefore more likely to provide expertise on different technologies and their performance and derive their credibility from finding suitable compromises to reach a set goal (Cooper *et al.*, 2020; Liote, 2022). As a result, boundary work might work differently for engineering advice than it does for science advice, with different strategies of credibility building and legitimation. We will start theoretically investigating the differences between science and engineering advice below however, as we will see, a thorough exploration of those differences call for empirical investigations of the *engineering*-policy interface (Cooper, Lioté and Colomer, 2023).

2.2 Engineering Studies

2.2.1 Differentiating science and engineering

Conflating science and engineering has not just been an issue in the science advice literature but in academia (and perhaps even society) more widely. The most famous example is the 1945 US presidential report, “Science: The Endless Frontier”, by Vannevar Bush, then Head of the US Office of Scientific Research and Development. The report laid out an assembly-line model of innovation where the input is science and output is technology, reducing the engineers’ role to simply applying science to create technology (Bush, 1945; Kant, 2018). Bush’s work was hugely influential in constructing the post-war US policy on research and development, shaping much of the discourse around science policy for the following years (Kant, 2018). This led academia to consider engineering knowledge simply as applied science, and by extension understanding the engineers’ role as applying scientific knowledge in a straight forward and therefore un-interesting way (Downey and Lucena, 1995; Williams, 2002; Durbin, 2009; Bijker, Hughes and Pinch, 2012; Kant and Kerr, 2019). As a result, academic debates either focused on “the input”: science, or “the output”: technology, overlooking engineers and their practices (Brooks, 1994; Downey and Lucena, 1995; Mitcham and Kang, 2018).

In the late 1980s – early 1990s however, a few authors fought against the idea of engineering as 'just applied science' and started differentiating engineering epistemology from that of science (Winner, 1986; Bucciarelli, 1988; Blockley, 1992; Vincenti, 1993; Brooks, 1994; Downey and Lucena, 1995; Simon, 1996). Epistemology here refers to a community's way of knowing and doing and by extension a community's way of thinking (Weinberg, 1975; Wenger, 2002). Distinguishing between engineering and scientific epistemologies means understanding what engineers do, their unique skills, habits and ways of thinking and how that differs from scientists (Weinberg, 1975; Anderson *et al.*, 2010; Cunningham and Kelly, 2017).

These authors argued that the main epistemological differences between science and engineering stem from the aims of the disciplines, with science aiming to understand the world as it is and engineering looking to change the world (Brooks, 1994; Kant and Kerr, 2019). Science is therefore explanatory, it is concerned with "how things are" whereas engineering is goal oriented, it is focused on how things "ought to be" (Simon, 1996; Kant, 2018). As a result, scientists strive to adopt a neutral stance[5] and test hypotheses about the natural world to see if they are "true or false" (Blockley, 1992; Bijker, Hughes and Pinch, 2012). Engineers are more likely to be involved in "how to do something", how to attain a goal and solve a particular problem (Blockley, 1992). Because of their different aims, science and engineering also differ in terms of their products: science produces theories and models for understanding whereas engineering produces models for designing/improving a design, blueprints and built systems (Winner, 1986; Bucciarelli, 1994). In designing objects, engineers draw on more than just scientific principles, they take into account the context of the ask and the context of application (Downey and Lucena, 1995; Juhl, 2016; Houkes, 2020). This includes, for instance, a combination of scientific knowledge with economic, safety and production limitations (Bucciarelli, 1988; Vincenti, 1993). Engineers then try different combinations and compromise until they find an acceptable solution to the problem at hand, often creating and discarding non-satisfactory solutions along the way (Davis, 1998; Lawson, 2005).

[5] It would be wrong to think that scientists are never biased and science cannot be value-laden, however, as a discipline, science is underpinned by the idea that scientists should aim to adopt as neutral a stance as possible (Douglas, 2009)

Table 2.2: Epistemological differences between science and engineering from the literature

	Science	Engineering	Initial Author
Aims of discipline	Understand the world as it is	Change the world	Brooks, 1994
Resulting orientation	Explanation oriented – concerned with how things are	Goal oriented – concerned with how thing ought to be	Simon, 1996
Methodological inclination	Test hypotheses to see if they are true or false	Combine knowledge relevant in the context of the ask and application	Blockley, 1992; Vincenti, 1993; Bucciarelli, 1994; Downey & Lucena, 1995
Attitude and practice	Strive to adopt neutral stance to answer question	Compromise until acceptable solution is found and goal is reached	Blockley, 1992; Vincenti, 1993; Bucciarelli, 1994
Output	Theories and models about the natural world	Artifacts and built systems	Winner, 1986; Bucciarelli, 1994

2.2.2 Bucciaralli and Vincenti: Laying down the foundations of engineering studies

Our discussion has remained quite theoretical until now, however two authors mentioned above stand out for their exploration of engineering epistemology in practice. After highlighting the epistemological differences between science and engineering, Bucciarelli and Vincenti went a step further and began to empirically study engineering practice. Both authors' works were hugely influential in establishing the field of engineering studies in the mid-1990s, concerned with studying engineering epistemology in-situ. Before we discuss the aims and key findings of engineering studies, let us take a closer look at Bucciarelli's and Vincenti's articles and books.

Bucciarelli's work takes an ethnographic look at engineering design in two engineering firms, one making photovoltaic panels and the other making X-ray equipment for medical diagnostics (Bucciarelli, 1988, 1994). In both the article and book, Bucciarelli argues that the engineers work in "object worlds", that the objects designed drive engineers thinking and practices. In practice, engineers draw on different types of knowledge to design objects that meet a certain number of specifications under a set of constraints. This includes, for example, balancing scientific law, dollars and cents specifications, IEEE (Institute of Electrical and

Electronics Engineers) codes, and the norms and practices of the firm to produce a certain number and type of devices under a certain cost per unit (Bucciarelli, 1994). The design process often includes multiple attempts at combining different types of knowledge in different ways until an optimal object design (one that meets all the specifications and respects all the constraints) is found. Bucciarelli ends with a call to action for scholars to empirically look at engineering practices in more firms to further explore what types of knowledge engineers draw on and how they are combined in object design.

Drawing on examples from the aerospace industry, Vincenti takes a deeper look at the activities through which engineers generate knowledge and the types of knowledge produced (Vincenti, 1993). Overall, he argues that engineers are involved in "organising the design, construction and operation of artifacts that transform the physical world to meet some recognised need" (p. 6). Here, organising the design means putting together the plan (both in terms of strategy and drawings) from which the airplane will be built, construction refers to the manufacture of actual airplanes, and operation denotes the maintenance and flight operations of the airplane. To achieve all these steps, engineers engage in the following activities: they transfer some knowledge from science, engage in theoretical and experimental engineering research, learn from previous designs and design processes (including physical practice like how to appropriately beat down rivets), engage in direct trial and prototyping, and consult clients and stakeholders. These activities generate the criteria and specifications for the final design as well as the theoretical tools, quantitative data, practical considerations, and design know-how the engineers need to plan, build, and maintain the aircraft. Like Bucciarelli, Vincenti concludes that his work is not exhaustive and more empirical research into engineering practices will surface additional knowledge-generating activities and knowledge types.

Bucciarelli and Vincenti, by differentiating science and engineering epistemologies, and empirically exploring engineering practice, are seen as laying down the foundations of the field of engineering studies (Downey and Lucena, 1995; Davis, 1998; Kant, 2018). Many authors have followed in Bucciarelli and Vincenti's footsteps from the mid-1990s onwards, empirically looking at the epistemic culture of engineering. Engineering studies authors, looking at engineers in different industries, try to understand what kinds of knowledge engineers use and have and what kind of practices they engage in (Mitcham and Mackey, 2009; Downey, 2015; Carl Mitcham, 2020). This is often done using ethnographic methods, describing the engineers' life from their point of view, capturing their knowledge, practices and roles within their organisation without removing them from their work (Baird, Moore and Jagodzinski, 2000; Jesiek *et al.*, 2020; Jesiek, Buswell and Nittala, 2021). The following sections take a thematic look at the findings of engineering studies before highlighting the gaps in the literature.

2.2.3 Engineering studies: Boundary spanning and engineering identity

Looking at different countries and industries, engineering studies authors have validated Bucciarelli and Vincenti's findings. Engineers start with a specific job to do, often phrased as a problem to solve or situation to improve by designing, changing, or tweaking an object or ensemble of objects (Anderson *et al.*, 2010; Jarratt *et al.*, 2011). The overall design must meet specifications set by whoever requested the product (often referred to as 'the client') and respect a certain number of constraints (Cunningham and Kelly, 2017). To design the product, engineers draw on different types of knowledge including scientific knowledge, learning from previous designs, following standards and codes, and prototyping and testing (Buch, 2016).

In addition to generalising Bucciarelli and Vincenti's conclusions, engineering studies authors have made a distinction between historically established and practice-generated knowledge (Gainsburg, Rodriguez-Lluesma and Bailey, 2010). Historically established knowledge refers to the profession's knowledge base created by academics, researchers and early practitioners and embedded in design manuals and building codes (Pitt, 2001). This type of knowledge also makes up the bulk of what is taught in engineering university courses (Cunningham and Kelly, 2017). Practice-generated knowledge on the other hand is constructed by engineers in the context of their work and includes a wider understanding of the system they operate in. Engineers' practice-generated knowledge can be, for example, what best material to select in a specific situation or the preferences of other actors including clients, contractors, and users (Gainsburg, Rodriguez-Lluesma and Bailey, 2010). Engineering studies authors have stressed the importance of practice-based knowledge, it is only learnt 'by doing' and enables engineers to solve problems in context (Wilde and Guile, 2021).

Exploring engineering practice across different sectors, engineering studies works have also highlighted the importance of the social dimensions of engineers' work. Most of the time the expertise needed to make a product is not held by one actor but distributed across different groups involved in the product design (Trevelyan, 2007, 2010). This of course includes the engineers but also different teams within their organisations, including sales, marketing and finance teams who have insights into user preferences and cost-related issues. Engineers interact with suppliers and contractors to, for example, source materials and take care of some of the manufacturing process (Anderson *et al.*, 2010; Wilde and Guile, 2021). Engineers also rely on other engineers within the organisation and beyond for help and to check and review their work (Trevelyan, 2010). To design a product, engineers have to engage and interact with all these actors, who often come with their own set of physical, economic and production criteria and constraints (Vinck and Blanco, 2003; Cunningham and Kelly, 2017). Engineers therefore spend a lot of their time communicating and negotiating with different stakeholder groups, an activity which engineering studies authors have described as "the social core of engineering practice" (Trevelyan, 2010). Please note that the definition of "social" here is that of Trevelyan and understood in a narrow sense, referring to social interactions. It does not refer to the impact of engineering practice and the systems designed by engineers on society.

This "social core" where engineers are frequently involved in coordinating, collaborating and communicating across different stakeholder groups has been conceptualised by engineering studies authors as boundary spanning (Trevelyan, 2007; Jesiek *et al.*, 2020; Jesiek, Buswell and Nittala, 2021). In their daily work, engineers have to interact across social (inter- and intra-teams) and work sites boundaries to ensure the end product meets the client's specifications (Jesiek, Buswell and Nittala, 2021). This entails bi-directional communication across boundaries to get all stakeholders on the same page, with the need to readjust communication strategies depending on the audience (Anderson *et al.*, 2010; Cunningham and Kelly, 2017). Most of the time this involves translating technical knowledge and limitations into layman's terms, or using metaphors and simple diagrams, and understanding the technical impact of marketing and financial constraints on the design process (Vinck and Blanco, 2003). As a result, experienced engineers cite effective communication as their most important skill; it enables them to negotiate across stakeholder groups to solve problems and design products that respect criteria and constraints (Anderson *et al.*, 2010).

The importance of the social dimensions of engineering work in practice however clashes with the predominantly technical view of the discipline many engineers develop in their studies (Trevelyan, 2010). Academic engineering programmes often phrase the case studies and problems to be solved in quantitative terms: issues and entities must be identifiable and amendable to physical manipulation, instrumentation, numerical calculations, causal explanations, and control (Buch, 2016). Young engineers therefore enter the workplace with a technical understanding of engineering, and are often surprised by the importance of the social side of their work, i.e. communication and coordination. In fact, engineering studies authors report that many new starters feel like they are “doing less engineering than expected” given how much communication work they do compared to “calculation, design, technical stuff” (Trevelyan, 2007, 2010). As engineers gain experience however, as we noted above, they acknowledged the social side of their work and emphasise how important communication skills are for the job, often regretting the limited schooling they had in it (Anderson *et al.*, 2010).

Engineering studies authors conclude that, across countries and industries, engineers identify themselves as problem-solvers, recognising that problem-solving involves social and technical knowledge and skills (Anderson *et al.*, 2010; Cunningham and Kelly, 2017). In practice, technical tasks include completing design modifications using a CAD (Computer-Aided Design) program, running computer simulations, troubleshooting a circuit board, reviewing designs to ensure they met code, or machining a part for a test model (Anderson *et al.*, 2010). Social activities include spanning boundaries to communicate and coordinate different stakeholder groups involved in commissioning, designing and manufacturing a product (Jesiek *et al.*, 2020). Often times the social and technical side of the job are intertwined, with engineers having to translate technical knowledge and limitations for non-technical audiences or taking into account marketing constraints into the design process (Vinck and Blanco, 2003). Relying on historically established and practice generated knowledge, practicing engineers identify as socio-technical problem solvers (Gainsburg, Rodriguez-Lluesma and Bailey, 2010).

2.2.4 Engineering studies gaps: What about engineering advice in public policy?

The engineering studies literature is key for our research as it explores the differences between science and engineering and ethnographically studies engineering practice. With that said, there is one gap which we need to concern ourselves with: the field does not consider engineering practice, let alone advice, in public policy. A few authors have attributed this to the fact that engineering is a very privatised affair, with a lot of the research and development, design and manufacturing happening in industry (Downey and Lucena, 1995; Downey, 2015). In addition to this strong market-orientation, governments in many western economies including the UK, have since the 1990s reduced the number of engineers they have 'in-house' (Yates, 2001; Williams, 2002; Collins, 2013). This is especially true of the central government where a lot of the engineering capacity was outsourced to the private sector and/or separate government agencies in charge of overseeing certain types of infrastructure – many of which were later reclassified as commercial organisations (Yates, 2001; Collins, 2013).

However, despite a lower number of engineers working in central governments than in the private sector, many engineers are still involved – and have an important role to play – in public policy (Petroski, 2011; Cooper *et al.*, 2020; McCarthy, 2021). This raises two important questions, first, what happens to the differences between science and engineering highlighted by engineering studies authors when thinking about *science and engineering advice for policy*? And secondly, do the engineers working in the private sector and public policy share the same practices and identity identified by engineering studies authors? To start answering these questions and construct a theoretical narrative of engineering advice in policy, we need to take a comparative look at the science advice and engineering studies literature.

2.2.5 Engineering studies gap: Differentiating science and engineering advice for policy

As science advice authors pointed out, "regulatory science" or science advice for policy is more than just science, it is the application of science to answer policy needs. As we mentioned above, regulatory science can best be conceived as science used for the purpose of policy making with scientific and policy considerations integrated at every step of its production and use. Following this definition, we can similarly define engineering advice for policy as the application of engineering to answer policy needs, with engineering and policy concerns intertwined in its production and use. Defined like this, regulatory science and engineering advice for policy are closely related, as both concepts are concerned with the application of domain-specific knowledge to answer policy questions. However, science and engineering advice for policy still have, respectively, science and engineering at their core; and as engineering studies authors highlighted, both are different disciplines with different aims and epistemologies (see table 2.2). These underlying disciplinary differences manifest themselves in policy, impacting the focus and narrative structure of science and engineering advice (Cooper *et al.*, 2020; McCarthy, 2021).

First, let's consider the difference in focus between engineering and science advice. As engineering studies authors highlighted, science and engineering have different outputs, science produce theories and models of the world whereas engineering is concerned with objects and built systems. In fact, engineering thinking is so driven by physical object design that Bucciarelli coined the term "object world" to refer to the mindset of practicing engineers. It therefore does not come as a surprise when a few authors note that engineering advice in policy is usually concerned with objects, technologies, and built systems (as in: an ensemble of objects and/or technologies) as opposed to science advice which tends to focus on the natural world, dealing with eco- and bio-systems (Collins, 2013; Cooper *et al.*, 2020). In other words, policy decision makers seek engineering advice when input about the physical properties of built objects and built systems is needed and when practical judgement and prescience are needed to evaluate technological options (Davidson, 1984; Cooper, 2017; McCarthy, 2021). The focus on built objects and systems at the core of engineering advice is not as present in science advice, setting engineering and science advice for policy apart.

The second way disciplinary differences between science and engineering manifest themselves in policy is by impacting the narrative structure of science and engineering advice. Drawing on Morgan and Wise and Roth, McCarthy explains that policy advice is often given as a narrative explanation, as a story charting a path through and connecting different events (McCarthy, 2021). Narrative explanations take a situation and problematize it, like a puzzle, and set out why and how things happen to provide a solution to that puzzle (ibid). Science and engineering advisers however do not structure the narrative of their advice in the same way (ibid).

Scientific advisers gather evidence and construct narratives that explain causal relationships and processes to give an account of the evidence observed (ibid). Engineering advisers, on the other hand, deal with the “possible” rather than the “actual”, they engage in the process of design rather than description, focusing actively on how to bring about change. Engineers therefore structure their advice in the following forms: to achieve A we must do B, if A happens we must prepare by doing B to reach situation C, or, the way the world is now we will be in situation A unless we do B (ibid). The focus is on drawing out the possibility space in order to say what should happen as opposed to scientific narratives which describe or model existing processes (Weinberg, 1972; Petroski, 2011; McCarthy, 2021). This not to say that science advice cannot be used in a predictive way but that engineering advice is always about bringing about a future situation or changing the context in which it will take place (McCarthy, 2021). Engineering advice narratives are therefore stories about possible worlds linked to our current situation through practical steps, with engineers identifying the tools that will get us to those possible worlds (ibid).

Just like the difference in focus, this discrepancy between the narrative structure of science and engineering advice for policy can be traced back to the disciplinary differences between science and engineering (see table 2.2). As engineering studies authors pointed out, science aims to understand the world as it is and, as a result, is explanation oriented. It makes sense then, that science advice mostly constructs descriptive narratives concerned with how things are and why they came to be. Engineering, on the other hand, aims to change the world, it is goal oriented and focuses on finding solutions to practical problems. Engineering advice narratives are structured around the same principles, they focus on change and goal-reaching through active intervention. Differences in disciplinary aims and resulting disciplinary orientation therefore shape the narrative structure of science and engineering advice, setting engineering and science advice for policy apart.

2.2.6 Engineering studies gap: Engineering practice in policy

As mentioned above, engineering studies authors ethnographically explore engineers' practices and identity in the private sector. In the context of this research, this leaves us with an important question: do engineers advising policy makers share those same practices and identity? Academic literature is extremely thin on engineering practice and advice in policy with only one author, McCarthy, having touched on the topic (McCarthy, 2017, 2021). With that said, McCarthy's work provides a great basis to start looking at whether engineering studies' findings apply to public policy.

McCarthy observed that engineering advice, as mentioned above, is often sought out when policy makers need input on the properties and performances of built objects and built systems (Cooper *et al.*, 2020; McCarthy, 2021). Many engineers working in policy however feel like policy makers fail to grasp the language and findings of engineers, constituting a barrier to successful collaboration (McCarthy, 2017). The challenge here, is that engineering and policy concepts are not always easily translatable, that some engineering theories do not feature an equivalent set of laws and generalization in policy and vice-versa (ibid). According to McCarthy however, this is not an insurmountable issue, bringing up the idea of having individuals that speak the language of engineering *and* policy on both the engineering and policy sides in addition to a systems architect who can see where communication might break down.

Alternatively, some engineers and policy makers are able to build "trading zones" to collaborate with each other (McCarthy, 2017). The idea of "trading zones" comes from Galison's work, which focuses on how different sub-groups in physics can collaborate despite working with different theories and therefore different professional languages (Galison, 1997). To explain this phenomenon, Galison uses the concept of "trading zones", which originally come from anthropology and describes how communities with different languages come together to trade commodities with a common value. These communities develop shared, simple languages to communicate in a common space of exchange, a "trading zone". Galison, explains that this applies to physicists from different branches of physics, who develop a pidgin that allows them to successfully collaborate in the lab.

Drawing on Galison, McCarthy explains that this concept of "trading zones" can also be applied to engineers and policy makers working together (McCarthy, 2017). When working together on a specific project, engineers and policy makers develop their own shared language to be able to collaborate. Again, engineering and policy worldviews do not come together to form one single picture, rather a simplified language is developed to enable collaboration between the different collaborating parties (ibid).

McCarthy's account of engineering advice practice in policy seems to echo many of the engineering studies literature findings. Just like in the private sector, engineers' practice and advice in public policy revolve around objects and built systems. McCarthy's work also highlights the social dimension of engineers' work in policy, communicating and negotiating with policy makers. This of course is reminiscent of "the social core of engineering practice" observed by Trevelyan in the private sector, where engineers span boundaries between different stakeholder groups who come with their own sets of criteria and constraints. Engineering studies authors noted that this collaboration entailed translating technical knowledge into easily understandable terms or developing a shared understanding through metaphors or diagrams. This is very similar to the concepts of translation and trading zones introduced by McCarthy to describe engineering advice practice in policy.

Comparing McCarthy's work and engineering studies literature findings, it seems like engineers in the public and private sector share many common practices. Literature on engineering practice in policy however is quite limited and additional empirical data is needed before we can draw more links or lines between engineering studies conclusions and engineering advice practice in policy.

2.2.7 What does this mean for science advice concepts?

Now that we have a clearer, albeit limited, theoretical view of engineering advice in policy practice and how it differs from science advice, let's turn our attention to what this might mean for the concepts put forward in the science advice literature. As we mentioned, the science advice literature conceptualises science advice mechanisms for policy and explores scientific advisers' practices and skills. We started our discussion there as science advice literature was thought to include engineering advice, mostly due to science advice author's broad definition of science. We pointed out however that engineering and science are two different disciplines with different goals and ways of thinking, raising questions around the transposability of science advice concepts onto engineering advice.

To explore this point further, we turned our attention to engineering studies, a field that looks at the differences between science and engineering in more depth as well as engineers' skills and practices. Engineering studies however does not consider those differences and skills in policy practice, so we had to use the very few articles available on engineering in policy to extrapolate engineering studies authors' findings.

We defined engineering advice for policy as the application of engineering to answer policy needs, a definition that brings the concept close to science advice as both concepts are concerned with the application of domain-specific knowledge to answer policy questions. It is clear from this definition that, just like scientific advisers, engineering advisers operate at the interface between their discipline and policy. Concepts put forward by the science advice literature that are related to interdisciplinarity, and the boundary-spanning process therefore seem applicable to engineering advice. This includes the idea that science and engineering advisers negotiate between scientific or engineering facts and socio-political values and context, between their disciplinary community, political decision-makers and the lay public. The ideal engineering adviser, just like the ideal scientific adviser, is therefore one that can transcend disciplines and summarize knowledge from different fields while understanding the policy agenda. Engineering and scientific advisers alike act as knowledge brokers at the engineering-policy and science-policy interface, meaning the gather and synthesise information from the engineering or scientific and policy communities and align needs with outputs. This last point is clearly visible when considering the significant overlap between concepts of translation and trading zones in the case of engineering advice and knowledge brokerage in the case of science advice.

With this said, science and engineering advice for policy have, respectively, science and engineering at their core, two disciplines with underlying differences impacting the focus and narrative structure of the advice. With regards to differences in focus, science produces theories and models of the natural world, whereas engineering advice is concerned with objects and built systems. Looking at differences in narrative structure, scientific advisers construct mostly descriptive narratives giving the impression of a balanced account of how things are and came to be. Engineering advice narratives, on the other hand, focus on change and goal-reaching through active intervention. These differences in focus and narratives, have a significant impact on the transposability of certain science advice concepts onto engineering advice.

Echoing our point about science advice narratives, Hilgartner noted that science advisers build credibility in the eyes of the policy makers by creating advice narratives that emphasise their objectivity, that make their advice look like a neutral description devoid of political judgements. Engineering advisers, at least from our theoretical understanding, seem to build credibility differently as their focus is not on adopting a neutral stance and projecting objectivity but reaching a goal and doing what is necessary to attain it. It would follow that engineering advisers build credibility by showing policy makers, taking into account different physical constraints and stakeholders' preferences, what the courses of action could be, embracing negotiation and compromise rather than objectivity. Unlike science advisers, engineering advisers seem less likely to draw sharp disciplinary boundaries when giving advice, disclosing instead the different possible trade-offs and steps to take to achieve the policy goal.

With all this said, our discussion of engineering advice, it's differences and similarities with science advice and what it means for science advice concepts is based on very little empirical data. To see if engineering advice matches our theoretical description and, by extension how it differs with science advice, more primary data is need. Additional empirical data, on top of validating or infirming the points made above, might also surface additional links between engineering studies findings and how engineering advice for policy works as well as additional similarities and differences between engineering and science advice concepts.

2.2.8 Moving on to the importance of policy context

The final point to note in this section is that engineering and science advice do not exist in a policy vacuum; meaning the way the advice is generated, given and received depends on the structure and culture of the policy institution in which the actors are embedded (Stevens, 2011; Christensen, 2021). In the case of our research, that institution in the UK's energy ministry. To finish constructing a relevant theoretical narrative of engineering advice, we therefore need to turn our attention to the existing literature on intra-ministerial policy advice.

2.3 The Intra-ministerial Advice Literature

2.3.1 Filling in literature gaps: The importance of intra-ministerial advice

As we have established, the science advice literature has neglected advice within ministries, making no specific attempts to understand how concepts like negotiation and boundary work hold up in an intra-ministerial context. This gap is also present in engineering studies, which does not consider engineering practice in policy, within ministries and within public institutions more broadly. Our current theoretical narrative of engineering advice, based on a combination of science advice concepts and engineering studies' findings, therefore misses the intra-ministerial policy advice angle. This is an issue in the case of our research, as we know that in the UK, a lot of policy making is done by middle ranking officials in ministries (Page and Jenkins, 2005; Stevens, 2011; Page, 2012; Cooper *et al.*, 2020). To complete our theoretical picture of engineering advice in UK policy practice, it makes sense to turn to the literature on intra-ministerial policy advice.

This strand of literature provides an overview of the impacts of the UK's civil service culture and ministerial structure on policy advice in general. The UK's civil service culture and structure, also known as the "Whitehall Model", refers to the values, practices and collective understanding of the British executive branch (E. Page, 2010; Schein, 2010). Working this literature's insights into the theoretical narrative of engineering advice we have developed prompts a reflection on the applicability of science advice and engineering studies concepts in the context of our research. Of course, as we will see, the resulting discussion of intra-ministerial engineering advice remains to be empirically tested.

Before we delve into the literature's findings, a quick note on definitions. Based on science advice literature we broadly defined policy advice as the application and combination of domain-specific knowledge to answer policy needs (Jasanoff, 2009; Stevens, 2011). This knowledge sometimes takes the form of "evidence", the different types of data that are entered into policy debates, including internally collected government data, academic analysis, thinktank or consultancy reports (Stevens, 2011). Both policy advice and evidence also tie into the concept of expertise, a policy actor's perceived high level of familiarity with domain-specific knowledge, evidence and/or experience that is neither widely shared nor simply acquired (E. C. Page, 2010; Grundmann, 2017). Policy advice, evidence for policy and expertise in policy, although closely related, have often been the subject of different policy debates (Stevens, 2011; Oliver, Lorenc and Innvær, 2014; Christensen, 2021). Instead of trying to summarize each debate separately, the following section looks across all three to surface insights specifically about UK intra-ministerial advice.

2.3.2 EBPM: Findings and shortcomings

Findings about UK intra-ministerial advice can be found in the Evidence-Based Policy Making (EBPM) corpus, one of the better-known debates about the use of evidence in policy (Christensen, 2021). The conversation around EBPM emerged from the fields of health policy and health management, focusing mostly on the uptake of evidence by policy makers, with evidence referring to peer-reviewed academic research (Oliver, Lorenc and Innvær, 2014). Research on EBPM was particularly popular in the UK in the mid to late 1990s onwards as the then Prime Minister Tony Blair used the phrase EBPM as a battle-cry for public service reform (Stevens, 2007; Head, 2016; Newman, 2017). Research on EBPM became particularly concerned with how to increase the uptake of evidence by identifying barriers and facilitators or evidence use by policy makers (Oliver, Lorenc and Innvær, 2014; Christensen, 2021). This included, of particular interest for our research, cultural and structural barriers to the uptake of academic research by policy makers in the UK civil service (Oliver *et al.*, 2014).

Drawing mostly on survey work and large scale structured interview work, research on EBPM concluded that the most frequently reported barriers relate to the lack of time, support and incentives for scientists to disseminate high-quality information effectively (Cairney, Oliver and Wellstead, 2016). EBPM studies also highlighted the low policy relevance of academic research and the lack of academic knowledge about identifying relevant policy makers and opportunities for timely engagement (Oliver *et al.*, 2014). The EBPM literature noted the widespread perception that policy makers rely on personal experience, ad-hoc links with experts and simple decision-making and stories rather than state-of-the-art scientific research (Cairney, 2015). Based on those findings, EBPM researchers' suggestions included packaging the evidence well to make it easy to understand and frame it in a way that is attractive to policy makers (Cairney, Oliver and Wellstead, 2016). Additionally, EBPM literature argued that academic-practitioner workshops and networks should be developed and supported to improve research visibility within policy and encourage academic-policy collaboration (Oliver, Lorenc and Innvær, 2014).

EBPM research however is not without its shortcomings. The main criticism of the EBPM literature is that it assumes the policy-evidence gap needs bridging yet approaches researchers and policy makers separately for their accounts of evidence use (Oliver, Lorenc and Innvær, 2014). On top of producing conflicting accounts, asking researchers about their perceptions of what policymakers do does not adequately portray the policy process (ibid). This misunderstanding of the policy process is a problem for the EBPM literature as evidence use is heavily dictated by who steers policies through and how (ibid). Authors have therefore argued that, to make recommendations about the impact of research in policy, the literature should focus on who the main policy actors are, where the decisions are made, and how evidence fits in the policy process (ibid).

Many academics focused on policy making in the UK civil service have added to that criticism of the EBPM literature (Hammersley, 2013; Cairney, 2015; Parkhurst, 2016; Newman, 2017). They argue that EBPM tends to assume that a small number of senior policy actors make evidence-based (or not) choices at specific points in time when, in reality, the policy making process is continuous and distributed (Cairney, 2015; Cairney, Oliver and Wellstead, 2016). UK government departments for instance take an open approach to policy making, consulting with a wide range of internal and external stakeholders and working in partnership with those groups to deliver policy (Hammersley, 2013; Parkhurst, 2016). This means that the evidence-to-policy process is a non-linear and interactive process in which many actors negotiate the implication of evidence, academic or other, alongside other sources of policy-relevant information (Nutley, Walter and Davies, 2007; Cairney, 2015). During this process, policy makers rely on a mixture of emotion, knowledge, and experience to gather relevant information and consider the value for money, opportunity costs and political feasibility of different policy options (Hammersley, 2013; Cairney, 2015). Of course, this is all very context dependent, therefore authors conclude that future studies should adopt deep qualitative methods to contextually describe the policy process and explore the role of evidence within it (Oliver, Lorenc and Innvær, 2014; Head, 2016; Christensen, 2021).

2.3.3 An ethnographic description of UK intra-ministerial policymaking

In response to the shortcomings of the EBPM literature, a few authors have attempted deep qualitative studies of the UK policy process with a particular focus on intra-ministerial policy making (Page and Jenkins, 2005; Stevens, 2011; Page, 2012). Page and Jenkins argue that, most of the policy literature, not just EBPM, assumes that policies are set by the top, whether politicians or senior civil servants, leaving lower-ranking officials with the simple task of 'embellishing and detailing' the policy for it to be implemented (Page and Jenkins, 2005). Policy literature therefore restricts the role of middle-ranking officials to policy implementation leaving policy advisory tasks to senior bureaucrats, ministers and interest groups (Page, 2006). Page and Jenkins' work however, based on ethnographic interviews of mid-ranking officers in UK government departments across the civil service, debunk these misconceptions (Spradley, 1979; Page and Jenkins, 2005). The authors show how important strategic policy issues involve settling detail and therefore how many strategic policy decisions emerge from the work of those developing this detail. Mid-ranking officers, in this sense, are not just routine workers in bureaucracy, but have an extremely important role to play in policy – it could even be argued that they are the ones "making policy" (Page and Jenkins, 2005).

According to the UK civil service grade structure, Page and Jenkins explain that mid-ranking officers are the civil servants employed as: Higher Executive Officers (HEOs), Senior Executive Officers (SEOs), Principal Officers or equivalent (Grade 7) and Senior Principal Officers or equivalent (Grades 6) (Page and Jenkins, 2005). These terms are still in use today. Most of them work within policy teams across the civil service and sit below the Senior Civil Service (SCS) grades (Grade 5 and above). Although most middle-ranking officers have a university education, their degrees do not make them specialists (ibid). In fact, following the "generalist ethos" of the UK civil service, mid-ranking officers tend to stay in their position for a relatively short time, Page and Jenkins' sample average was 17 months (Page and Jenkins, 2005; E. Page, 2010). The civil service rewards exposure to and experience of different policy areas, meaning policy officers mostly move around to further their career (Judge, 1981; Page and Jenkins, 2005; Stevens, 2011). This can either be a move to a more senior job in another team or a lateral move to gain experience in another policy area to build up one's portfolio (and then get promoted) (Page and Jenkins, 2005; Stevens, 2011). Mid-ranking officers therefore mention being adaptable, quick-learners and being sensitive to policy stakeholders concerns as important skills to do their job well (Page and Jenkins, 2005). For policy officers, knowledge of the policy processes and procedures is often more important than topical knowledge of the policy area (ibid).

Table 2.3: UK Civil Service rank and corresponding grades (adapted from Page & Jenkins, 2005)

Rank	Grade	Title
Senior Civil Service (SCS)	5 and above	Deputy Director and above
Mid-ranking officers	6	Senior Principal Officers
	7	Principal Officers
	SEOs	Senior Executive Officers
	HEOs	Higher Executive Officers

Beyond clearly identifying who those middle-ranking officers are and the skills they have, Page and Jenkins explore the different types of policy jobs they carry out (Page and Jenkins, 2005). Based on their interview work, the authors distinguish three types of policy jobs based on the output they produce: production jobs, maintenance jobs and service jobs. Production jobs produce a draft, statement or document and are concerned with a one-off task like developing a White Paper setting out policy proposal for future legislation. Maintenance jobs involve tending to a particular scheme or set of institutions, making day-to-day decisions about how the scheme should be handled. Service jobs are about giving advice or other assistance to an individual body, usually on a continual basis, like Ministry of Defence (MoD) officials advising ministers on how to handle relations with other countries.

Policy making, encompassing all three types of policy jobs, is shaped by four components: principles, policy lines, measures and practices (Page, 2006). Principles are general views on how public affairs should be arranged, like privatisation or consumer choice, and policy lines refer to the specific strategies aimed at addressing specific policy problems. Measures are the instruments that give effect to the policy lines and practices are the behaviours of the officials expected to carry out policy measures. Interestingly, Page notes that mid-ranking policy officials develop policy lines and measures without an imposed precise political direction (ibid). In other words, politicians do not generally have clear ideas about what they want, resulting in officials using their own judgement in developing policy. Mid-ranking officers still look for cues about what is politically acceptable but do so indirectly, looking at parliamentary speeches, news and government responses instead of relying on clear directions from senior civil servants and ministers (Page, 2012).

Having established that mid-ranking officers are directly involved in multiple forms of policymaking, Stevens builds on Page and Jenkins' account and takes an ethnographic look at how UK policy officers use evidence in criminal justice policy (Stevens, 2011). Stevens explains that policy officers within his government department know they have done their job when their proposals are accepted as government policy. To do so, policy officers have to persuade their superiors by turning evidence (see definition in 2.3.1) into a coherent policy narrative, a "policy story". Officers do this by ensuring the internal coherence of policy drafts, leading the reader to the conclusion that the suggested policy is the only alternative that makes sense. Included in the policy drafts are "killer charts", simple diagrams, tables and graphs where data is carefully selected to push a certain narrative forward. Stevens concludes, echoing Page's point about political acceptability cues, that mid-ranking officers make sure that the general story line of their policy proposal reflects the dominant modes of thought the civil service. This includes, for example, the belief in the power of the purchaser/provider split to increase value for money in the public services. Matching and therefore reproducing these dominant modes of thought not only helps proposals go through but also enables policy officers to signal that they hold appropriate beliefs, increasing their chances of promotion.

2.3.4 Mid-ranking policy officers and expertise

The final point surfaced by Page and Stevens' ethnographic approaches to the civil service is about expertise: a policy actor's perceived high level of familiarity with domain-specific knowledge, evidence and/or experience that is neither widely shared nor simply acquired (as defined in section 2.3.1). Page identifies four different types of expertise, starting with discipline-specific expertise, referring to familiarity with the theories and concept of a specific discipline like epidemiology or economics[6] (E. C. Page, 2010). The second and third types of expertise refer to familiarity with the range of policy lines and measures past and present (policy expertise) and the knowledge of the processes to be followed for a proposal to be put into effect (process expertise). The last type of expertise is instrument expertise, the knowledge of how to put a law together. All four types of expertise are of course made up of explicit and tacit elements, of formally expressed knowledge and informal contextual rules of actions acquired through experience (Nutley, Walter and Davies, 2007; Collins and Evans, 2008; Stevens, 2011). From the accounts of the civil service above and especially its "generalist ethos" it is clear to see that policy officers are encouraged to build policy and process expertise, to understand the complex inner workings of Whitehall and how to solve problems within it (Stevens, 2011).

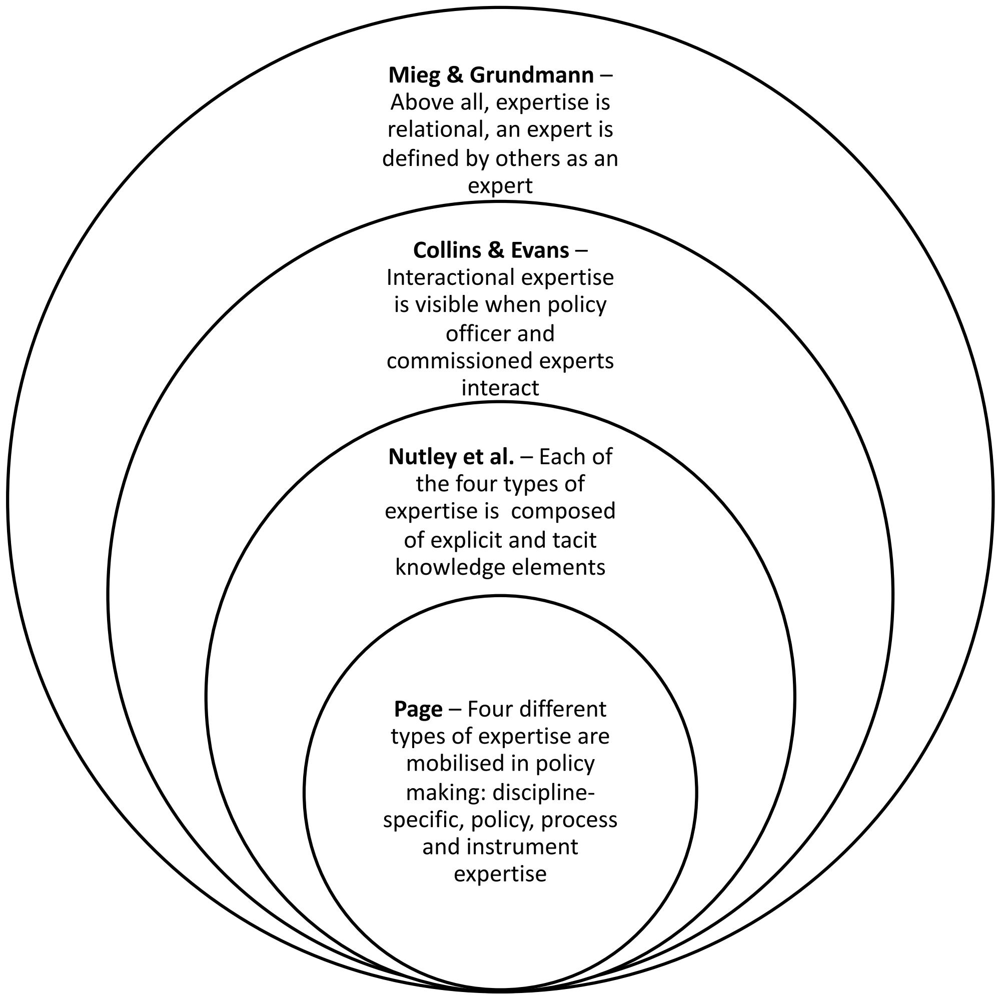
Policy making often requires discipline-specific expertise however, in which case policy officers have the position and sometimes also the budget to get disciplinary experts to talk or work for them (E. C. Page, 2010). In this case, policy officers become "mobilisers of expertise", formally or informally commissioning expert advice internally or from consultants or

[6] Page originally labels this "scientific expertise" but refers to examples beyond the natural sciences. To avoid any confusion given previous discussion of science and science advice, I have taken the liberty of re-naming Page's concept as discipline-specific expertise which, I believe, still reflects the original definition.

universities (ibid). Interestingly, as Collins and Evans note, an additional type of expertise is expressed when policy officers and commissioned experts interact: interactional expertise (Collins and Evans, 2008). Like concepts of translation and trading zones mentioned previously, interactional expertise refers to the mastery of the language of a domain that enables different experts to communicate, reflect upon their subject matter and articulate their findings in a way that makes sense to their counterparts. In the case of policy officers commissioning expert advice, interactional expertise is visible when policy and process expertise communicated by the policy officers is combined with discipline-specific expertise articulated by the commissioned experts (ibid). When mobilizing expertise, policy officers also have to ensure that their involvement in the policy making process is not overshadowed by the commissioned advisers' discipline-specific expertise. Otherwise, policy officers run the risk of becoming the "servant of experts" (E. C. Page, 2010).

The last point to note here is that expertise is "relational", expertise is constituted by familiarity with a body of knowledge or experience *and* the attribution of an expert role (Mieg, 2006). In other words, to be an expert, one has to be considered or perceived as an expert by others (Grundmann, 2017). A commissioned expert is an expert because of their familiarity with their disciplinary knowledge and because the policy officer considers them an expert in their field. In the same way, a policy officer who has develop a specific policy proposal can be considered an expert in the policy area by a senior-civil servant. Mid-ranking officers can therefore be perceived as experts, on the basis of their policy and process knowledge, as well as mobilisers of expertise (E. C. Page, 2010).

Figure 2.2: How different types and dimensions of expertise relevant to mid-ranking policy officers relate and build on each other.



2.3.5 What does this mean for our theoretical picture of engineering advice?

Ethnographic accounts of the UK intra-ministerial policy making process shed light on the role mid-ranking officers play in advising senior civil servants and developing policy. Most of this body of work however looks at policy teams 'in general', which, in the context of our research, begs the question: how do these insights apply specifically to engineering advice in a UK government department? To explore this, let us see what the insights from the UK intra-ministerial advice literature might mean for the theoretical picture of engineering advice (linking science advice and engineering studies) we started painting above. Combining this strand of policy literature with the theoretical narrative we started earlier prompts a reflexion on engineers, their knowledge and skills in a UK government department while considering useful concepts from the science advice literature.

From the very few works published on intra-ministerial engineering advice we know that, in some government departments, engineering teams made up of engineers by training are responsible for advising other policy teams in their ministry on engineering matters (Cooper *et al.*, 2020; Liote, 2022). This creates an interesting situation where the engineers provide internal advice to policy officers while being mid-ranking civil servants themselves. It follows that the insights surfaced by the ethnographic accounts above about the UK civil service culture and structure will impact both the way engineers advise policy officers but also their own role and career development.

The "generalist ethos" of the civil service for instance has ramifications for engineering advice. As we have established, mid-ranking policy officers stay in their position for a relatively short time as the civil service rewards exposure to different policy areas. To move around the government, policy officers are encouraged to build process and policy expertise rather than topical knowledge of their current policy area. This raises several questions with regards to engineering advisers who, as we have established earlier in this review, possess domain-specific (i.e. engineering) expertise. Firstly, between the engineering adviser and policy officer, who brings what type of knowledge and expertise into the policy making process and how are those combined? Secondly how is engineering advice affected by the amount of turnover within policy teams? Do new policy officers need to be brought up to speed on more technical engineering issues every time they move into an engineering-heavy policy area? How does this affect the relationship between engineering advisers that hold this engineering knowledge and policy officers – are new policy officers more likely to become the "servants" of engineering advisers? Thirdly, do engineering advisers move around the civil service as much as other mid-ranking officers do despite having what might seem like a less generalist profile?

Empirically answering these questions will likely draw on and refine concepts mentioned before. This includes our earlier conversation about knowledge-brokerage, translation, and trading zones and how different actors negotiate between engineering and policy issues.

Looking at engineering advice in a UK intra-ministerial setting might refine our understanding of boundary work by exploring how policy officers receive engineering advice, how they take it into account and what evidence, or expertise might go against it. Additionally, empirical data on which actors brings what expertise to the policy process is likely to shed light on the role of different concepts like practice-based knowledge (section 2.2.3) and tacit knowledge (section 2.3.4) play in engineering advice.

The UK civil service's "open approach to policy making" also has implications for our theoretical picture of engineering advice. As mentioned, UK government departments consult with a wide range of internal and external stakeholders to deliver policy, with policy officers often acting as "mobilisers of expertise". Again, this raises several questions when it comes to engineering advice, especially around actors and roles that might not have been considered by the science advice and engineering studies literature. First, as mid-ranking civil service officers, do engineering advisers act as mobilisers of expertise as well? If so, does their role change when they formally commission research or when the policy teams they advise commission engineering-related research? Secondly how does this affect relationships and perception of expertise between the senior civil servants, policy officers, engineering advisers and commissioned researchers or consultants?

Again, finding empirical answers to those questions is likely to draw on insights raised in our discussion of boundary-spanning, albeit in a more distributed environment than what some of the science advice literature has described. Looking at if and how engineering advisers act as mobilisers of expertise will refine our understanding of negotiation, coordination and boundary work introduced in the science advice literature by uncovering additional boundaries, mechanisms for bridging them and implication for the engineering advice process.

Finally, we need to consider the concept of "policy stories" introduced by Stevens in our conceptualisation of engineering advice. Policy stories are created by policy officers by turning evidence into "killer charts" and coherent narratives to convince their superiors. In the context of engineering advice this leaves us wondering if engineering adviser create policy stories as well when they advise policy officers. It also leaves us thinking if engineering advisers help policy officers in crafting the policy stories for their superiors and how complicated engineering knowledge is simplified in policy proposals?

These last questions clearly tie into our earlier point about engineering advice narratives; narratives that focus on goal-reaching and problem-solving through active interventions (section 2.2.6). It will be interesting to empirically see if, given engineering advice is about "problem-solving in the real (physical) world", it is valuable for "policy officers aiming to make policy that works" (Cooper *et al.*, 2020). Or, on the contrary, if ministerial engineering experts clash with policy officers who are also trying to solve a policy problem in a different way (ibid). Either way, answers to these questions will show how engineering advice fits within the wider policy story told in the policy proposals. This is likely to surface insights about what Hilgartner labelled "stage management" (see section 2.1.4), about what information is displayed and what information is concealed by engineering advisers and policy officers when drafting engineering-informed policy.

2.4 Final thoughts

Our theoretical discussion and combination of science advice, engineering studies and intra-ministerial policy literature has helped us paint a theoretical picture of intra-ministerial engineering advice. As repeatedly mentioned however, the assumptions, questions and hypotheses raised in the process remain to be empirically tested. To refine and develop our understanding of how engineering advice is deployed in policy we therefore need primary data to answer the following three questions, which encompass all our theoretical points raised so far:

1. How does engineering advice work in a UK government department?
2. What is the difference between science and engineering advice in a UK ministerial context?
3. What are the impacts of the UK civil service's institutional structure and culture on engineering advice?

3 Methodology

As established in the literature review, to better understand how engineering advice is deployed in policy practice, the following questions need answering:

1. How does engineering advice work in a UK government department?
2. What is the difference between science and engineering advice in a UK ministerial context?
3. What are the impacts of the UK civil service's institutional structure and culture on engineering advice?

This chapter set outs the methodology used to collect and analyse the data required to answer the three research questions above. It starts with a brief discussion of my research paradigm: the idealist ontology and constructionist epistemology underpinning my research questions. My research paradigm and similar intra-ministerial policy studies make it clear that adopting an ethnographic approach combining observation, interviews and document analysis is an appropriate methodological choice. The following sections describe the research process, divided into three research phases, each phase designed to ethnographically answer one of my research questions. The sampling strategy, data collection and analysis method for each phase are detailed in turn. The chapter ends with a reflexivity section reflecting on the limitations of the methods, issues encountered during the research process and how they were dealt with.

3.1 Research paradigm

As Blaikie and Priest explain, researchers always work within the context of a research paradigm: a particular set of ontological and epistemological assumptions (Blaikie and Priest, 2019). In other words, the questions driving the research carry explicit or implicit claims about the nature of the evidence or knowledge one is looking for and how to get to that knowledge. Reflecting on those assumptions early in the project and sharing this reflection with the reader is best practice as it sheds light on why specific methods were chosen for the research (Blaikie and Priest, 2019; Braun and Clarke, 2021).

My research questions aim to explore how engineering advice is deployed in policy practice. They are underpinned by a combination of literature focused on how science advisers, engineers, and mid-ranking UK policy officers understand their role, practices, and identity. In line with an idealist ontology, this implies that an understanding of engineering advice in policy can be found in the shared interpretations produced and reproduced by engineering advisers and their collaborators as they go about their day-to-day jobs (Given, 2008; Blaikie and Priest, 2019). As my research questions also imply, still aligned with an idealist ontology, special attention should be paid to the structural context in which the actors operate as it shapes their everyday activities (Given, 2008; Ritchie *et al.*, 2013). In my case, this means investigating how ministerial set-up influences the engineering advisers and policy officers' day-to-day work and their resulting understanding of engineering advice.

It follows that, to answer my research questions and gain an understanding of engineering advice in practice, the focus should be on the engineering advisers and their collaborators' understanding of their day-to-day activities. This is also known as a constructionist epistemology where the role of the researcher is to collect, process and analyse accounts from different actors on how they understand their roles, their sense of identity and the meaning they attach to their interactions (Bernard, 2011; Blaikie and Priest, 2019). After the actors' accounts are analysed, the researcher consolidates this everyday knowledge into more systematic social scientific knowledge to answer the research questions (Ritchie *et al.*, 2013).

3.2 Ethnographic approach

Given our research paradigm and its focus on engineering advisers and other policy actors' understanding of their own roles and interactions, an abductive research strategy seems like an appropriate methodological choice. An abductive research strategy stipulates that the way actors perceive their world should be discovered from the accounts provided by the actors themselves (Blaikie and Priest, 2019; Rhodes and Corbett, 2020). As a researcher, I therefore need to enter the engineering advisers and policy officers' world to uncover and analyse their understanding of engineering advice in policy and answer my research questions (Ritchie *et al.*, 2013; Blaikie and Priest, 2019).

"Entering social actors' world to understand their point of view, their vision of their life" matches the original definition of an ethnographic approach (Malinowski, 1978). Fitting in well with our research paradigm and strategy, the objective of an ethnographic approach is to understand the activities and interpretations of actors in a given "field" or setting, involving the close association of the researcher in this setting (Brewer, 2000; Cappellaro, 2017). To meet its objective the ethnographer employs an array of methods including participant-observation, in-depth interviewing, and document analysis (Spradley, 1980; Bernard, 2011; Madden, 2017). The data collected is analysed using thematic analysis, consolidating the actors accounts into theoretical themes, and related to existing literature (Bernard, 2011; Braun and Clarke, 2021). I will elaborate on what those data collection and analysis methods entail below in the discussion of my research phases (section 3.5 to 3.7).

Adopting an ethnographic approach to engineering advice in policy practice is not only an appropriate way to get the data I need to answer my research questions, but also a relatively underused approach to study policy making (Christensen, 2021; Rhodes and Corbett, 2020). As we saw in the previous chapter, some science advice authors (Hilgartner, 2004; Spruijt *et al.*, 2014) and UK policy advice scholars (Stevens, 2011; Page, 2012; Cooper *et al.*, 2020) noted that their fields would benefit from more ethnographic studies exploring how policy advice is constructed from the point of view of those who give and receive it. I also pointed out that engineering studies authors use ethnographic methods but have never applied them to engineers working in policy. Ethnographically exploring engineering advice in policy therefore presents a double contribution to all three fields mentioned, it fills in content and methodological gaps by looking into an understudied domain using an underused (but called-for) methodological approach.

3.3 Considering similar studies

As mentioned in chapter 2 (sections 2.3.3 to 2.3.5), three relevant studies have taken an ethnographic approach to explore intra-ministerial policy advice in the UK: Page and Jenkins (2005), Stevens (2011) and Cooper et al (2020)[7]. It therefore makes sense to look at the methodology of all three studies in more depth to inform the design of my research project on intra-ministerial engineering advice.

Page and Jenkins (2005) have looked at how the UK policy bureaucracy works from the point of view of middle-ranking officials doing the bulk of policy work within them. To do that, the authors carried out 20 minutes interviews of 128 middle-ranking officials across different UK government departments, to ask them about their work. The results of the study were presented thematically and include raw quotes illustrative of each of the themes discussed. Given my similar focus on middle-ranking officers and their experience of their work, interviewing and thematic analysis seemed like appropriate design choices. However, Page and Jenkins' study, unlike mine, did not target a specific type of expertise or team in the civil service.

Stevens (2011), referencing Page and Jenkins' work and approach, has explored how policymakers use evidence. To do that, the author worked at middle-ranking level, in a UK civil service team focused on social and criminal justice. Unlike Page and Jenkins, Stevens was embedded in one team, observing interactions, and carrying interviews with other mid-ranking officers he worked with. As Stevens was more reliant on observation and focused on one team, his interview sample was much smaller (5 interviews) and interviews longer (1 hour) than Page and Jenkins. However, like Page and Jenkins, Stevens used thematic analysis to code his results and identify themes in his data.

[7] Please note that Rhodes has also undertaken ethnographic studies of the British civil service and advocates for the use of ethnographic methods to study public administrations (see chapter 2, sections 2.1.8. and 3.2). However, his work is focused on SCS and ministers rather than mid-ranking officers, making it less topically relevant for the purpose of this study (Rhodes, 2011; Rhodes, 2019).

Given my focus on a specific aspect of policy advice (engineering advice) centring my research around one team like Stevens, seemed an appropriate design choice. Following Stevens, this would mean favouring a smaller and more targeted sample than Page and Jenkins. A smaller sample would lend itself well to in-depth interviews and observations, which could then be thematically analysed.

Referencing both Page and Jenkins' study and Stevens' work, Cooper et al (2020) took an ethnographic look at DECC[8] in 2012. Cooper's study, referenced throughout the literature review, looked at policy officials' narratives of working with internal engineer officers. The study, led by researchers working at DECC, is based on 18 interviews of middle-ranking officers. The results of the study were presented thematically with illustrative quotes from the participants along with a short description of their role and time in their role.

Again, given the similar aim of my study, following Cooper's interview and thematic analysis approach seemed like an appropriate design choice. To gain a better understanding of intra-ministerial advice however, and complementary to Cooper's study, I decided to focus my research on the intra-ministerial engineering experts rather than just looking at the policy officials they worked with. This informs the sampling for my first phase of research detailed below in section 3.5. Cooper's study, as mentioned in chapter 2 (section 2.2.6), also generated some results around the possible difference between engineering and science advice in policy. Those differences were drawn from the language used by policy officers when discussing engineering advice compared to concepts in the science advice literature, rather an empirical comparison between science and engineering advice in that context. I therefore decided to build on Cooper's study and try to establish comparative empirical accounts of intra-ministerial engineering and science advisers. This informs the sampling strategy for the second phase of my research detailed in section 3.6 below.

[8] DECC was the Department of Energy and Climate Change until it was merged with BIS (Department for Business Innovation and Skills) to become BEIS in 2016.

3.4 *Research design*

To investigate how engineering advice is deployed in policy practice, I divided my research into three phases, each designed to ethnographically answer one of my research questions. Based on my chosen methodological approach and learning from the three studies mentioned above I knew that:

- Targeting intra-ministerial engineering and science advice teams was an appropriate sampling strategy.
- Observation and in-depth interviewing were appropriate data collection methods.
- Data could be thematically analysed and presented.

I drew on these insights to inform the sampling strategy, data collection and analysis methods for each phase, as detailed below.

3.5 *Phase 1 (Pilot): How does engineering advice work in a UK government department?*

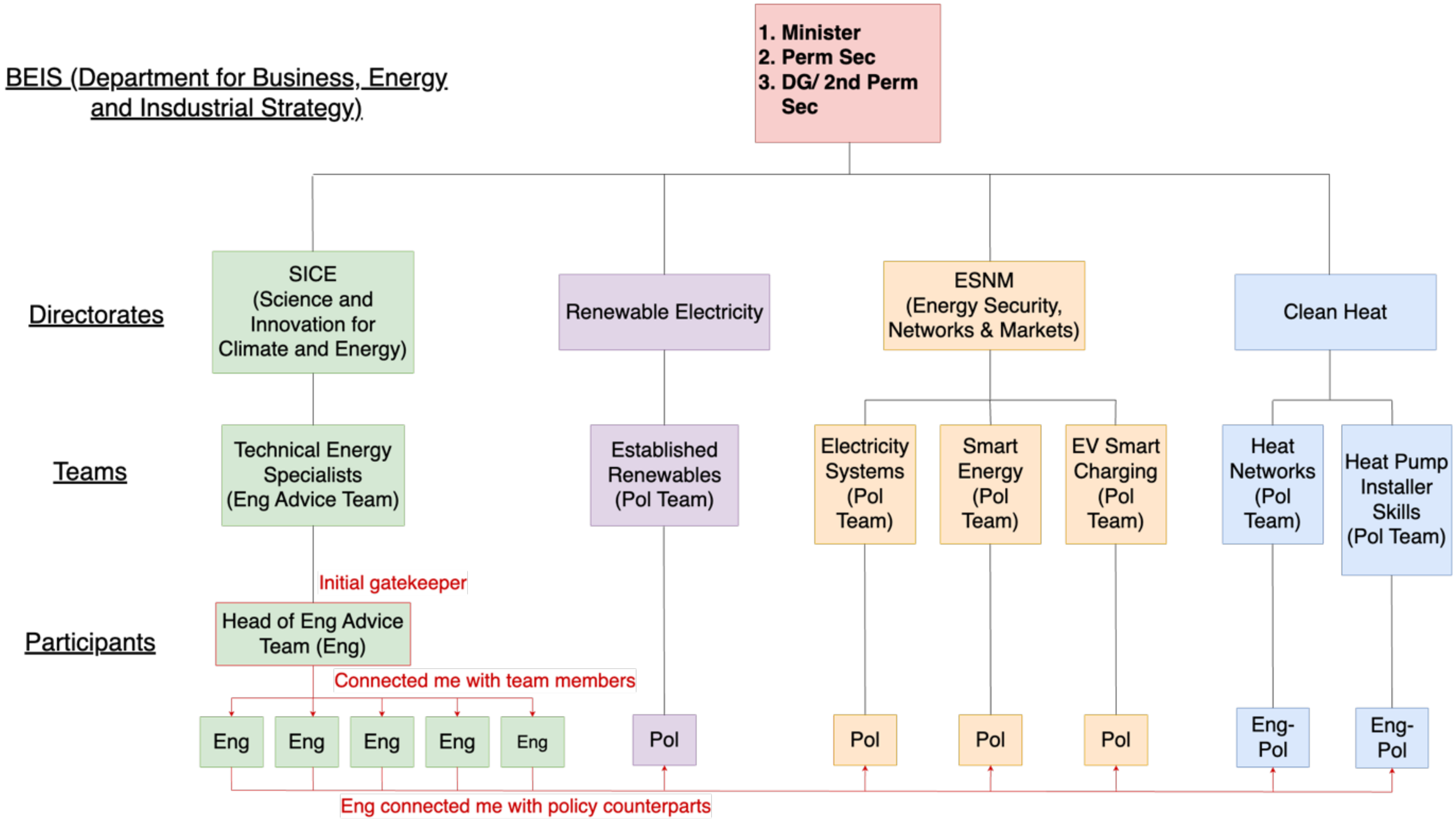
3.5.1 *Sampling Strategy*

As mentioned in the introduction, I decided to concentrate on energy policy as it is an engineering-dependent policy area and on the UK to facilitate access. As we saw in the literature review (section 2.3.3) and above (section 3.3), in the UK a lot of the policy making is done by middle-ranking officers in government departments. It therefore makes sense to explore engineering advice in policy practice by looking at middle-ranking officers at BEIS, the UK's energy ministry at the time of my research.

As mentioned above (section 3.3), my supervisor, Adam Cooper, had previously done a study at DECC (BEIS' predecessor), interviewing policy officers who worked with an internal team of engineering advisers. Through Dr. Cooper I reached out to this internal engineering advice team, formally called BEIS' "technical energy specialists' team". I contacted the head of the technical energy specialists' team to understand the remit of the team and discuss my project. After an informal conversation it became clear that the team would be an appropriate site for a pilot study on intra-ministerial engineering advice. Indeed, their remit is to "provide engineering advice to other policy units sitting within BEIS to deliver decarbonisation of energy at an acceptable cost"[9]. From here on I will refer to the technical energy specialist team as the engineering advice team and the policy units they advise within BEIS as policy teams. The teams are abbreviated "Eng Advice Team" and "Pol Teams", respectively, in figure 3.1.

[9] Description taken from the letter sent by BEIS to UCL to approve my fieldwork.

Figure 3.1: BEIS partial organogram, teams and participants involved in pilot study



I formally interviewed the head of the engineering advice team to get a better picture of the team structure and how it fits within the ministry. The engineering advice team is made up of 10 engineers, including the head of the team, and sits in a directorate called SICE (Science and Innovation for Climate and Energy). The engineers within the team (labelled 'Eng' in figure 3.1) work directly with policy officers (labelled 'Pol' and 'Eng-Pol' in figure 3.1) in other directorates on different energy policies. After my interview with the head of the engineering advice team, I asked them to act as my gatekeeper and put me in touch with the rest of their team. I interview 5 other members of the engineering advice team to understand their role and ask them to put me in touch with the policy officers they work with. I subsequently interviewed 6 policy officers, 4 with political science/humanities backgrounds ('Pol' in figure 3.1) and 2 with an engineering background ('Eng-Pol' in figure 3.1). Using respondent-driven sampling to get to the engineers' policy counterparts allowed me to gain insight into the engineering-policy interface and follow the same projects from an engineer and a policy officer's point of view (Bernard, 2011; Palinkas *et al.*, 2015).

Table 3.1 below provides a summary of my pilot study sample including anonymised participants numbers, their role type (same as figure 3.1), their civil service rank (as per Page and Jenkins, 2005), the time spent in their current role and interview date and duration. For the 'time in role', under one year in the position is marked as 'short', between one and two years is 'medium' and two years and above is 'long'. This presentation mirrors that of Cooper's 2020 study as mentioned in section 3.3.

Table 3.1: Pilot study sample

Phase 1 (Pilot)				
Anonymised Participant Number	**Role Type**	**Civil Service Rank**	**Time in Role**	**Interview Date and Duration**
32	Eng	Mid-ranking officer	Long	22/01/2021 – 2h
17	Eng	Mid-ranking officer	Medium	27/01/2021 – 1h
85	Eng	Mid-ranking officer	Medium	02/02/2021 – 1h
61	Eng	Mid-ranking officer	Long	03/02/2021 – 2h
96	Eng	Mid-ranking officer	Long	04/02/2021 – 1.5h
22	Eng	Mid-ranking officer	Short	23/03/2021 – 1h
69	Pol	Mid-ranking officer	Short	24/02/2021 – 2h
67	Pol	Mid-ranking officer	Short	09/03/2021 – 1h
29	Pol	Mid-ranking officer	Medium	10/03/2021 – 1h
55	Pol	Mid-ranking officer	Medium	12/03/2021 – 1h
58	Eng-Pol	Mid-ranking officer	Medium	22/03/2021 – 1.5h
65	Eng-Pol	Mid-ranking officer	Short	16/04/2021 – 1h

3.5.2 Data collection: Ethnographic interviews

My pilot project was carried out from January to May 2021, any in-person participant observation and interviewing were impossible because of the Covid 19 pandemic. Data was therefore collected through online ethnographic interviews lasting between 1 and 2 hours (see table 3.1). I recorded the interviews and did the transcription myself within 48 hours, with all transcripts immediately added to qualitative analysis software NVivo.

Ethnographic interviews are a type of semi-structured interviews, meaning I had some questions prepared but allowed for follow-ups on new ideas brought up by my participants (Robson, 2011; Kallio *et al.*, 2016). Questions included “grand-tour questions” on the participant’s role within BEIS, “specific-tour questions” to discuss day-to-day activities and “guided-tour questions” where the participant shared their screen and walked me through the documents they were working on (Spradley, 1979). The documents shared on screen, some of which I was not allowed to save to my computer for confidentiality reasons, included draft policy reports, policy infographics and academic article summaries, consultation documents, model data and presentation slides. Follow-up questions usually included "example questions" where I asked a participant to give an example of a theoretical situation mentioned and "native-language questions" where I asked for clarification on specific civil-service terms (Spradley, 1979). I took notes during the interviews about what I learnt, my reactions, contradictions or overlaps between participants' responses and comments requiring follow-up (McIntosh and Morse, 2015; Fujii, 2017). These notes were consolidated in interview memos and attached to their respective transcripts in my NVivo database to help reflect on concepts and terms during data analysis (Barry, Born and Weszkalnys, 2008; Braun and Clarke, 2021).

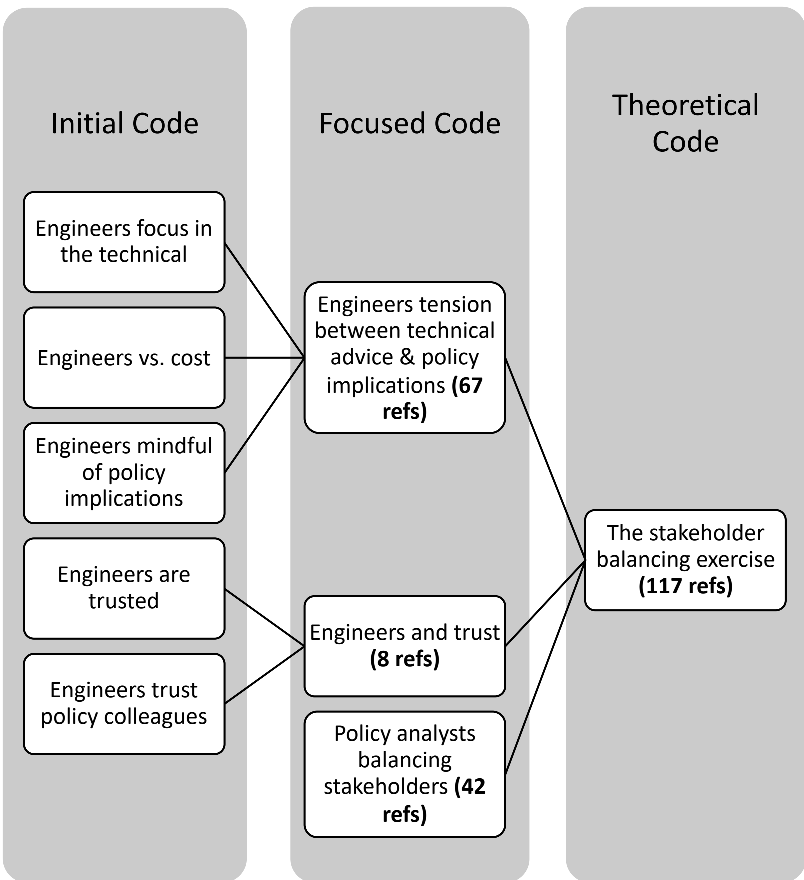
After finishing the interviews, I collected publicly available government documents where the outcome of the projects the engineers and policy officers were working on are presented. This included, for example, the Draft National Policy Statement for Renewable Energy Infrastructure (EN-3) where policy decisions are made on the back of a modelling project I was exposed to during my interviews. A full list of documents seen and collected as well as my pilot interview guide and an example of an interview memo can be found in the appendices.

3.5.3 Data analysis: Grounded theory

All the data collected was analysed on NVivo using Charmaz's grounded theory framework, a common framework to build theory from ethnographic data (Sbaraini *et al.*, 2011; Charmaz, 2014). For the framework to work, the aim of the research should be to create theory "from the bottom-up", that is from the raw data, instead of reusing an existing theoretical model (Charmaz, 2014; Blaikie and Priest, 2019). As established in chapter 2, science advice, engineering studies and policy studies provide some useful insights on engineering advice but no complete theoretical model to understand it. Given engineering advice had never been the subject of a specific existing theoretical model, Charmaz's framework seemed like an appropriate choice to analyse my pilot study data.

Following Charmaz's framework I coded my data, a process of breaking transcripts and documents down into smaller components (called "initial codes"), labelling these components and comparing these components within and between transcripts and documents to find pattern and variation in the data (Bowen, 2009; Charmaz, 2014). Initial codes were combined with each other to produce concepts (captured in "focus codes") that are related to each other in a cohesive whole and form a theory (captured in "theoretical codes") (Charmaz, 2014; Braun and Clarke, 2021). An example of the coding process is provided in figure 3.2. As I coded my data, I kept a trail of my reflection in different types of summaries attached to their respective focused and theoretical codes. This allows me to go back and check how my theoretical codes were built, drilling all the way back down to the quotes used to inform the code (Braun and Clarke, 2006; Cunliffe, 2015). My phase 1 (pilot) theoretical codes inform my answer to my first research question presented in the following chapter: how does engineering advice works in a UK government department?

Figure 3.2: Coding process example



My pilot study codebook listing how all codes fit together, and examples of focused and theoretical code summaries can be found in the appendices.

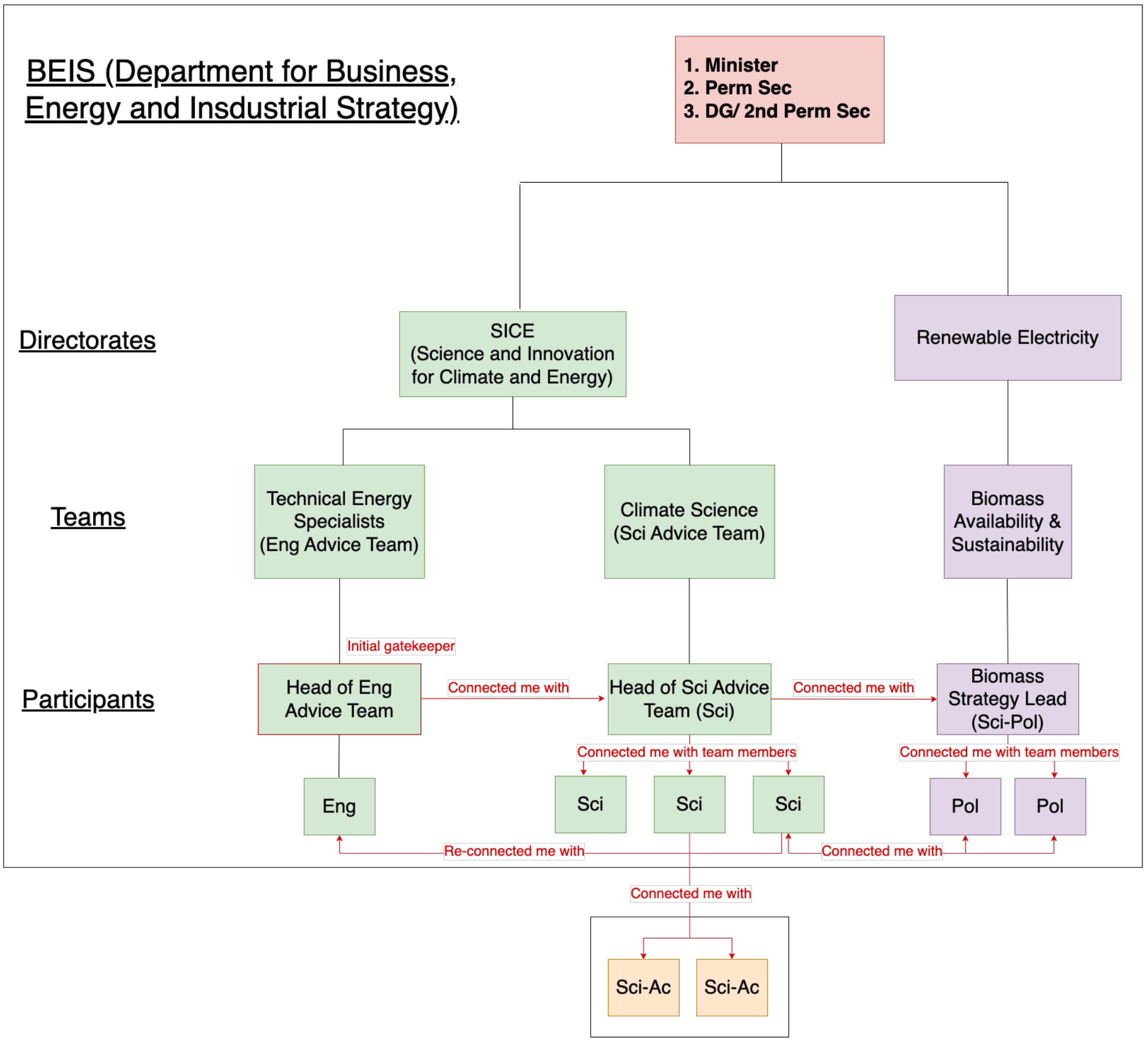
3.6 Phase 2: What is the difference between science and engineering advice in a UK ministerial context?

3.6.1 Sampling strategy

The second phase of my research was designed to answer my second question on the difference between intra-ministerial science and engineering advice, following-up on points raised in my literature review, Cooper's 2020 study (see section 3.3) and initial phase of research. To explore this difference, I decided to reach out to BEIS's climate science team, mentioned in my pilot interviews, through my gatekeeper's intermediary. The climate science team "looks after the UK's climate science capability and provides scientific advice to other policy teams within the ministry"[10]; it is based in SICE, the same directorate as the engineering advice team (see figure 3.3). Both teams therefore work in the same policy structure (ministry and directorate), and both provide advice to other policy teams within BEIS, allowing for a direct comparison of science and engineering advice in this context. From here on I will refer to the climate science team as the science advice team, abbreviated "Sci Advice Team" in figure 3.3.

[10] Quote from the head of the climate science team

Figure 3.3: BEIS partial organogram, teams and participants involved in phase 2



To make the comparison between engineering and science advice easier, I used the same sampling strategy as phase 1. I interviewed the head of the science advice team to understand the teams' remit and how it fits within BEIS. The science advice team is made up of 7 scientists, including the head of the team, labelled 'Sci' in figure 3.3. After our initial interview I asked the head of the team to put in touch with their team members, interviewed 3, and asked them to put me in touch with their collaborators to explore the intra-ministerial science-policy interface. This led me to interview three policy officers the science advice team works with, including one with a scientific background (abbreviated 'Sci-Pol'), and two academic scientists involved in projects contracted out by the science advice team (abbreviated 'Sci-Ac'). One of the science advisers also works with an engineer in the engineering advice team whom I re-interviewed. Table 3.2 below provides an overview of my sample for phase 2.

Table 3.2: Phase 2 sample

Phase 2				
Anonymised Participant Number	**Role Type**	**Civil Service Rank**	**Time in Role**	**Interview Date and Duration**
46	Sci	Mid-ranking officer	Long	06/01/2022 – 1.5h
50	Sci	Mid-ranking officer	Medium	22/02/2022 – 1h
26	Sci	Mid-ranking officer	Long	24/02/2022 – 1.5h
6	Sci	Mid-ranking officer	Long	15/03/2022 – 2h
94	Sci-Pol	Mid-ranking officer	Medium	25/02/2022 – 1.5h
79	Sci-Ac	Not applicable	Long	11/03/2022 – 1h
83	Sci-Ac	Not applicable	Long	23/03/2022 – 1h
13	Pol	Mid-ranking officer	Medium	28/03/2022 – 1.5h
37	Pol	Mid-ranking officer	Medium	01/04/2022 – 1h
22	Eng	Mid-ranking officer	Short	05/04/2022 – 1h

3.6.2 Data collection: Ethnographic interviews, observation and workshop

The second phase of research was carried out from January to April 2022, starting with online ethnographic interviews as pandemic restrictions were still in place (until March 2022) preventing in-person data collection. Again, to allow for comparison with collected data on engineering advice, interviews with the science advice team and their collaborators were designed and processed in the same way as phase 1. Interviews were all between 1 and 2 hours long (see table 3.2), and included grand-tour, specific-tour, and guided-tour questions to understand my participants' work and role within BEIS. I transcribed the interviews, wrote interview memos, and downloaded, where I was allowed, the documents my participants walked me through during guided-tour questions. All the data collected was added to my NVivo database, a list of documents seen and collected can be found in the appendices.

In March 2022 Covid restrictions were eased, allowing me to complement the data collected in phase 1 and 2 with in-person observation. I participated in BEIS Science and Engineering Network (B-SEN) annual event, the ministry's network open to all civil servants interested in science and engineering in and for policy. I met with engineering advisers, science advisers and policy officers (some I had interviewed online), participated in a workshop on networking skills supported by the Government Science and Engineering profession (GSE), listened to talks and a panel from senior civil servants on pressing issues for science and engineering advisers within the ministry. I took observation notes including additional quotes from engineering and science advisers, their reactions to points mentioned in talks and workshops, relevant informal conversation topics and questions asked to the panel (Spradley, 1980). I went to the pub with B-SEN members after the event and gathered more informal information about the ministry's structure and civil service tacit rules of behaviour. The B-SEN event agenda and an example of my observation notes can be found in the appendices. My observation notes were added to NVivo for analysis.

I also ran a community-based workshop on the day of the event to complement my phase 1 and 2 data and better understand the skills required and challenges faced by the engineering-policy community. Community-based workshops involve the researcher and members of the community studied and are designed to be useful to the community in question (Given, 2008). I had 16 self-selecting attendees (including 5 of my interview participants) and asked them to answer, in pairs or group of 3, what would help them do their day-to-day job better. Each pair or group wrote their answers on different colour post-it notes depending on their role type (Eng, Eng-pol, Pol), all post-it notes were added to a board for a general discussion. After the event, I tidied up the post-it notes and board (in appendices), typed up my notes on the discussion and added them to my NVivo database.

3.6.3 Data analysis: Thematic analysis

To make the comparison between engineering and science advice easier I also set up my phase 2 codebook using the same structure as my phase 1 codebook, reusing some initial, focused and theoretical codes from phase 1. Please note that, given that I was reusing parts of my existing theoretical model from phase 1, my analysis no longer followed a grounded theory framework (Charmaz, 2014). I used thematic analysis instead, which relies on the same coding principles but allows for existing codes to be reused (Braun and Clarke, 2021). New codes were created for concepts and themes not captured in phase 1 and a trail of my reflection was kept in different summaries attached to the corresponding codes. The theoretical codes from phase 2 and a comparison of phase 1 and 2 data underpin my answer to my second research question: What is the difference between science and engineering advice in a UK ministerial context?

3.7 Phase 3: What are the impacts of the UK civil service's institutional structure and culture on engineering advice?

3.7.1 Sampling strategy

The third phase of my research was designed to answer my last research question on the impact of the UK government's structure and the civil service's culture on engineering advice at BEIS. Picking up on arguments made in my literature review and data from phases 1 and 2, I became interested in understanding the structural decisions that shaped the role of the engineering advisers within the ministry. This included how and why the engineering and policy team remits evolved the way they did, how political decisions like the reliance on commissioning research affected engineering capacity within BEIS, and how UK civil service cultural specificities like high turnover in policy teams impacts engineering advice.

To take a higher-level view of the ministry I contacted senior civil servants who currently supervise the engineering advice team, its directorate, and policy teams that work with the engineering team. To take a more historical perspective, I contacted ex- senior civil servant who oversaw the science and engineering capacity of the ministry during its transition from DECC/BIS to BEIS. All participants but one were contacted through my supervisors who work with BEIS and used to work at/with DECC, the last participant was recommended during an interview. The job titles of the participants and where they sit within BEIS, for those still working for the ministry, are included in figure 3.4. Senior civil servants are abbreviated 'SCS' in the reminder of my thesis.

Figure 3.4: BEIS partial organogram, teams and participants involved in phase 3

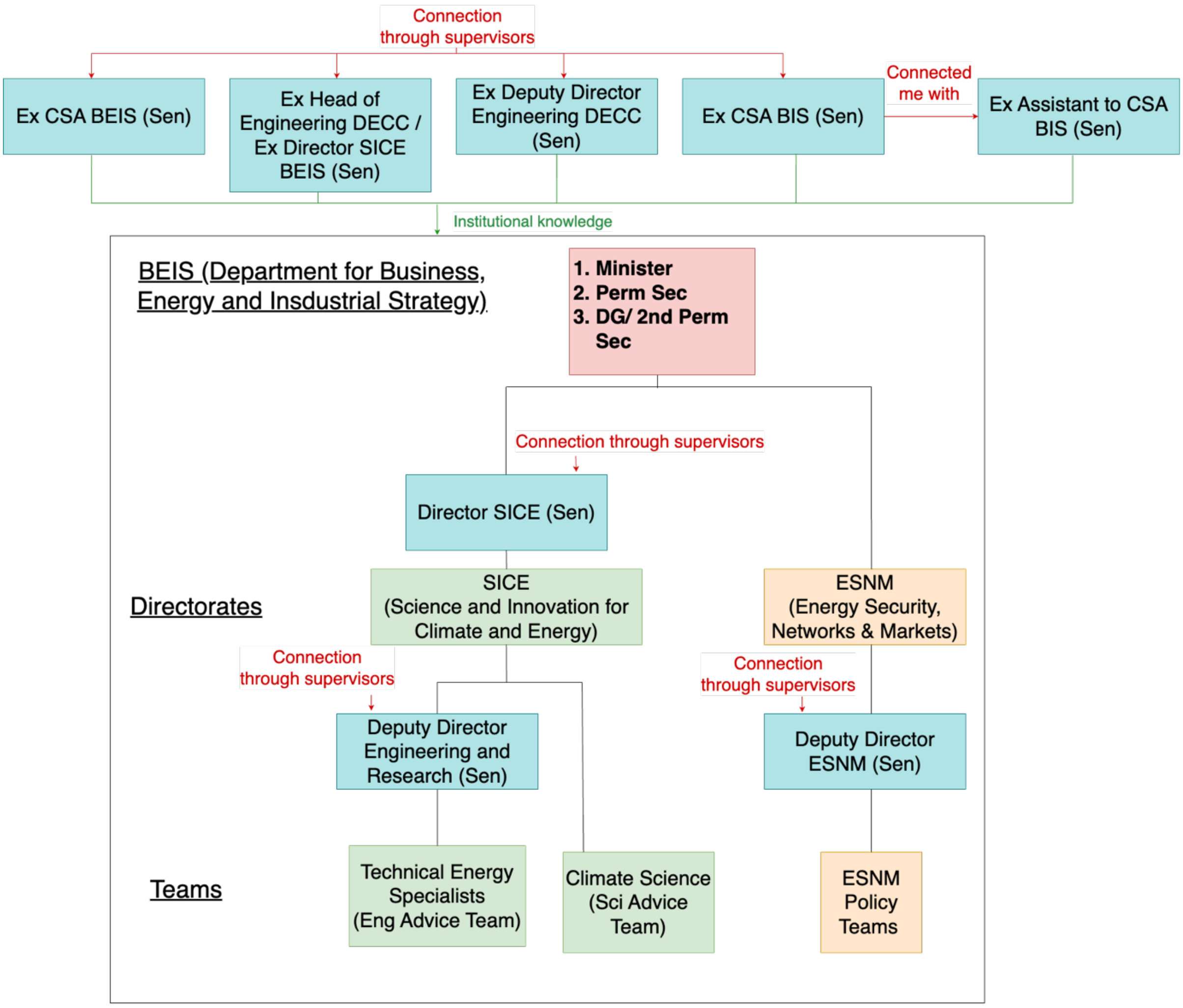


Table 3.3: Phase 3 sample

Phase 3				
Anonymised Participant Number	**Role Type**	**Civil Service Rank**	**Time in Role**	**Interview Date and Duration**
9	SCS	Senior Civil Servant (SCS)	Long	12/10/2022 – 1h
62	SCS	SCS	Long	10/10/2022 – 1h
3	SCS	SCS	Long	19/10/2022 – 1h
80	SCS	SCS	Long	21/10/2022 – 1.5h
70	SCS	SCS	Long	27/10/2022 – 1h
15	SCS	SCS	Long	01/11/2022 – 1.5h
5	SCS	SCS	Long	02/11/2022 – 1h
43	SCS	SCS	Long	16/11/2022 – 1h

3.7.2 Data collection: Ethnographic interviews

The last phase of research was carried out from October to November 2022, 8 interviews of 1 to 2 hours each were held, 7 online and 1 in-person. The interview guide for phase 3 was updated based on data collected in phase 1 and 2 but still included the same style of grand-, specific- and guided-tour questions. As with previous research phases, interview transcripts, interview memos, documents shared, and observation notes were added to NVivo for analysis. A list of all documents viewed and shared and be found in the appendices.

3.7.3 Data analysis: Thematic analysis

Like phase 2, the data was analysed using thematic analysis, re-using codes from phases 1 and 2 where applicable and introducing codes for new concepts brought up (Braun and Clarke, 2021). I kept track of the content of and reasoning behind initial, focused, and thematic codes in summaries linked to their respective code. Linking my phase 3 theoretical codes to phase 1 and 2 results informed my answer to my third research question, shedding light on the impacts of the UK government's structure and civil service culture on engineering advice at BEIS.

3.8 Reflexivity

Ethnographic approaches, beyond using ethnographic methods and thematic analysis, have one final key component: reflexivity (Malterud, 2001). Reflexivity is the attitude of systematically reflecting on the context of knowledge construction from research design to write-up (Cohen and Crabtree, 2006). This includes reflecting, as a researcher, on my assumptions, choices, and actions throughout the research process (Finlay and Gough, 2008; Fujii, 2017).

To communicate reflexivity to the reader when writing an ethnography, Brewer has develop the following guidelines (Brewer, 1994):

1. Establish the wider relevance of the setting and topic and clearly identify the grounds on which empirical observations are made.
2. Identify the theoretical, historical, and political frameworks authors and participants are operating within.
3. Reflect on experiences during all stages of the research including the problems that arose during the research, limitations of the methods and how they were dealt with.
4. Document the grounds on which the categorisation of data has been developed and provide sufficient data extracts to allow the reader to evaluate the inferences drawn from them.
5. Identify features that are addressed in the study and those left unresearched.

In the reminder of this section, I will discuss my attempt at following Brewer's guidelines.

3.8.1 Relevance of the topic of study and empirical grounds

I hope to have addressed Brewer's first two points on the relevance of my research and the empirical ground covered in the introduction, literature review and methodology sections of this thesis. The introduction and literature review were designed to communicate the importance and relevance of developing a better understanding of engineering advice in policy practice. The literature review should also give readers an understanding of the theoretical and historical framework science advice, engineering studies and relevant policy studies authors operate within. The theoretical framework I am operating within is covered in the research paradigm section of the methodology. The grounds on which empirical observations are made and the political context my participants are embedded in are detailed in the research design section above.

3.8.2 Research problems, limitations of the methods and mitigation

Addressing Brewer's third point on problems that arose during the research, I ran into a common issue associated with ethnographic research: fieldsite access. Both UCL and BEIS required each other's green light to grant me ethical clearance, trapping me in a loop where I could not get both parties to sign off on the project. This was resolved by getting an agreement *in proviso* from UCL, which I used to get BEIS's authorisation to then fully validate my UCL ethics clearance.

My ethics application flagged up another issue: the ethical risk associated with gathering civil servants' view of the ministry they work in. Indeed, participants might share views that do not align with those of their employer or even criticise the institution they work for. Conversely, participants might be reluctant to say what they really think fearing professional repercussions. To mitigate this risk, I made it clear that participation was optional, that the data would be anonymised, that only I will have access to this data and that the final report would only feature anonymised quotes. This was discussed and captured in the information sheet and consent forms (in appendices) given to and signed by my participants before any type of data collection.

To protect the identity of my participants to the best of my abilities, I followed UCL ethical guidelines. Names were removed during interview transcription, which I did myself, and the interview recordings were deleted after the transcription. I attributed a randomly generated string of numbers to each participant using the 'rand' function on excel and kept the spreadsheet with the participants' name and number password protected on the UCL data haven.

Still addressing Brewer's third point, before the start of phase 1, I reflected on the different biases that might arise during ethnographic data collection. This included "social desirability effects", when participants tell the researcher what they think will make them look good, especially according to prevailing standards of behaviour and thought (Bernard, 2011). Participants might also tell the researcher what they think the researcher wants to hear and not what they actually think (Collings, 2009). Biases can also happen "as the result of the ethnographer's selective interpretations" . Researchers might construct *their* version of what happened instead of capturing *their participants'* accounts. In interviews for instance, questions and probing can reflect the researcher's bias and might influence the participant's answers (Willis, 1999). During fieldwork, deep engagement with participants might also cause researchers to write up their findings in a way that might benefit their participants (Cunliffe, 2015).

I tried, throughout the research process, to employ techniques to mitigate these limitations. I wrote down my observations and interview notes during and right after the interviews took place to capture as much detail as possible. When designing interview questions, I also reflected on how the questions were phrased and how that might influence the participants' answers (Spradley, 1980). I also practiced critical listening, listened intently while critically reflecting on what was said simultaneously (Wolcott, 1995). I tried to cross reference my participants' accounts during the interviews and analysis, noted how much probing I had to do and if my participant was nervous or evasive (Bernard, 2011). All these reflexions were captured in my interview memos, attached to their respective interview transcript in my NVivo database.

To ensure that my analysis was credible and rigorous I also set up my NVivo database to ensure I could retrace my steps from the themes I developed back to quotes that make up these themes (a demonstration is available upon request). To do this, as explained in the research design section above, I kept a trail of my reflection in different summaries attached to their respective code during my thematic analysis of the data. This allowed me, in line with

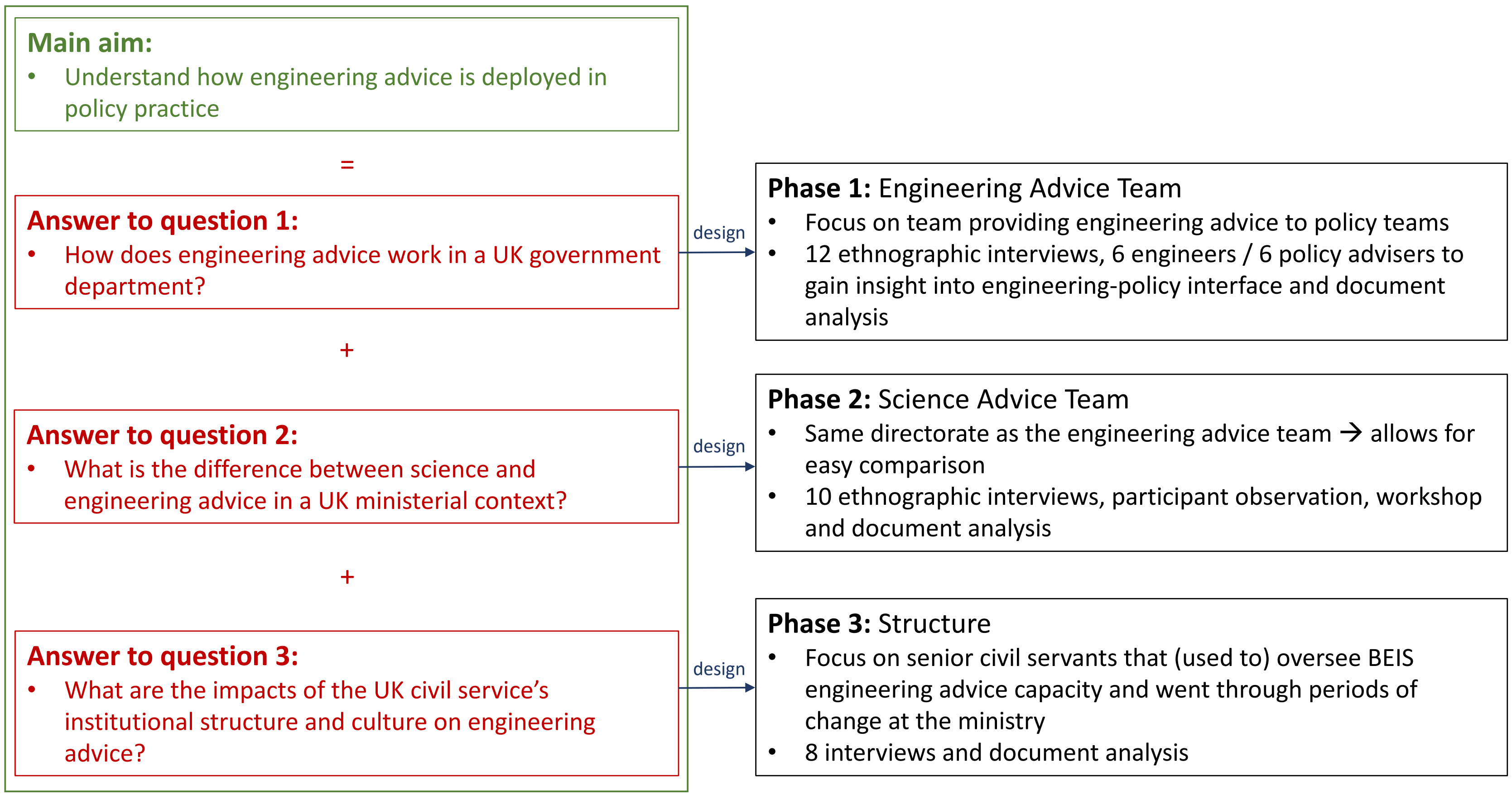
Brewer's fourth point and similar studies (see section 3.3) to easily include illustrative quotes for all the themes discussed in the following chapters of this thesis. My efforts to ensure I could provide my readers with enough data to understand how I developed my theoretical arguments earned me a UCL transparency in research award.

Finally, to address Brewer's last point, I hope that the introduction, literature review and methodology sections have made the topic of this study clear. Of course, methodologically, ethnography can only provide a picture of a limited range of reality (Brewer, 2000; McNeill and Chapman, 2005; Stevens, 2011, Rhodes and Corbett, 2020). This study focuses on specific teams in BEIS, and I cannot claim that the data I obtained are representative of the entire body of British civil servants, let alone of other actors (inside and outside government) who play a part in engineering advice in policy. I hope, however, that this study reveals at least some of the mechanisms that characterise the engineering advice process for policy making. Issues left unresearched in this study and avenues for future research are discussed in more depth in the conclusion of this thesis.

3.9 Moving on to the results chapters

As we saw, my research is underpinned by an idealist ontology and constructionist epistemology making an ethnographic approach an appropriate methodological choice. To investigate how engineering advice is deployed in policy practice, each research phase was therefore designed to ethnographically answer one of my research questions (see figure 3.5). Some of the issues encountered during the research process and how they were dealt with are presented in my reflexivity section. The next chapters discuss, in turn, the results from each phase of research with some original observations and quotes from my participants and shared policy documents.

Figure 3.5: Each research phase was designed to answer a research question



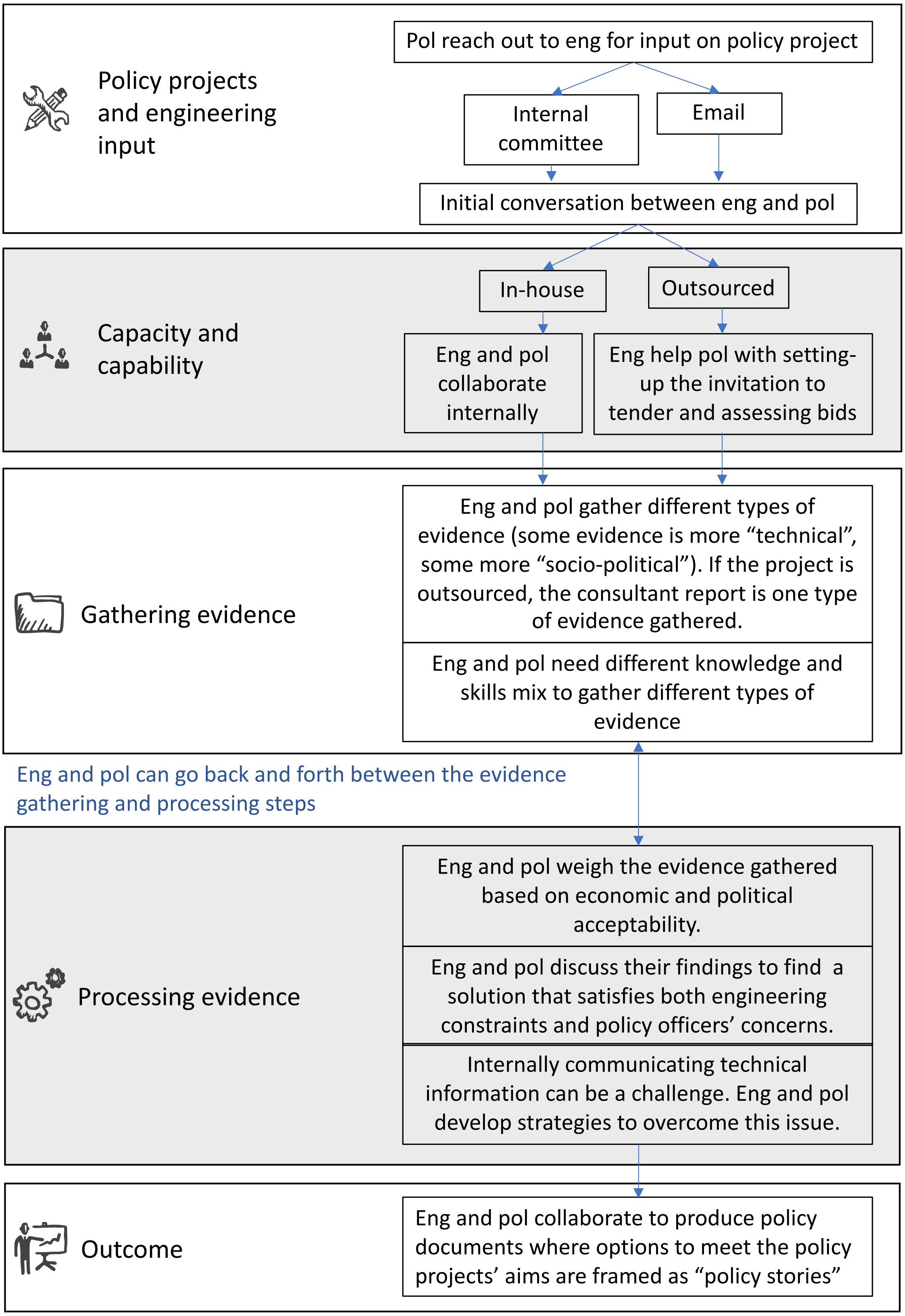
4 *How does engineering advice work in a UK government department?*

This chapter details the results from the first phase of my research designed to understand how engineering advice works at BEIS, the UK's energy ministry. As defined in my literature review, I take engineering advice for policy to mean the application of engineering knowledge to answer policy needs, with engineering and policy concerns intertwined in its production and use (section 2.2.5). This section is based on document analysis, workshop data and ethnographic interviews of BEIS engineers and the policy officers they work with (see methodology section 3.4).

As previously stated, the engineers work in BEIS' engineering advice team tasked with "providing engineering advice to other policy units sitting within the ministry to deliver decarbonisation of energy at an acceptable cost". At the time of my research, this meant collaborating with policy teams on projects looking at: regulating electric vehicle (EV) charge points, enabling the blending of hydrogen into the natural gas grid, facilitating utility-scale solar deployment and improving the uptake of demand side response (DSR) activities.

To explore what these policy projects entail and how engineering advice works in this context, this section follows the different steps of the advice process. The process starts with policy officers reaching out to engineers to get their input on the policy projects. This is followed by an assessment of the engineering team's capacity and capability, determining how much of the engineering work required is carried out in house. The engineers and policy officers then gather and process the evidence needed to inform the policy project. The last step of the process covers the final output and outcome of the project. Throughout this section I come back, in-turn, to what happens at each step of the advice process and why. This includes a discussion of how engineers and policy officers interface at each stage, what evidence is entered in the policy debate, by whom, and how it is combined to deliver the policy project. Points raised are accompanied by illustrative quotes from my participants along with their anonymised number, role type and time in role based on methodology table 1. I have emphasised key parts of the quotes in bold. An outline of the advice process can be seen in figure 4.1, the process steps and roles of engineers and policy officers at each step are developed in the sections below.

Figure 4.1: Outline of the advice process between the engineering advice and policy teams at BEIS. The process is broken down in different steps and the engineers and policy officers' role at each step are highlighted.



4.1 Policy projects and engineering input

At BEIS, different policy teams are responsible for leading on different energy policy areas. At the time of my research, I gained exposure to policy teams working on four energy decarbonisation projects:

- The EV smart charging team worked on a project aiming to introduce new regulation for electric vehicle (EV) charging stations.
- The heat networks team worked on a project aiming to change existing policies to allow the injection of hydrogen into the UK's natural gas grid.
- The established renewables team worked on a project aiming to change the regulation for large scale commercial photovoltaic power stations (also known as "utility-scale solar").
- The electric systems and smart energy teams worked on a project aiming to develop demand side response (DSR), encouraging the take-up of smart technologies to enable industrial actors to increase, decrease or shift their electricity use to better balance the electricity grid.

All four policy projects were perceived, by policy officers, as requiring engineering input. However, most of the policy officers working on these projects did not have an engineering background; and the few who did could not provide all the engineering input required on their own. The policy officers therefore reached out to the engineering advice team to help them answer the engineering-related questions they had.

One way policy officers asked for the engineering team's input was on internal committees and policy boards.

> *"There are a number of* ***internal committees and boards*** *that BEIS has which we and the* ***policy teams*** *sit on and jointly discuss subjects.* ***Sometimes*** *they* ***ask us questions through those, it's more formal****. I'd be lying to you if I said that's the way we work on a day-to-day basis though.* ***Most of the questions actually come through emails****." – 32, Eng, Long*

> *"So, one thing that the government is looking at the moment is options for blending hydrogen into the existing natural gas grid. I was* ***on this working***

> ***group*** *where [58, Eng-Pol, Medium] had a few* ***questions on the technical limitations of blending hydrogen****. Like* ***what are the negatives?*** *So that's* ***something I had to pick up****." – 96, Eng, Long*

> *"I sit on a* ***committee with the EV smart charging team*** *and the* ***Department for Transport*** *EV people. They're looking to put* ***regulations on charge points for electric vehicles*** *to make sure that these vehicles can be charged in a way that is smart and flexible. At the moment, people are putting in like dumb charge points and so* ***they asked me what smart functionality they could require****." – 61, Eng, Long*

Committees and boards bring together the policy teams, engineering team and other departments (in the case of cross-ministerial initiatives) working on a specific policy area. They establish an official channel of communication between the policy teams and engineering team. When they are first set up, they give policy officers the opportunity to ask engineers general initial questions as illustrated by the quotes above. As time goes on, committees and boards also become a forum for engineers and policy officers to exchange their views and ask more precise questions as we will cover in the sections below.

However, as the first quote above suggests, policy officers more commonly reach out to the engineering team via email.

> *"The volume of* ***emails****? It varies. There are* ***certain people*** *who I know would* ***come to me because they know that it's my area*** *but there will be other people who go to just whoever they know in the team and then it gets passed on. So probably* ***often it is down to [the head of the team] to pass it to the right person*** *because* ***they have the highest profile****. Basically, everyone knows them." – 17, Eng, Medium*

> *"I* ***sent [17] a quick email*** *asking '****if we change the threshold*** *for utility-scale solar farms to be considered NSIP [Nationally Significant Infrastructure Project] from 50MW DC [Megawatt Direct Current] to 50MW AC [Megawatt Alternative Current],* ***how much more energy would we put into the grid****? Also,* ***how many more solar panels would developers' plant****?'" – 69, Pol, Short*

> *"When you start coping with potential barriers to DSR, you definitely need* ***a better understanding of how things work****. So I* ***sent the engineering team an email****, saying: if we want to* ***regulate the communication networks*** *that*

*are used to control electricity load, **what are our options**?" – 55, Pol, Medium*

Policy officers tend to email whoever they know in the engineering team, most often the head of the team because they are the most visible in the ministry or, sometimes, an engineer they already have a working relationship with. The engineering team lead then redirects the email to the engineer covering the policy area in question, same goes if the email reaches the wrong engineer in the team. For policy officers, emailing is a quicker, less formal alternative to setting up or going to a policy board.

Once the policy officer has reached out to an engineer and asked for their input, whether on a committee or via email, the engineer has an initial conversation with the policy officer to clarify the question asked.

> *"The process of **me not having quite a clear understanding of what they need** and **them not knowing what they want** is like the analogy of the horse carts and cars. In the old days, when people were riding around in horse carts, if you asked someone 'what do you want to get around better' they would say 'a faster horse'. If they don't know cars exist, they can't ask for a car. So that would be my good example, **I tell them that cars exists and 'by the way you can have a petrol one or an electric one or you want to keep your horse and you just want it faster, let me know**.'" – 61, Eng, Long*

> *"I think **they know kind of what they're asking but they don't necessarily know how you'd go about answering it.** But I would say normally they do know, I mean I think it's fair to say a lot of **policy people understand their subject area very well but not the technical aspects** of it." – 96, Eng, Long*

Policy officers, as we mentioned, often do not have an engineering background, hence why they reach out to the engineering team. The initial questions asked, as illustrated in the quotes so far, tend to be about the properties and performance of built systems (gas grid, electricity grid) and their components (charge points, solar panels). However, due to their limited engineering knowledge, policy officers phrase these questions in general and imprecise engineering terms. Engineers therefore need to have an initial conversation with the policy officers to understand what the question entailed from an engineering perspective and how it can be answered.

After an initial conversation between the engineer and policy adviser, the general questions asked about utility-scale solar farms, DSR and EV charge points mentioned in previous quotes were rephrased as follows:

> *"So the outcome of the meeting was to breakdown the question. As the result of the threshold change from DC to AC: What would be the impact on **land use**? What would be the impact on **energy production**? What would be the impact on **load factor**? What would be the impact on **cost/levelized cost of energy**? I suggested we could **model most of it** as we already had some existing data on the topic." – 17, Eng, Medium*

> *"In the meeting we discussed what node of the [electricity system's] communication network was the most important to regulate. It is the **charge point operators, the industrial aggregators or the building energy management systems**? Turns out **[55] was keen to collaborate on all options**." – 85, Eng, Medium*

> *"Quite early on in the meeting I highlighted that there was a bit of a gap in terms of existing standards for smart charge points so we developed a project to **write some technical standards on what a smart charge points could be."** – 61, Eng, Long*

The initial conversation clarified the ask and output of the project the engineer and policy officer would work on. In the case of the utility-scale solar regulation change, breaking down and rephrasing the initial question made it possible for the engineer to suggest collaborating on a model to inform the policy decision. In the case of DSR and power systems' communication network regulation, breaking down the question led to the joint writing of a policy brief exploring regulation through different components of the network. As for EV charge points, the initial conversation between the policy officer and engineer led to the development of technical standards for smart charging.

4.2 Engineering team capacity and capability

The initial conversations on solar, DSR and EV policy mentioned above all led to an internal or "in-house" project.

> *"Anything which has to do with **things we [engineering team] cover internally, as long as we have the capacity**, they [policy teams] get from us. It **stays in-house**." – 32, Eng, Long*

In-house projects refer to projects where the engineers and policy officers collaborate without formally commissioning any part of the research work for the project. Engineers and policy officers still engage stakeholders external to the ministry to gather their views but the evidence gathering and analysis is led by the engineering and policy teams, not an external provider.

Research work on some projects however is commissioned or outsourced to a provider external to the ministry.

> *"We're only a team of 10 engineers so **we don't have the capacity to do everything**. You know a six-month study on something is going to be 5% our capability so we don't do that. **Instead, we'll work with [policy teams] to commission some of the work.**" – 32, Eng, Long*

> *"I mean the **kind of work that we commission? Research we don't have the expertise or the resources to do**" – 17, Eng, Medium*

> *"We predominantly **commission research from** external organizations like **universities or consulting companies or a consortium of both** types of organizations." – 22, Eng, Short*

The engineering team is relatively small so it might not have the capacity (available staff) or the capability (subject matter expertise) to answer certain policy questions. In this case, the engineers will work with the policy officers to commission some of the research for the project.

This was the case for the policy project looking at the technical limitations of blending hydrogen into the natural gas grid.

> *"For [the hydrogen project], it was too much to handle alone. So we went through the **process of establishing a business case**, **justifying spending the***

*money, **getting that signed off** and **then tendering for the work. I worked with [58] to design the requirements**, then we receive some bids and **reviewed those bids**. We compared different applications and see who's going to do better job and assess that. And **then during the work itself** we **agreed** exactly **what the consultants were going to do** and then **checked up on their progress**. That's where the **intelligent customer** idea comes in, you're going to **be interpreting the results** they're generating and **asking the right questions** and so on." – 96, Eng, Long*

*"You can **see from the ITT** [Invitation To Tender], it's a bit more complicated than asking what the limitations of blending hydrogen into the grid are. So, for instance **I imputed into a section on purge rates and volumes according to IGEM [Institution of Gas Engineers and Managers] standards** and **asked the consultant if the same standards would apply to hydrogen**" – 96, Eng, Long. The ITT is now publicly available, a working link to the document can be found in the references.*

*"It's **hard to know the right language you should be using** and making sure you're **articulating the scope** of all of the product services **in the right way**. I think there's a huge **role for engineers in** helping us understand the landscape that we're working in and **giving us the clear framing**." – 29, Pol, Medium*

In the case of outsourced projects, engineers work with policy officers to set up and review the bids, helping policy teams frame and express technical requirements in a clearly understandable way for the consultants. Again, this is linked to the fact that policy officers often do not have an engineering background, and therefore need the engineers help to phrase their needs in specific and precise engineering terms. Once the work is ongoing the engineering team acts as an "intelligent customer", monitoring the consultants' work, asking relevant questions, and translating some of the technical outputs of the commissioned research for the policy officers. I will discuss how engineers and policy officers engage policy stakeholders and process evidence, including consultants and their reports, in more depth in the following sections of this chapter.

4.3 Gathering evidence

4.3.1 Types of evidence and policy stakeholders

It is clear from the discussion above that EV charging, heat networks, DSR and utility-scale solar regulation changes required engineering input. However, engineering evidence is only one of the evidence types needed to inform these policy changes. As a reminder, and in line with the definition introduced in my literature review, I take evidence to mean the different types of data that are entered into policy debates.

> *"There are a lot of different factors you want to consider in a policy decision the political, the social, the technical, the legal… **Usually, the social and political that's us [policy teams]** and **the technical that's the engineers.**" – 65, Eng-Pol, Short*

> *"For the [utility-scale solar] model, we used **renewable energy generation and storage data**, historic **weather data**, and **electricity demand data**. We also had to go and get some **land use data** and **panel pricing data** too." – 17, Eng, Medium*

> *"I had some **feedback from [solar power facilities] developers on their panel planting** practices that we got from a consultation about the policy change. And a fair amount of consultation feedback on **constituents' views on the visual and noise impact of solar facilities** across the countryside." – 69, Pol, Short*

> *"Our DSR work is based on quite a lot of stuff. We have internal **reports on smart appliance** use as well **as smart meter uptake data**. Obviously, **some grid usage stats** and **reviews of existing standards and regulation** in this space. There are **some academic articles** too, oh and **feedback from** different stakeholders in the **electricity system industry**. We did some workshops and consultation work with **businesses** too, to get their **opinion on** what [smart technologies] **they want and** how much they are willing to **spend**." - 55, Pol, Medium*

Engineers and policy officers gather different types of evidence to inform the policy projects they work on. As described by my participants, this evidence can be of a more "technical" nature, that is relating to engineering and its applications, like energy generation data, standards, or PV (Photovoltaic Panel) pricing. Or it can be of a more "socio-political nature", as in concerned with social and political views, like constituents' views or businesses willingness to spend[11]. As the quotes suggest, and reflected in my observation notes from the B-SEN event, energy policy is a socio-technical field therefore any policy changes in that space are informed by technical and socio-political evidence.

The different types of evidence mentioned above are held by different actors in the energy sector. To gather the evidence needed to inform the policies, the engineers and policy officers therefore engage a range of stakeholders.

> *"[On utility-scale solar policy]. Some of the data was already collected by* ***BEIS*** *so we had that on hand. The weather data I got from the Hadley Centre in the* ***Met Office****, for the panel pricing stuff it's based on* ***industry*** *consultation mostly. I also spoke to colleague at the* ***Energy Catapult****, and few* ***academics at Imperial, Cambridge, Oxford and Loughborough****. Just to get some* ***informal input*** *into the model I was building, a bit of free consultancy advice basically" – 17, Eng, Medium*

> *"[On the DSR project].* ***Internally, we talk to the engineering team, the smart meter team and smart appliance team****. For* ***external stakeholders*** *you have* ***industry*** *for sure and obviously* ***National Grid****. We also talk to* ***Elexon*** *which takes care of some part of the regulation and groups that represents the interests of several parties in the electricity system. I would say there is also some* ***academia****. Pretty sure* ***[85] talks to everyone as well****." – 55, Pol, Medium*

> *"[On blending hydrogen in the gas grid project].* ***Most of the data came from the consultants****. I spoke to a few* ***academics*** *on my end to check up a few things. But it's part of a bigger body of work so [58] and myself are also in touch with* ***Ofgem*** *[energy regulator] and* ***IGEM*** *[gas engineers' industry body]." – 85, Eng, Medium*

Policy actors engaged include internal (to BEIS) stakeholders, like other ministerial teams, and external stakeholders, like regulatory bodies, national grid, industry representatives and

[11] Please note that the difference between technical and socio-political evidence in this space is not always clear cut, this is discussed, along with its implications, in section 4.3. below.

academia (example in figure 4.2). The evidence collected includes data sets and reports but also informal feedback. As mentioned above, constituents and businesses' views on a specific policy are also gathered through consultations and ensuing consultation reports. In the case of an outsourced project, the consultant or consultant consortium is one of the stakeholders engaged.

Figure 4.2: Example of the stakeholders engaged on the DSR project

4.3.2 Engineers and policy officers: Knowledge and skills mix

Engaging stakeholders and gathering the different types of evidence needed to inform energy policies requires different knowledge and skills. After an initial conversation with the policy officers to clarify the engineering input required, engineers use their knowledge and skills to gather the technical evidence needed to inform the policy project.

> *"I **focus on the technical** side of things you know, and that's where my **engineering training is useful**. It takes me less time to **get to grips with the underlying physics** of the problem and **understand the trade-offs**. It's also*

*useful just to **review the data** and do some **quick calculations too** you know." – 85, Eng, Medium*

*"We tend **to engage the consultant more on the engineering side of things**, like **the technical claims** they make. We challenge them on those and review how they came up with their conclusions." – 96, Eng, Long*

*"So when I recruit I tend to try and recruit people **early in their career**, some **right out of universities**, so PhDs and research assistants, some with a **few years in industry**. I look for people **who can learn quickly** and **across different areas of engineering**, because we deal with a wide variety of technical policy problems." - 32, Eng, Long*

*"Before my PhD I went and **worked for an engineering consultancy** as a consulting engineer for about a year and a half. This is really **useful for what we do now** [at BEIS], **gives me insight into how engineering consultants work** and a better idea of **how to engage with businesses** too." – 17, Eng, Medium*

Engineers rely on their engineering backgrounds rooted in maths and physics to gather, analyse and review mostly technical data. This can be reports focusing on different engineering trade-offs related to the policy problem and/or quantitative data and calculations. When interfacing with consultants, engineers focus on the technical points made, reviewing and following up on some of the engineering conclusions they have reached. Because the engineers work in a small team that has to handle various types of engineering issues, the engineers in the team tend to be what I call "generalist engineers". They are trained engineers but do not specialise in a narrow area of engineering in their work, instead they have to learn on the job and adapt to different engineering issues depending on the policy question. Engineers with industry experience in the team also see that as an asset, helping them navigate the engineering industry and engage with business actors within it.

Policy officers, on the other hand, rely on their political science, social science and humanities backgrounds and policy experience to gather the socio-political evidence needed to inform the project.

*"I started with **political sciences** and then **international relations** following which I also did a master's **degree in environmental policy** and regulation. It's good, **helps me understand different points of view** and **process a lot of documents and reports quickly**." – 55, Pol, Medium*

*"So I did a **policy degree** and was with my **previous policy team for 2 years**. I guess my undergraduate and time in my previous **role prepared me to consult different relevant actors in the space**, and **understand** policy **documents and survey results**. I think it prepared me well to **communicate** as well, like **how to talk to different stakeholders**." – 29, Pol, Medium*

*"Yeah, **we talk to the consultants as well**. The engineering points they make are usually handle by [the engineering] team, like they review those and clue us in. We tend to **make sure the consultant's output is still in line with the bigger policy project**, like **are the costs going to be acceptable** or **what will people and industry think about this**?" – 67, Pol, Short*

Policy officers' backgrounds and policy experience help them gather and analyse mostly qualitative data gathered through consultation with various stakeholders. Their background and experience also seem to have equipped policy officers with good communication skills, including understanding different stakeholders needs and communication styles. When the project is outsourced, engineers deal with the technical data (as mentioned), and policy officers try to ensure the consultant's work is aligned with the needs and/or demands of the population and other policy stakeholders.

Of course, technical and socio-political evidence are not always easily separable, and engineers can gather evidence that has a socio-political component. Equally policy officers can collect data with a technical component.

*"I mean it's **not always** super **clear-cut** you know. **Like some of the data we bring in is engineering-related in some ways**. I just had a look at some industry reports on EV batteries for instance. But, in fairness, **most of the in-depth technical stuff we leave to the engineering team**." – 29, Pol, Medium*

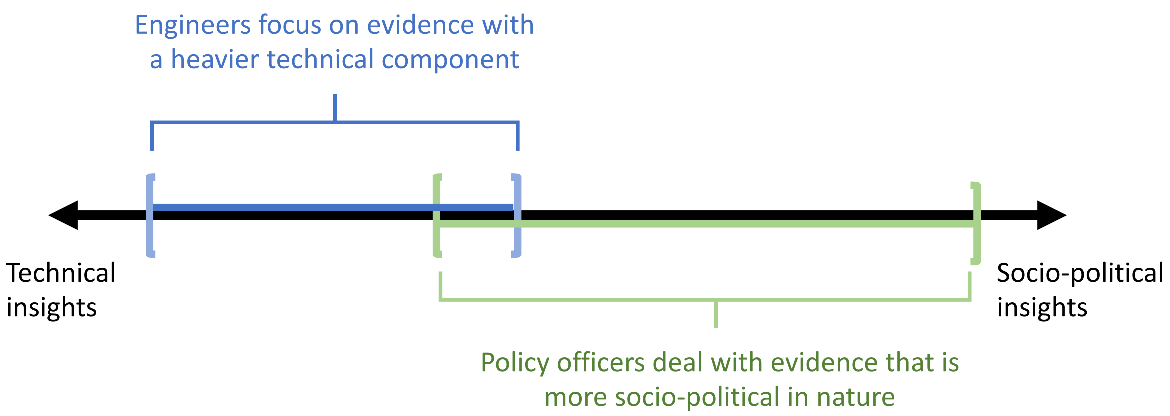
*"**Sometimes**, especially when it comes to cost, I would say the **data we look at is not so technical**. We have to bear in mind the broader policy landscape, be sensitive to the concerns of the people and other stakeholders. **But that's***

***mostly [the policy teams' job]**, I think **they also interact with more [stakeholders] than we do**." – 61, Eng, Long*

Engineers and policy officers recognise that the difference between technical and socio-political evidence is not always clear cut. However, as the quotes above suggest, overall engineers still focus mostly on the technical and policy officers on the socio-political. Worth noting that policy officers engage with more actors than the engineering team.

Perhaps one way to illustrate the points made so far is to create a spectrum to represent the evidence needed to inform energy policy (figure 4.3). The evidence can either be of a more technical nature or socio-political nature. The engineers will focus on evidence with a heavier technical component (leaning towards the technical end of the spectrum) although some of the data gathered can contain socio-political insights. Policy officers will engage a wider set of stakeholders to gather views that are more socio-political in nature (leaning towards the socio-political end of the spectrum); although the data they collect can sometimes contain technical elements.

Figure 4.3: The evidence needed to inform energy policy can be represented as a spectrum where engineers gather mostly technical evidence and policy officers gather evidence that is more socio-political in nature.



Engineers rely on their knowledge and skills to gather mostly technical evidence yet feel like they could use better communications skills.

*“**I don't think, coming from an engineering background, communicating [technical information] is a skill as valued as it could be**. I think really good engineers do have that skill, but I think it's very much seen as a premium thing, whereas in policy it is like absolutely the core thing. **Like you know, really thinking depending on your audience. It’s hard, because you need to be able simplify and compress complex technical information into 2 lines** or something that someone non-technical will get.” – 65, Eng-Pol, Short*

*“I think a lot of us **struggled with summarising and explaining engineering issues to non-engineers**. But **the more you talk to people with no technical training**, whether internally [to BEIS] or outside, **the easier it gets**. But, at least to me, it’s still the trickiest part of the job.” – 85, Eng, Medium*

As the quote above suggests engineers did not feel like communication skills, especially summarizing information and adapting to their audience, was a valued part of their training. As a result, engineers find it hard to interact with non-technical audiences to gather and process all the evidence they need to inform the policy project. This is an issue when interacting with policy officers to combine the evidence gathered as we will see in the ‘processing evidence’ section below. Experienced engineers however, because they have repeatedly interacted with non-technical audiences, picked up some of those skills on the job.

Policy officers on the other hand, possess good communication skills, engaging a wide variety of stakeholders to gather socio-political evidence, yet feel like more technical fluency would be an asset.

*“I think if **you had worked on solar panels and done academic work on it** that would **definitely be an asset though** and would be something that **would be valued**. I'm sure you could use to your benefit, and it could **add to your credibility. Especially in the eyes of industry**.” – 69, Pol, Short*

*“Of course, **it gets easier with time**, like **the more you work in this [policy] area, the more you pick up** some more **engineering**-y **concepts**” – 67, Pol, Short*

*“I mean there is a **point where I understand that I'm getting lost in like very technical details**, especially when I go through annexes or technical*

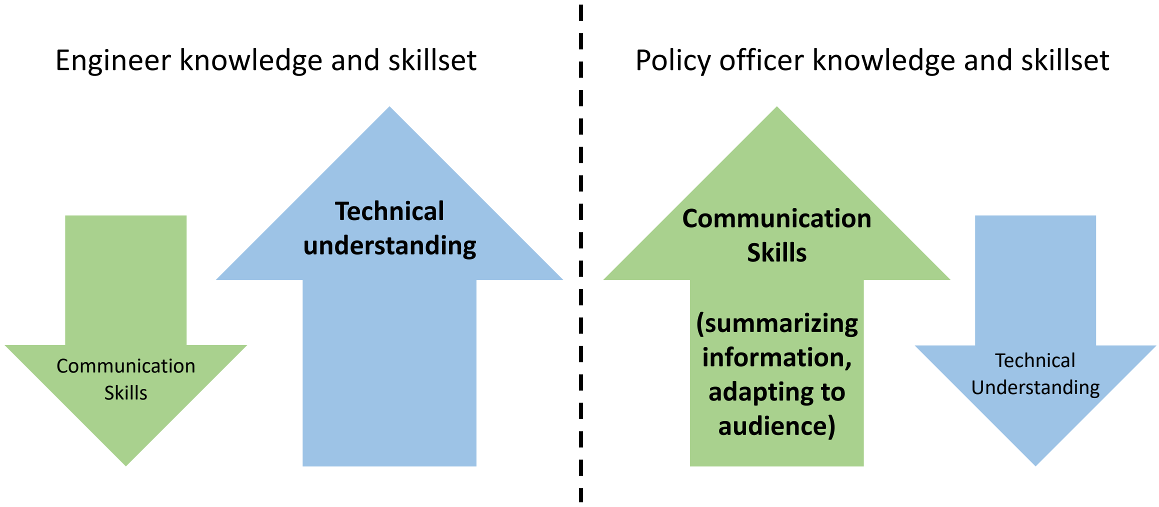
*documents. And then I'm like: '**I am not supposed to do this**'. So I think that a good exercise for me sometimes is to **understand when is the time to stop**." – 55, Pol, Medium*

Policy officers felt like having a technical background or engineering experience would be seen as an asset, especially when engaging with industry. It would also be valued when interacting with engineers to combine the evidence gathered as we will see in the 'processing evidence' section below. As with engineers and communication skills, policy officers pick up some technical knowledge on the job provided they stay long enough in the energy policy area. It should be noted however that, even if a technical background is seen as an asset, policy officers are not expected to understand the technical issues of the policy project in-depth, that is the role of the engineer.

My understanding is that this stems from the fact that engineers and policy officers work on energy policy, a socio-technical field. As I said, engineers focus on evidence with a heavier technical component and therefore need a good technical understanding. However, engineers also engage with multiple actors internal and external to BEIS some without an engineering background. Engineers therefore learn, with experience, how to better communicate with non-technical audience. Policy officers on the other hand, need and use strong communication skills to gather the views of a wider set of stakeholders. However, policy officers are also exposed to and need to understand some engineering evidence, gaining technical knowledge on the job.

The knowledge and skills mix required for both roles can therefore be conceived as a shifting balance (figure 4.4). The mix here is composed of technical understanding and communications skills like summarising information and adapting to the audience. Engineers and policy officers gather different types of evidence and perform a different role in this socio-technical policy area so the knowledge and skills balance shifts. Engineers need, first and foremost, a good technical understanding and policy officers need strong communication skills. However, because this is a socio-technical field, engineers still need good communication skills and policy officers need a higher-than-average technical understanding.

Figure 4.4: The knowledge and skills mix for both roles is best conceived as a shifting balance



4.4 *Processing evidence*

Once they have gathered evidence, engineers and policy officers 'process' the evidence. Processing here refers to the way in which the engineers and policy officers weigh the evidence they gathered and then work together to combine the resulting knowledge to inform the policy project. Before I look at evidence processing in more depth and the challenges it brings, let me add a note on the timing of the evidence gathering and processing steps in the advice process.

Engineers and policy officers always start by gathering evidence but, as the project goes on, the gathering and processing of the information becomes intertwined. Engineering and policy officers will gather data, assess it, discuss their findings between themselves, gather more evidence and reconvene again. Engineers and policy officers will therefore go back and forth between the evidence gathering and processing steps of the advice process (described in figure 4.1). To make the process more legible however, I separated evidence gathering and processing into two distinct phases and covered them in turn. This is a slight simplification of how the process works in practice.

4.4.1 Weighing evidence

Engineers and policy officers point out that the evidence they gather can be contradictory:

"[On the utility-scale solar project] It's hard sometimes because the ***data that you get from different sources is not aligned****. Like, the local consultations tell us residents in the countryside don't want bigger solar farms. But at the same time, to hit the net-zero targets we committed to, we've got to push renewables and solar is a low-hanging fruit. So,* ***that's something we have to work out****." – 69, Pol, Short*

"[On EV charge points] As you can imagine, ***depending on who you talk to you get a different answer****, every [charging technology manufacturer] will try to pitch you their charging technology as the best.* ***It's up to us to see through all that****." – 61, Eng, Long*

"[On DSR policy] The classic in our space is having ***academics tell us about their research*** *and how it would work concretely. But then you think about it,* ***run it past industry, and realise it would be way too costly****." – 85, Eng, Medium*

Both engineers and policy officers handle conflicting evidence, sometimes because different stakeholders in that policy space have competing interests or sometimes because stakeholders disagree with the aim of the policy project. Engineers for instance engage competing businesses, creating competing evidence as each try to sell their technology as the best option for the problem at hand. Engineers also engage with academic research which, if scaled-up and brought to market, would be too expensive for industry and/or government actors to deliver. Policy officers face similar problems when a stakeholder group's view does not align with policy objectives, in this case, consultation reports clashing with governmental net-zero targets.

As implied in the quotes above however, engineers and policy officers make choices and compromises, weighing the evidence gathered and what it means for the policy project.

"Our role is to try ***to put together the views we have gathered from other policy teams, ministers and consultations and what our view might be within that.*** *Quite often it's about* ***finding compromises on what will be deemed acceptable and feasible****, which* ***we kind of guess based on the political agenda and internal discussions.****" – 67, Pol, Short*

> *"Industry and academia's motivation is for their technology to get more funding and more interest, whereas my motivation is for public money to be spent for the public good.* ***So, part of our role is to ensure that we remain unbiased. We have to use our own judgement, to deliver for the public good not to deliver goods for a particular individual in that public****." – 61, Eng, Long*

> *"As a team we are trying to* ***work with consultants*** *to think a little bit more outside the box as to how they can take the work they've already been doing and just provide that narrative that then allows people to make an informed decision on your work.* ***I guess it's about how do you take this engineering knowledge and turn it into something the higher-ups could make a decision with.****" – 96, Eng, Long*

Engineers and policy officers use their own judgement when assessing the evidence gathered including consultant reports. Engineers try to remain aware and critical of the interests of industry and academia when evaluating different technologies. Policy officers try to reconcile and/or find compromises between the different stakeholder views they gathered. In doing so, engineers and policy officers, weigh up different technological options and stakeholders' views based on economic cost and political acceptability. Interestingly, what is economically and politically viable is not always clearly stated and engineers and policy officers rely on their tacit knowledge of what senior civil servants want to infer it. This tacit knowledge is acquired through conversations with other civil servants, reading policy documents and government statements and keeping up with political news. By weighing the evidence collected based on economic and political acceptability, engineers and policy officers go beyond summarizing evidence and develop their own knowledge, that is their own understanding of the issues at hand within the context of the policy project.

4.4.2 Combining knowledge

Engineers and policy officers then discuss, between themselves, the evidence they collected, how they weighed it and the resulting implications for the policy project.

> *"Whether* ***on committees or one-to-ones*** *we'll* ***answer the [policy teams'] questions****. That's often about* ***the different options we've assessed****, like the pros and cons of different EV charging stations, like technology and price,* ***and why we think this one is the best in this case****." – 61, Eng, Long*

> *"When I talk to [69, Pol] I try to show them **how the upper and lower bound of the [utility-scale solar] model were selected**. And I make a point of saying I've got someone else in the team, [32, Eng] or whoever to review my calculations." – 17, Eng, Medium*

> *"During my meeting with [17, Eng] he **showed me the data that goes into the model. I made sure to stress the compromises though,** we're keen to put more solar into the grid, but we can't increase the size of the solar facilities too much, otherwise local residents won't be happy." – 69, Pol, Short*

> *"**Sometimes we have long conversations because we know an option suggested by the engineering team might not work for a key stakeholder,** like a particular industry key to the policy change. Like regulating charging station types might not work for certain cities that have invested in a certain type of station already**. So [the engineering team and my team] try to find a compromise between the data they have and what we know**." – 67, Pol, Short*

Whether on policy boards or committees, during one-to-one meetings and through email conversations, engineers and policy officers discuss the evidence they gathered, what they did with it and what it means in the context of the policy project. For the engineers this means answering the questions asked by the policy officers asked at the beginning of the project (see section 4.1). This can be going through different technological options that can be applied to solve a problem or the results of a model designed in response to a policy question. During these conversations, policy officers also mention the views of the stakeholders they engaged. Sometimes the engineers and policy officer points are compatible, sometimes stakeholders' views conflict with an option suggested by the engineering team. The latter leads to a longer internal discussion which, in turn, leads to the formulation of policy options that meet the policy project's aim and satisfies both engineering constraints and policy officers' concerns. This is not always easy as we will see later, as policy officers and engineers do not always share the same understanding of economic and political acceptability within a policy project and struggle to communicate/understand technical information.

If engineers and policy officers are successful in communicating how they weighed the evidence they collected and the new knowledge generated as a result, they consider each other as experts.

> *“**Choosing the data for the model** that’s all [17, Eng], they were very rigorous, **they are the technical expert**.” – 69, Pol, Short*

> *“**Well [policy officers] are the experts on their policy topics**, you can usually tell they know what the views are within their area. Like I wouldn’t know the first thing about developing policy and [policy officers] they actually know what they’re doing on that side” – 85, Eng, Medium*

As the quotes suggest, by sharing how data was analysed and weighed, the engineers and policy officers become experts in the eyes of each other. As a reminder and as defined in my literature review, I take expertise to mean: a policy actor’s perceived high level of familiarity with domain-specific knowledge, evidence and/or experience. Worth noting that, by considering economic and political acceptability when weighing the evidence they gathered, engineers create new knowledge mixing socio-political concerns with the more technically focused evidence they gather. This knowledge, however, still includes more technical components than the one created by policy officers, who only balance evidence of a more socio-political nature. By comparison, policy officers therefore consider the engineers as the technical experts.

By opening up about how they engaged with the evidence collected and considering their counterpart as an expert, engineer and policy officers also develop mutual trust.

> *“It was good to have **[17, Eng] analysis as a counterweight to some of the industry figures**. We didn't end up using any of the industry figures because we thought that some of them were probably not accurate and so having **[17, Eng] model gave the recommendation much more credibility** than if we had relied on industry data only.” – 69, Pol, Short*

> *“[61] walked us through different options and what they mean so we went for the one they recommended, **I trust them, they did their research**” – 67, Pol, Short*

*"As I said, **I trust that policy teams have weighed all the policy options**. They **usually disclose the trade-offs to us** as we progress through the projects anyway." – 32, Eng, Long*

As the quotes above suggest, overtime, mutual trust can develop between engineers and policy officers. On the utility-scale solar project for example, the policy officer was aware that the engineering team had collected and compared data from different sources when building the model, making the model's insights reliable and by extension the engineer's recommendation trustworthy. This was echoed on the EV project where one of the policy officers trusted their engineering counterpart's recommendation and the research that went into it. This trust also goes the other way with policy officers disclosing how they balance different stakeholder views to the engineers, leading engineers to trust the policy officers' judgement. Mutual trust facilitates conversations between engineers and policy officers where, as mentioned earlier, both need to work together to suggest policy options that satisfies both engineering constraints and policy officers' concerns.

Having said that, conversations where engineers and policy officers try to find a compromise between engineering constraints and stakeholder views do not always go smoothly.

*"That's an area where there is **big tension because the engineers propose a solution that is technically excellent** and that would make things technically much more effective. **However, they don't get that we are worried about implementing a solution that would be overly burdensome to industry and has impacts on consumers, that's not going to fly**." – 67, Pol, Medium*

*"The issue with that is, **yes [the policy team] wants this cost reduced, but the latest committee on climate change [Intergovernmental Panel on Climate Change - IPCC] report is showing the cost of not doing anything is extremely high.** So, ok you want these costs to come down but even if you just paid what they are now it may be already cheaper than the cost you're going to pay if you do nothing." – 61, Eng, Long*

*"As I said **we don't have technical experts in our team so when we push back against [the engineering team] we do it without the same level of expertise. But we do it with other considerations in mind**. It is really difficult when that happens, and it happens a lot in this role. **At the end***

> ***though, [61] and I had to come to an agreement to push the policy through****."* – *67, Pol, Medium*

Although engineers take cost constraints and political acceptability into account when making recommendations to policy officers, sometimes the recommendation is not in line with what policy officers consider acceptable. The example in the quotes above shows that the engineer based some of their understanding of economic acceptability on IPCC reports. This clashed with the policy officer's concerns about the impact on industry and consumers which would see the policy proposal rejected. The policy officers' push back is therefore not on technical grounds, as they don't have the engineering knowledge to argue with the engineers, but economic and political grounds based on the stakeholder views they collected and their tacit understanding of the current government's policy principles and policy lines (see literature review section 2.3.3). In situations like this one where the engineer's recommendation and policy officer's concerns clash, it can take longer to find a solution that satisfies both parties. Ultimately, as pointed out in the third quote, policy officers and engineers have to come to an agreement in order to propose viable policy options that meet the project aims. In this case, the engineer took the policy officer's arguments on board and came back with alternative recommendations recognising that the solution initially suggested would not have been approved by the senior civil servants overseeing the policy area. The outcome of the discussions between engineers and policy officers and the resulting policy options are written-up in policy documents, as we will see in the final section of this chapter.

4.4.3 Internally communicating technical information

Another important challenge faced by engineers and policy officers when internally discussing the policy project was the difficulty in communicating technical information. In line with points made earlier, this was a challenge for engineers who struggle to explain technical information to a non-technical audience and for policy officers who lacked an engineering background.

> *"And you know it's* ***not easy explaining engineering to [policy officers], that's not something I was trained to do… but I'm getting better at it****."* – *22, Eng, Short*

*"It gets **uncomfortable** sometimes, trying to have a **discussion with a technical colleague but not having prior technical knowledge**. It got quite confusing at the beginning." – 29, Pol, Medium*

*"**Having an engineering background is really useful when talking to the engineering team**. Having done a PhD on reusing discontinuous waste heat from power plants I know the basics, saves [96, Eng] some trouble!" – 58, Eng-Pol, Medium*

Again, and this is a thread running through this chapter, internally communicating engineering information to policy officers was a challenge for engineers who were not trained communicate this type of information to non-engineers. Equally, policy officers struggled to understand some engineering information because they lacked an engineering background. This proved to be an issue when discussing potential policy options that satisfy both engineering constraints and policy officers' concerns. The policy officers who were trained engineers noted that their engineering background was a real asset in this case, helping them converse with engineers more easily.

Overtime and with experience, engineers and policy officers however develop strategies to overcome their communication issue.

*"**[Policy teams] wouldn't appreciate for example an introduction to physics course on a 50sq millimetre cable that carries 564 amps at a voltage of 12000 volts.** But **a discussion on the bigger you make the cable the more power it can transmit, the more expensive it is, that's what they want to see.**" – 32, Eng, Long*

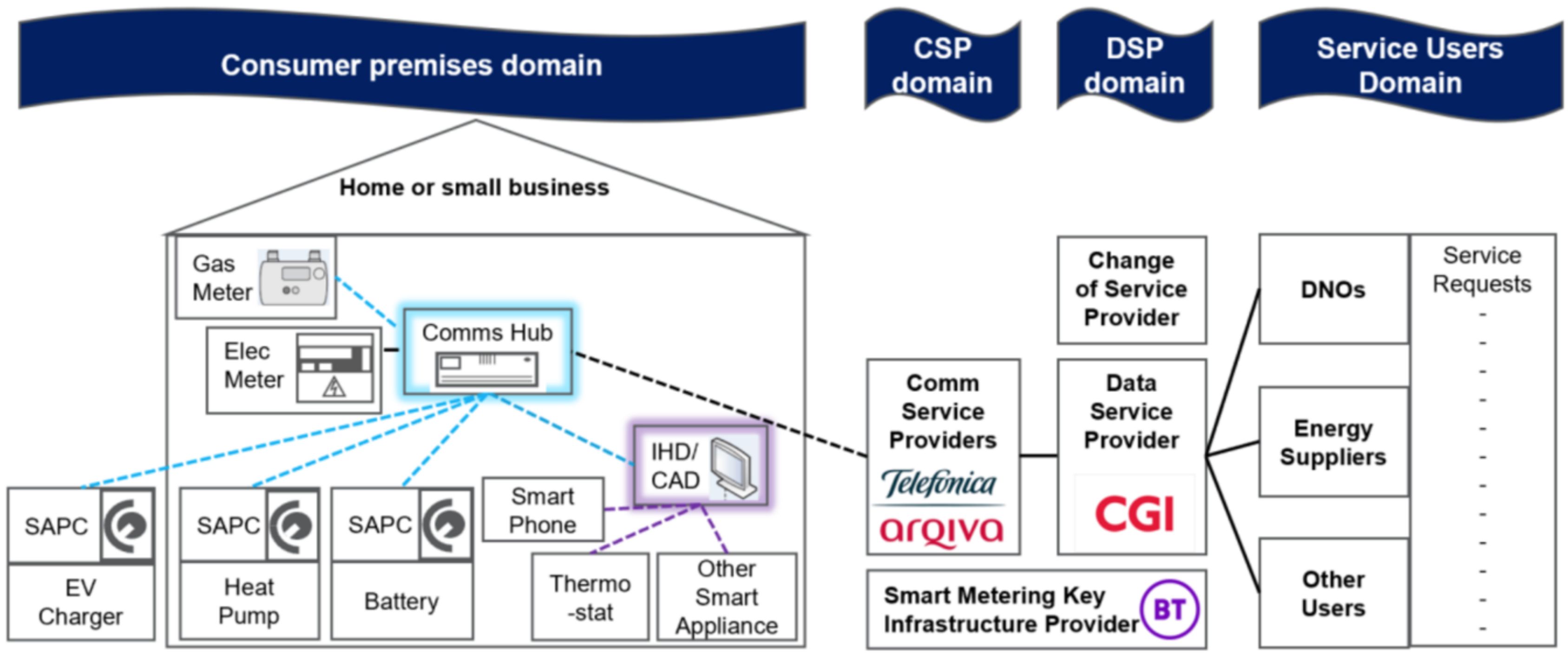
*"What works for me, is to have some **visuals which is something that [85] is used to as they work with policy advisors**. So, we have this little household here where you have the smart meter, the energy management platform and the electric vehicle, the washing machine and stuff and that really helped me out. **I tried to make those visuals my own to some extent, write upgrades on those, and come back to [85] like 'could you just please better explain to me how this part is supposed to be working'**" – 55, Pol, Medium. The figure referred to here can be seen in figure 4.5 below.*

> *"Then the **consultants** go away and produce a **technical report and it needs to be translated into terms that policy units understand.**" – 32, Eng, Long*

> *"In the end, **the final product has to be shared between our teams, so it is important that we speak the same language if you know what I mean.**" – 85, Eng, Medium*

These strategies rely on simplifying engineering concepts and focusing mainly on the impact that changes to engineering systems and components of those system might have in the policy context. This can be explained in, easy to understand terms as the first quote above illustrates or by creating diagrams and figures (see figure 4.5) as the second quote suggests. Engineers apply the same strategies to communicate to policy officers the results of the technical reports consultants produce in the case of commissioned research. As we mentioned before, the longer policy officers have worked on policy issues requiring engineering input, the more engineering knowledge they pick up. This also helps developing a "common language" between engineers and policy officers, helping them communicate on the evidence they collected and weighed, creating mutual trust (see section 4.4.2) and facilitating collaboration on the final policy document.

Figure 4.5: Figure designed by a policy officer (55) in collaboration with an engineer (85) to communicate how components of the electricity system's communication network interlink in the context of the DSR policy project.



4.5 Outcome

4.5.1 Policy documents

The outcome of the discussion between engineers and policy officers is captured in different types of policy documents depending on the policy project. As mentioned above, "outcome" here refers to the policy options resulting from the conversations between the engineers and policy officers, options that: satisfy engineering constraints, satisfy policy officers' concerns, and meet the aims of the policy projects.

> *"I'm putting together the 'EV smart charging response', it's a* ***government response*** *to a consultation we ran in 2019. It sets out the* ***different requirements and policy positions*** *for charge points including the standards* ***[61, Eng] and I worked on.*** *[…]. Yeah, it'll be* ***reviewed by my grade 6 first and then up the chain."*** *– 67, Pol, Short*

> *"So the first step, and we're almost there, is to finish the* ***ITT [invitation to tender]****. That's where we set out what we need from the consultants, in this case, as I said, research on the feasibility of putting hydrogen into the existing grid." – 96, Eng Long*

> *"The* ***results [of the utility-scale solar model] and our discussions [with 17, Eng] I used to draft the section of the statement for renewable energy*** *my team is in charge of. It went to our* ***deputy director, we delivered a presentation on it****, and it was approved." – 69, Pol, Short*

> *"The final product is the* ***'smart systems and flexibility plan'****, that's where what I discussed with [85, Eng] goes. […] The* ***final sign off will be the Minister of State I think."*** *– 55, Pol, Medium*

The different policy documents, in my case, included a draft: government response, ITT, section of national statement and national policy plan. Policy documents are often supported by presentations, and therefore slide packs, as is the case with the national statement for renewable energy. The documents, as we will see below, embed the policy options coming out of the collaboration between engineers and policy officers into a coherent narrative. Once the drafts of the documents are finalised, they go to the head of the policy teams and senior civil servants for final approval, including deputy directors, directors and ministers.

Engineers and policy officers play different roles in the write-up of policy documents.

> *"I lead the final draft but that's after we kind of decided what we were going to say. We usually work on a* ***shared document, like Word or PowerPoint****. I start* ***populating the template*** *in a way that* ***matches what we discussed*** *and* ***when I need clarification or verification on something I ask [the engineering team]****." – 29, Pol, Medium*

> *"I would say the* ***Word documents*** *are what works best when we need to produce a substantial draft. Internally speaking,* ***live documents help us reach each other in a quick and timely way. I write most of it but [61, Eng] always has access if I need help or it needs checking****." – 67, Pol, Short*

> *"That's where the* ***common language and the trust*** *we built in our working relationship is really useful. Just* ***speeds the drafting up****, I trust them, they trust me.* ***Sometimes I need a quick clarification but [85] is happy to let me do the writing up****." – 55, Pol, Medium*

The policy officers lead on the write-up of the final drafts with the engineers in support. As the quotes above suggest, the policy officers write-up the policy options they decided on with the engineers into shared document templates. They reach out to the engineers if they need help or if something needs checking. Engineers also have access to the documents if they want to read them over. If a common language and trust were developed when discussing policy options, it also helps with the writing process. Indeed, if the engineer and policy officer trust each other and share a common language it enables them to more easily and quickly communicate and exchange information.

4.5.2 Policy stories

The policy documents tell a "policy story" (Stevens, 2010), they embed the policy options in a coherent narrative.

> *"If you want a Minister to make a decision on something you need to provide them with the **background, and policy options set out in really simple stories**. It will just **set out a recommended option and some assessment of like the consequences of the different options**." – 65, Eng-Pol, Short*

> *"I mean typically I'm a big fan of a **good graph**, so I always try to **use a figure that kind of conveys the key result up**. They love what they call a one pager, it's always **very hard to get anything substantial into one page. But that's kind of the challenge**." – 29, Pol, Medium*

> *"That was a challenge because there's a **big emphasis on keeping things brief and say things in the minimum amount of words possible**. That means **losing some of the finer details** and **looking more at the bigger picture.**" – 67, Pol, Short*

When writing up the policy documents drafts, policy officers create a clear narrative to explain why they are suggesting certain policy options. This includes describing the background to the policy document, the different options and the consequences of choosing between different options. This is laid out in a linear way where the reader can see what the policy problem or question is, what the potential impact of the different solutions might be and generally why the recommended option is the most viable. The documents are short, forcing policy officers to summarise a lot of information, focusing on the bigger picture rather than the details. Policy officers also use figures as they can convey a lot of information in a limited space and, if well used, help corroborate the document's overall narrative.

For the four policy projects I've mentioned, the outcome of the discussions between policy officer and engineers were phased as the following narratives.

> *"We suggested that the government had to mandate requirements for [EV] charge points to follow cyber security standards and be compatible with any energy provider, so that works for businesses. We suggested that the pre-set should be off-peak charging and that there should be a randomised delay function, that was to satisfy National Grid's concerns. We also included a section on feeding back energy consumption and export data from the charge point to the individuals, that's an answer to consumer consultations." – 67, Pol, Short*

"The ITT highlights that 85% of homes in the country are gas-heated, making heating decarbonisation through hydrogen blending a possibly wide-ranging policy option to achieve net-zero. But in order to know if it's a viable option, we are commissioning research to make sure that the gas grid can be purged to blend hydrogen in and that the pipes and vents are compatible." – 58, Pol, Medium

"We presented our results as graphs showing land use and energy output of current DC threshold versus new AC threshold for different regions. The reason for the regional split was that the more north you go, the less sunlight you have. Results showed a potential 30% increase in energy production overall and, with now more efficient technology, a limited impact on land use. So that should work for residents of those areas too." – 69, Pol, Short

"The argument is to say that, with the electrification of transport, industry and heat, electricity demand will rise and flexibility from consumers will become increasingly important. To enable this flexibility, we need to push smart appliances, tariffs and services to incentivise consumers to change their consumption patterns. But to do that we suggest a standards-driven regulatory approach to get service providers and load-controlling organisations on the same page." – 55, Pol, Medium

The four narratives suggested a preferred policy option that satisfies engineering constraints, satisfy policy officers' concerns, and meet the aims of the policy projects. They are laid out as policy stories where the reader can see what the policy problem is, what the potential impact of suggested solution is and how it is satisfactory to all the actors concerned by the new policy or policy change. The EV Smart Charging Government Response (BEIS, 2021c), ITT for the Provision of Hydrogen Standards for Heat Supporting Research and Evidence (BEIS, 2021d), National Policy Statement for Renewable Energy Infrastructure (BEIS, 2021b) and Smart Systems and Flexibility Plan (BEIS, 2021e) are now all publicly available, the links can be found in the references.

4.6 A note on 'proper engineering'

A final point to note: throughout the process, engineers, because they are working in policy, feel like they are not doing 'proper' engineering.

*"So my job includes a bit of technical work but **not really proper engineering in the sense of** sitting down and **doing calculations and designing**. The traditional chemical engineer, **what I've been taught at [university]**, is design a process. But at BEIS we don't do any of that. So yeah, in that sense it is quite different, **we don't really build stuff so I wouldn't characterise it as 100% engineering.**" – 22, Eng, Short*

*"I've been thinking about this, you know, it's like **I continue to consider myself an engineer. But** like **I'm sure there are plenty of people out there who might raise an eyebrow at that.** And you know, if I wanted to get **chartered**, how **difficult** would that process be given that most of my experience is in policy? **So, I think there's like an interesting question there for the engineering profession about if we want to sit at the policy table, how do we value those policy skills and promote them?**" – 58, Eng, Medium*

*"I would say that the work we do sometimes... **I wonder whether we're a bit fraudulent as engineers because we never have to get bogged down in the detail too much.**" – 85, Eng, Medium*

*"And having that kind of a **generalist view** and knowing enough that you know what you know and what you don't know. When we need to ask as part of our job, where we will go and **speak to academics who are specialists**, we can **have the conversation even though we don't know the details.**" – 17, Eng, Medium*

Engineers working in policy are reluctant to call themselves 'proper' engineers as their current role is not necessarily in line with the view of the discipline developed in their studies. The same point was made by engineers during the workshop I ran a year after the interview data presented above was collected. Engineering, as taught at university and implied in some chartership requirements, is about calculation and design to build tangible objects and/or systems of objects. In BEIS' engineering advice team, the engineers' role is quite different, they have to adapt and learn quickly to cover different areas of engineering depending on policy needs. They develop a general view of their field (they are 'generalist engineers') and engage different stakeholders if they need to gather more precise information on a specific engineering issue. Although they sometimes do some calculations, most of their work consists of gathering and processing data and reports to inform policy measure like developing standards and regulations. To carry out this work, engineers rely on communications skills they learn on the job like summarising information and adapting to their audience, skills not necessarily valued in their training.

5 *What is the difference between science and engineering advice in a UK ministerial context?*

This chapter explores the results from the second phase of my research designed to understand the difference between science and engineering advice at BEIS. This section is based on observation, document analysis, workshop data and ethnographic interviews of BEIS' scientists and engineers, and the policy officers they work with (see methodology section 3.5).

As stated in the methodology, BEIS' science advice team sits in the same directorate as the engineering team, allowing for comparison between science and engineering advice in this context (see methodology section 3.5). The science advice team aim is to "look after the UK's climate science capability and provides scientific advice to other teams within the ministry". To achieve its aim, the science team is divided into three workstreams, each responsible for a different set of projects:

- The inventory stream is responsible for producing the UK's yearly greenhouse gas emission inventory.
- The capability stream ensures that the ministry has access to sufficient climate science to understand the consequences of a changing climate for policy making. This means working with policy teams in BEIS to commission climate science research, overseeing the contracted-out projects and helping communicate the results back to the policy teams.
- The mitigation stream works directly with the policy teams, providing them with scientific advice to support the department's sustainability policy projects.

This chapter details, in turn, the work of the three streams and the similarities and differences between each of the streams and the engineering team's work covered in the previous chapter. This highlights the differences in process and content between science and engineering advice at BEIS. Points raised are accompanied by illustrative quotes from my participants along with their anonymised number, role type and time in role based on methodology table 2. I have emphasised key parts of the quotes in bold.

Figure 5.1 provides an outline of the contents of this chapter including the science team's streams remits, examples of projects they work on, and the similarities and differences between each stream and the engineering team's work.

Figure 5.1: The science advice team's streams, their remit, the projects they work on and the similarities and difference between their work and the engineering team's work

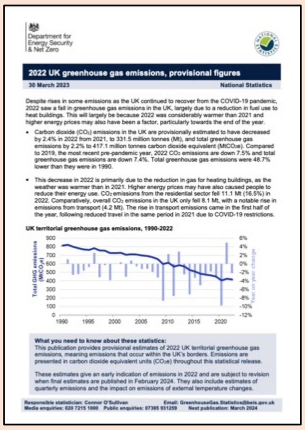
BEIS' Science Advice Team

Aim: look after the UK's climate science capability and provides scientific advice to other teams within the ministry

Stream 1 | Stream 2 | Stream 3

Inventory Stream

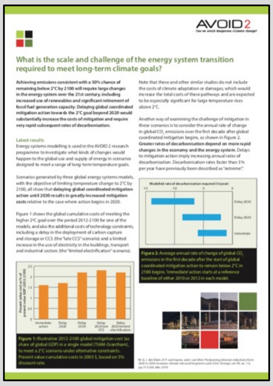
- Responsible for producing the UK's yearly greenhouse gas emission inventory.
- Project: Works only on the inventory



- The inventory streams work is different for the engineering team's work, both in term of process and content. Summary in **table 5.1**.

Capability Stream

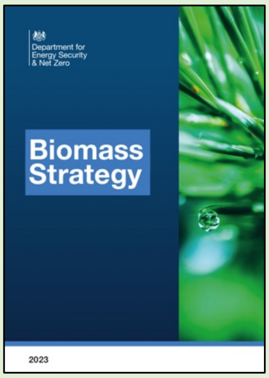
- Works with policy teams to commission research, ensuring that BEIS has access to sufficient climate science for policy-making.
- Projects include CS-N0W and Avoid2



- The capability stream and engineering team both behave as 'intelligent customer' of commissioned research, but the advice content is different. Summary in **table 5.2**.

Mitigation Stream

- Works directly policy teams, providing them with scientific advice to support the department's sustainability policy projects
- Projects include collaborating with engineering and policy teams on Biomass Strategy



- The mitigation stream and engineering team follow the same 'in-house' advice process, but the content of their advice differs. Summary in **table 5.3**.

5.1 The science team's inventory stream

5.1.1 Inventory stream: Remit and process

The science team's inventory stream's main task is to oversee the production the UK's yearly greenhouse gas emission inventory.

> *"**Every year we produce a systematic assessment of greenhouse gas emissions** from anthropogenic activities across the whole UK economy, which includes land, industry, energy, waste, agriculture". – 46, Sci, Long*

> *"The **IPCC taskforce on inventories designs the inventory process**, the **UN [United Nations] adopts the process** and the **UK then follows the IPCC guidance** to produce an inventory that meets the structure the UN is asking for. The **inventory workstream then works with Ricardo-AEA, the inventory-agency**, to gather the additional data they need for the inventory [note: Ricardo-AEA itself relies on sub-contractors to gather data]." – 50, Sci, Medium*

> *"So, we were using the evidence they have collected over time and transfer it into models. **We gather and funnel a range of evidence together overtime**. Sometimes we have **to make a decision with regards to what is counted in which emission source** but most of the time we follow a set process." – 46, Sci, Long*

> *"We have **international reviews of the inventory**, so inventory experts from other countries come over to the UK or do it at the moment by Zoom. **Reviewer of the inventory and practice scrutinize models, so that's the UN actually**. They review all the inventories and our contribution to that is to contribute money to the UN so that they can hire our experts to review the German inventory for example. So effectively there's a global pool of expertise, which is drawn on." – 50, Sci, Medium*

The inventory process, which sets out what type of emission data should be collected and how it should be analysed, is designed by the IPCC and approved by a UN commission, which the UK is part of. The inventory stream then follows this process and works with an external agency to gather and analyse the data to produce an inventory of greenhouse gases emissions across different sectors of the UK economy for that year. Most of the process is set, however, the inventory stream sometimes has to decide which emissions is attributed to which source. The inventory stream documents how the inventory was compiled, including justification of emission source attribution, so that UN experts can review and approve the UK's inventory.

Once the inventory is approved, the inventory stream shares the inventory with the wider UK government.

> *"The **inventory is then shared back with the UN and obviously across the whole UK government**." – 46, Sci, Long*

> *"So the **inventory measures greenhouse gas emissions, most of it is net carbon dioxide emissions**. It **breaks it down per sector** like energy supply, transport, agriculture and what goes in what sector, as I said, is more or less decided at UN level. So what **you end up with is a million tonne CO2 equivalent number overall and per sector**, all the stats are available online if you want to check them out" – 46, Sci, Long*

> *"It's a **numbers and reporting tool**. **We don't work with the policy teams directly**, the policy team might use the data in the inventory but this is not something we are responsible for**. We just compile the inventory as specified by IPCC guidelines."** – 50, Sci, Medium*

As the quotes above suggest, my participants in the inventory stream were keen to stress that they did not work directly with policy teams in BEIS either before or after the publication of the inventory. As mentioned, the inventory stream mostly follows a process set by the IPCC, not policy teams. Once finalised and approved, the inventory, containing statistics on greenhouse gas emissions per sector, becomes publicly available and shared across the government. As such, policy teams can use and reference the inventory, but this falls beyond the inventory stream's remit; the stream does not offer any post-publication support to policy team wishing to use inventory information.

5.1.2 Differences between the inventory stream and the engineering team

The inventory stream's work is very different from that of the engineering team, both in terms of process and content (see table 5.1). The inventory stream does not work directly with policy teams, nor on a product (the inventory) that is specific to a particular policy problem. Instead, every year, the inventory stream follows a process set by the IPCC to produce a tool that is then shared with the entire government. Most of the process, as in the data to collect and how to analyse it, is not set by the inventory stream; and in the few situations where the inventory stream has some discretion, they need to document what they have done to get UN approval. This is not to say that greenhouse gas inventories are apolitical, the IPCC and the UN are political organisations and states can influence the way the inventory process is designed (Beck, 2011). However, this type of influencing is not carried out by the inventory stream and falls beyond the scope of this thesis.

This contrasts with the work of the engineering team which works directly with policy teams, as we saw in the previous chapter. Unlike the inventory stream, the engineering team advises policy teams within BEIS, which requires a discussion between both teams to clarify what is asked of the engineers, and collaboration (sometimes clashes) to meet the aims of the policy project. Unlike the inventory stream which produces a descriptive report containing emission measurements that all policy teams can use, the engineering team is embedded in policy development and provides policy teams with prescriptive options to solve specific policy problems (see chapter 4, section 4.5).

Table 5.1: Differences in work process and content between the inventory stream and the engineering team

	Inventory Stream	Engineering Team	Differences
Work process	Follows process set by the IPCC to produce the yearly UK greenhouse gas emissions inventory. The inventory is shared across the UK government.	Advises specific policy teams, collaborates (sometimes clashes) with policy teams to propose solutions that meet the aim of the policy project.	The inventory stream is not as embedded in policy development as the engineering team. Unlike the engineering team, it does not work directly with policy teams, nor on a product (the inventory) that is specific to a particular policy problem.
Work content	The inventory is a descriptive report containing emission measurements that all policy teams can use.	Provides policy team with prescriptive options to solve specific policy problems.	The inventory stream produces a descriptive report shared across the UK government. By contrast the engineering team provides direct advice to policy team to solve a policy problem.

5.2 The science team's capability stream

5.2.1 Capability stream: Remit and process

The capability stream's work differs from the work of the inventory stream and, as explored below, is more similar to some of what the engineering team does. The capability stream's remit is to ensure that BEIS has access to sufficient climate science to understand the consequences of a changing climate for policy making.

> *"The capability stream is in charge of **ensuring that [the UK] has sufficient** fundamental **climate science to understand the consequences of a changing climate** both nationally and internationally" – 46, Sci, Long*

> *"For instance, we are the **custodians of** a department-wide **initiative called climate services for a net zero resilient world program [CS-N0W**]. This is a program of research of 5 million over 4 years designed to help the UK meet its decarbonisation targets." – 26, Sci, Long*

> *"The **program is designed to help the entire department**, not just one policy team but all of them in theory. A specific board was appointed when the programme was designed, I was on it, and we **consulted relevant policy teams across BEIS**. But the **results will be communicated back to all the policy teams** so they have access to the analysis that came out of the research to make policy decisions." – 46, Sci, Long*

> *"We launched the program recently **starting with research on the consequences of decarbonisation overshoot pathways carried out by UCL actually**. That's basically **modelling different scenarios on what happens to the climate if we exceed our CO2 emissions targets**, by how much and for how long, before bringing them back down to where they need to be." – 26, Sci, Long*

Ensuring BEIS has access to sufficient climate science means, in the case of the capability stream, working on department-wide research programs like CS-N0W. As explained in the quote above, the aim of the program is to model different scenarios on what might happen to the UK's climate if the international community exceeds its emissions targets before bringing them back below target (a process known as 'overshooting'). The capability stream oversees CS-N0W, but the program is designed in consultation with multiple policy teams across BEIS that work on policy topics related to climate change. The research is commissioned out with the capability stream working with the consultants, UCL academics for the first phase of the project, to oversee the research and communicate the results back to the policy teams. Note that the capability stream is not working with a specific policy team on a policy project but with multiple policy teams with the results of the project being communicate to the entire department. The capability stream's role at each stage of the CS-N0W project is covered in more depth in the following paragraphs.

As touched on above, the capability stream started by consulting policy teams to design the CS-N0W program before commissioning out the research.

*"As I said we **consulted with the relevant policy teams when designing the program of work**, like **what information they would find useful**. But it's always a **challenge** to try and **get policy colleagues to articulate what they don't know and what they need to know**, **and when** they need to know it. Especially because **very few of them come from a climate science background**" – 46, Sci, Long*

*"So **I'm a geologist by training** and [**46, Sci] has a background in chemistry** so that's useful when setting up the project and **translating what the policy teams say into scientific terms**. For example the term 'overshoot pathway', they wouldn't use that, they would say 'what happens if we don't meet the emissions' target'" – 26, Sci, Long*

The initial challenges faced by the capability stream are linked to the policy teams' lack of scientific background. To understand what information the policy teams would benefit from within the scope of the CS-N0W project, the capability stream worked with multiple policy teams that struggled to articulate what scientific information would be useful to them. Either the policy teams lacked a deep enough understanding of climate science to know what information they needed or expressed their needs in non-scientific terms. The capability stream scientists' initial role was therefore to help policy teams understand what scientific information might be of use and/or translate the needs expressed by policy officers into scientific terms.

Throughout the project, the capability stream interfaces with the academics carrying out the research.

*"So now that the project is ongoing, we have **regular check-ins with the UCL teams** in charge of the work packages. There are **different interim reports and datasets they have to provide** along with a presentation of their results. **We make sure that everything is consistent with what we asked for**, ask them for clarification if need be. Just making sure the project is on track really." – 26, Sci, Long*

*"I guess the thing I've learned is that you have to **keep the message very simple**, and I think, as researchers, we're a bit cautious when it comes to it, in particular with modelling and you know the associated errors, measurement errors and so on. And so, because we are so aware of the*

*limitations of our methods, **we tend to overemphasize the caveats that might come with the findings**." – 79, Sci-Ac, Long*

*"I think **keeping it simple** and acknowledging the limitations but not making it the focus of your message perhaps is something I learned. **You have to adapt to who is going to be the recipient of your message**." – 83, Sci-Ac, Long*

Echoing a concept introduced in the previous chapter (section 4.2), the capability stream acts as an "intelligent customer". The capability stream monitors the consultants' work, ensures that the research carried out is consistent with the project plan and asks for clarification when needed. The academics working on the CS-N0W project also report that they adapt to their policy audience, making sure they communicate their findings in a simple, high-level way. This means acknowledging the limitations of their work, measurement approximations in the case of modelling for instance, without over-emphasizing them or making it the focus of their message.

Once the project is over, the capability stream is responsible for sharing the research results back with the department.

*"After the end of the project, **we will share the findings with the rest of the department**. So we **create documents based on the results** of the program and push them across the department, we **present them to different head of directorates and teams**, make sure the directors are aware of them too." – 26, Sci, Long*

*"Back to your question earlier **we don't work directly with one team or on a specific policy project. Sometimes, a policy team will reach out if they need more information** or clarification on a number in one of the reports. But it would be **nice to know if and how the evidence from projects like CS-N0W are taken on board** by policy teams actually." – 46, Sci, Long*

*"What would be your one piece of **advice to [the BEIS science team] to ensure scientific evidence is embedded into decisions**" – Question asked by the science team to the senior civil servant panel at the B-SEN event*

As mentioned before, the capability stream takes the results of projects like CS-N0W and turns them into different tools and documents for different policy teams within BEIS to use. The capability stream shares and presents the different documents and tools, which are covered in more detail below, to the policy directorates and teams. Although the projects overseen by the capability stream are department-wide projects, the capability stream is sometimes contacted by specific policy teams wanting to know more about one of the project outputs. In this case the capability stream gets in touch with the policy team to clarify a specific result and how it was obtained. Worth noting that the capability stream does not go beyond clarifying results in project output documents, they have limited exposure to if and how the project results are then used by the policy team in policy drafting. This last point was raised, by the science team, at the B-SEN event.

The capability stream produces different types of documents that present the findings of the research projects as an easy-to-follow narrative.

> *"Given that **policy teams don't have the time to get into** lots of granular **detail**, **we turn the reports** and datasets we get from academia or whoever **into policy cards, infographics, interactive tools** and seminars". – 26, Sci, Long*

> *"I find the [capability stream's] document very helpful. **I don't have a scientific background so it's really useful for have those documents** that **put complex** climate phenomena **into easy-to-understand terms** and layout." – 37, Pol, Medium*

> *"The CS-N0W documents won't be ready for a while but I can show you something we did for a similar program called Avoid2. We created **two-page policy cards with simple charts and language** to communicate the results of the modelling we commissioned. For example, this figure shows **how much $C0_2$ would have to be sequestrated per year to stay in line with a 2-degree temperature rise scenario**. Each of the three models make different assumptions with regards to that so we put all three on there."– 26, Sci, Long. See figure 5.2.*

Figure 5.2: Policy card figure showing three climate models' yearly $C0_2$ sequestration assumptions to stay in line with a 2-degree temperature rise.

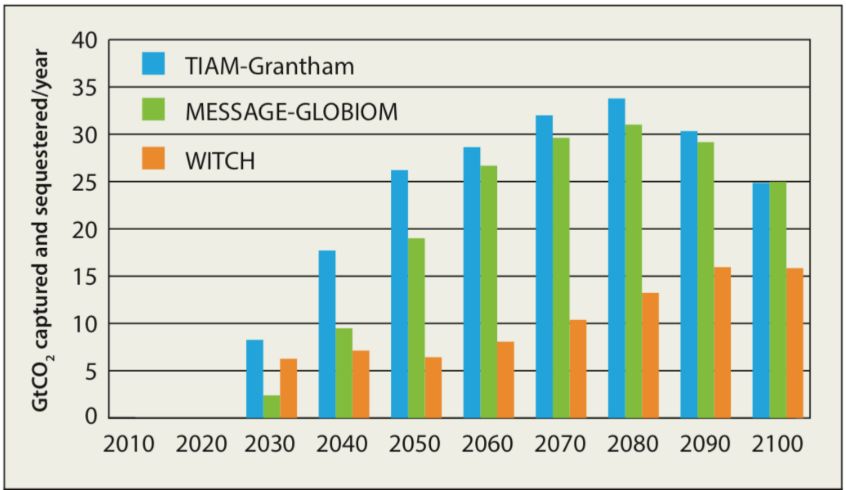


Figure 4: Global CO_2 captured and sequestered annually, 2°C scenario with global coordinated mitigation action delayed until 2020. WITCH has a greater scope for energy demand reduction so does not rely so heavily on CCS (cf figure 3).

The documents produced by the capability stream on the back of projects like CS-N0W and Avoid2 present the results of the research in simple and visual ways. Again, because a lot the policy teams viewing this information do not have a science background, the capability stream puts a lot of emphasis on turning scientific data into creating short, simple narratives accompanied by easy-to-understand charts (see figure 5.2). As echoed in my observation notes, being able to translate science into something non-technical people can understand is seen as one of the science team's key skills.

The narratives of the documents produced are descriptive, they answer questions on what happens if a certain target is not met or how much of a gas can be emitted without exceeding a target. As the example above shows the question posed was how much $C0_2$ needs to be captured to stay in line with a two-degree temperature rise scenario. The document answers this question showing data from three different models, each setting targets in gigatons of $C0_2$ to be capture until 2100 by 10-year intervals (figure 5.2). Although the narrative here looks to the future, it does not include what should be done to meet those targets, either the steps to take of technologies to consider.

5.2.2 Capability stream vs. engineering team: Similarities and differences

There are some similarities in the advice process followed by the capability stream and the engineering team (summarised in table 5.2). Both are involved in outsourcing science or engineering work because of a lack of internal capacity (available staff) and/or capability (subject matter expertise) in their respective stream or team. Although the capability stream does not work directly with one policy team, it still engages multiple policy teams on department-wide projects. This means working with policy teams to understand their needs and define the scope of the outsourced work. This can be challenging because many policy officers do not have a science background and struggle to articulate what scientific information they might need and phrase it in scientific terms. As a result, the capability stream often translates the policy teams' needs into scientific terms for the consultants, just like the engineering team translates policy needs into engineering terms when drafting ITTs. As the project is carried out, both the capability stream and engineering team act as "intelligent customers" of the research, monitoring the work of the consultants, making sure the scope of the project is respected and asking for clarification when needed. The capability stream and the engineering team also both translate the scientific/engineering contents of the consultant's work back for the policy teams using simple narratives supported by figures and visuals.

The narratives produced by the capability stream and the engineering team however are different. The capability stream answer policy questions that require setting thresholds based on specific measurements (CO_2 emissions for instance) and describing scenarios about what might happen if a threshold is exceeded or not. The narrative does not include what can be done to avoid exceeding the thresholds mentioned. The engineering team, by contrast, produces prescriptive narratives that propose solutions to a particular policy problem like how smart EV charge points should be designed (see previous chapter, section 4.5). This includes the steps to take and standards to include to ensure the design meets the policy project aims, for instance smart grid compatibility. This echoes McCarthy's point about science and engineering advice narratives mentioned in the literature review (section 2.2.5).

The difference in narratives generated by the capability stream and the engineering team is also reinforced by the fact that the capability stream does not work with a specific policy team on a policy project. The capability stream works on department-wide projects and feeds back the results of the outsourced research to the whole department. The narratives of the documents produced by the capability stream are therefore general, they are not tailored to a particular policy project. The engineering team, on the other hand, works directly with a policy team on a specific policy project. Unlike the capability stream, it is fully embedded in the policy drafting process, giving advice relevant to a specific policy issue. The differences between the capability stream and the engineering team and captured in table 2 below.

Table 5.2: Similarities and differences between the capability stream and the engineering team

	Capability stream and engineering team similarities	Capability stream and engineering team differences
Advice process	Both involved in commissioning science or engineering research due to lack of internal capacity/capability. Both work as "intelligent customers" of the research: work with policy teams to define research scope, monitor work of consultants, translate research back for policy teams	Unlike the engineering team, the capability stream does not work with one policy teams. It engages multiple policy teams on department-wide projects.
Advice content	Both translate the consultant's engineering/scientific work back for the policy teams using simple narratives supported by figures and visuals.	Narratives produced by the two teams are different: Capability stream answer policy questions that require setting thresholds based on specific measurements and describing scenarios about what might happen if a threshold is exceeded or not. Engineering team produces prescriptive narratives that propose steps to take to solve a particular policy problem.

5.3 The science team's mitigation stream

5.3.1 Mitigation stream set-up

The mitigation stream is the third stream of the science team, and, unlike the inventory and capability streams, it supports specific policy teams on particular policy projects.

> *"The **mitigation workstream supports** the **policy teams with scientific evidence for** long-term **work on sustainability**" – 46, Sci, Long*

*"The **mitigation stream is really set-up like [the engineering] team**, the **information is different, but the processes of communicating it are similar**." – 46, Sci, Long*

*"Our focus right now is on **helping the biomass policy team** with the Biomass Strategy. **We supply them with scientific information** to help them **understand how biomass feedstocks**, like biological residue from different sources, **can be processed to generate energy** and the **implications** this has **for the environment**." – 06, Sci, Long*

*"On the **biomass project we** actually **work closely with the engineering team** because the policy needs both types of input." – 46, Sci, Long*

The mitigation stream provides scientific advice to other policy teams sitting within the ministry working on sustainability policy. This set-up, as the quote above suggests, is the same as the engineering team's set-up detailed in chapter 4 section 4.1. Both the mitigation stream and the engineering team share the same set-up and therefore follow the same advice process, collaborating with policy teams on in-house projects. This means answering policy teams' questions by gathering evidence and discussing their findings with their policy counterparts to meet the aims of a policy project (see chapter 4). In the case of the mitigation stream, this includes, working with the biomass availability and sustainability policy team on developing the UK's Biomass Strategy (DESNZ, 2023). The mitigation stream provides the biomass policy team with scientific advice on how biomass feedstocks can be processed to generate energy and the environmental consequences of doing so.

Interestingly, the engineering team also works on the project, collaborating with the mitigation stream and the biomass policy team to provide engineering input into the Biomass Strategy. The mitigation stream and the engineering team follow the same advice process to provide the biomass policy team with scientific and engineering information, respectively. The Biomass Strategy therefore provides a great site to compare the work of the mitigation stream and engineering team at each stage of the advice process. Breaking the process down in the same way as the previous chapter, the following section focuses on the differences in advice content, stakeholders engaged and advice narrative between the mitigation stream and the engineering team in context of Biomass Strategy.

5.3.2 *Mitigation stream vs. engineering team: Policy questions, scientific and engineering input*

The mitigation stream and the engineering team both sit on the biomass policy board however the questions they are asked by the biomass policy team differ.

> *"We **sit on the policy board for biomass**, **with the biomass policy team and the engineering team** actually, so that's **where** some of the **original questions came from**. We also get a lot of questions on mail and engage with the policy team one on one." – 06, Sci, Long*

> *"We **need advice from both the engineering and science** teams because **some elements** that deal with the production **of biomass are more scientific**, and **then elements** to do with the use of biomass in machines are **more engineering**." – 94, Sci-Pol, Medium*

> *"One of the questions we [**science team**] got was**, what might be the amount of leakage from biomass reactors and** what would the **environmental impact** be? Then the **engineers** worked on the other part of that issue which is **what can you do to do about it**?" – 06, Sci, Long*

As is the case with the engineering team, policy officers ask for the mitigation stream's input through policy boards and via email. In the context of the Biomass Strategy, the biomass policy team initially asked the mitigation stream and the engineering team for their input through the biomass policy board on which all three teams sit. As the quote above suggests, the biomass policy team need advice from both the mitigation stream and the engineering team because some elements of the policy are seen as more scientific and others more related to engineering. Scientific elements related to the production of biomass, that is what type of feedstock can be used to produce energy, what chemical reactions happen in biomass reactors, what gases might be released from those reactions and what impact might those have on the environment. Engineering elements relate to the reactors themselves, this includes the engine efficiency of different reactors on the market, the design and materials used in different types of reactors and how gas-tight they are, and additional technologies that can be used to capture released gases. The question asked to the mitigation stream was therefore more explanation-oriented, focusing on measuring the possible gas leakage from biomass reactors and the potential environmental impact of those leaks. The question asked of the engineering team on the other hand was goal-oriented and focused on what can be done to prevent gas leakage and reduce its potential impact.

After the initial questions were asked, the mitigation stream and engineering team had one-to-one conversations with members of the policy team to clarify what was asked of them.

> *"Most of the time we need to have a chat with the policy team because their* ***questions are a bit unclear****, or rather, too vague. And it's not necessarily their fault you know, it's just that* ***they don't have a scientific background****.* ***In the case of the biomass work though****, it's nice because [94, Sci-Pol, Medium] is leading the project* ***on the policy side and they have an earth sciences background****." – 46, Sci, Long*

> *"So the example I just gave you, we had a one to one chat with [13, Pol, Medium] to* ***work out what they meant by amount of leakage****. First you need to think about the production process so the* ***organisms you introduce in the digester****, the type of* ***wet material you use as feed****, the* ***types of gas produced – in this case methane****.* ***Then*** *you can start thinking of the* ***amount of gas you get per unit of feedstock and the potential volumes of methane leaked into the atmosphere.****" – 06, Sci, Long*

> *"It was* ***strangely worded but*** *ultimately* ***what the policy team settled on*** *was an* ***economic and technological assessment of different types of biomass reactors****. So, what is* ***less likely to leak****, what* ***technologies*** *can we put in place* ***to reduce leakages*** *if they happen and* ***how much*** *do different* ***options cost****." – 22, Eng, Short*

Policy officers often do not have science background and, as a result, phrase their questions to the mitigation stream in general and imprecise scientific terms. Scientists therefore have a conversation with policy officers to clarify what information they need. Conversely, as mentioned in the quote above, the phrasing of the questions tends to be more precise if the policy officer has a scientific background. These points are also made by the engineering team in the context of engineering advice as pointed out in the previous chapter (chapter 4, section 4.1).

In the context of the Biomass Strategy, the mitigation stream's scientist needed clarity over what "amount of leakage" meant in the policy officer's initial question. This clarification required a conversation about the feedstocks and organisms in the biomass reactors and the amount of methane produced per unit of feedstock as a result. The mitigation stream scientist explained that the impact on the environment would be contingent on the quantity of methane released into the atmosphere which they would work out based on the amount of methane produced and potential size and occurrence of gas leaks per reactor.

In parallel, the engineer working on the project also asked the biomass policy team for clarification. The engineer and policy officer worked out that what the policy team needed was a technological and economic review of different types of biomass reactors and associated methane capture and storage technologies. This included an assessment of the gas-tightness of different types of reactors, additional technologies that can be used to reduce leakage and capture emitted gases and the cost of different options.

5.3.3 Mitigation stream vs. engineering team: Engaging stakeholders and gathering evidence

Once the initial questions are clarified all three teams engage different stakeholders to gather the evidence needed to answer the question at hand.

> *"We're in touch with **academics at UCL, Imperial and Oxford** so we **got some information on feed type and gas production through them**. Obviously, we're in constant contact with the **Hadley Centre at the Met Office** and the **have data on greenhouse gas emissions**. And we're of course re-using some of the **work we've already done** internally, especially work **on modelling the impact of** greenhouses gases, of which **methane, led by [the capability stream] and UKRI [UK Research and Innovation].**" – 06, Sci, Long*

> *"A lot of **industry engagement**, so we led several **workshops** and **consultations with** different **manufacturers**. A bit of **desk research** too, and a few **calls with colleagues in universities** as well. In the end we had an assessment of different reactors and associated infrastructure, the benefits of each, their **level of readiness and potential costs**." – 22, Eng, Short*

> *"Well, we're liaising with different **teams in BEIS and DEFRA**, including the science and engineering teams you spoke to, but also other policy teams, to see what the needs and hurdles are. We **use a lot of strategy documents that have already been published**, to **give us** a sense of **direction**, as well as **ministerial briefings**. I know my grade 6 also had a **conversation** with the **Secretary of State about the costs and budgets** for biomass." – 13, Pol, Medium*

The mitigation stream engaged with academics in different UK universities to gather scientific information on biomass feedstock types and gas production. The stream also obtained data on greenhouse gas emissions from the MetOffice and were able to use some of the work led by the capability stream on the environmental impact of greenhouse gases. The engineering team engaged with industry, leading workshops and consultations with manufacturers about different biomass technologies and associated cost. In addition, the engineering team reached out to academics to get a better sense of the readiness level of the different technologies presented by industry. In parallel, the biomass policy team consulted other policy teams in BEIS and DEFRA to understand what related work was being carried out or had already been done. The policy team used different policy documents, like the 2021 Biomass Policy Statement (BEIS, 2021a) and ministerial briefings to understand what was expected and acceptable in this policy space. The biomass policy team lead was also in touch with the Secretary of State's office to gather information on the budget allocated to the biomass strategy.

As hinted to above, when it comes to stakeholder engagement and evidence gathering, the engineering team is more connected with the private sector than the mitigation stream.

> *"The **engineering team is more involved with industry because** they **deal with** the actual **technology**, if that makes sense. They're the ones looking into what we might build, and the **R&D happens within industry**, **and so will** the **delivery** of the actual reactors." – 94, Sci-Pol, Medium*

> *"We would like to keep more in touch with the **real engineering world** through more exposure to **industry projects**. This could be by identify more personal development opportunities especially short-term secondments into industry." – B-SEN workshop*

*“The **engineering team deals with costs** a lot **because** we asked them to do so, to look at the **infrastructure** and that **has a direct cost**.” – 13, Pol, Medium*

*“There's **more of an exchange between engineering consultancies, energy companies, industry and [the engineering] team**. A lot of the information they work with sits with industry, whereas **for us [science team] it’s more academia and consortiums**.” – 46, Sci, Long*

As we established above and in the previous chapter, the engineering team at BEIS answers questions on technologies and built systems. This is clearly visible in the case of the Biomass Strategy where the engineering team was asked to explore the performance of different types of biomass reactors and associated gas-capture technologies. As the quotes above suggest, the engineering team therefore interfaces with the private sector because the research and development and the delivery (i.e., the building) of biomass reactors is carried out by industry. This was also echoed during the B-SEN workshop where BEIS engineers described industry as “the real engineering world”. For the engineering team, dealing with the performance and potential delivery of new technologies, like biomass reactors, also means directly dealing with costs implications. Indeed, looking at technological development and delivery implies looking at different options which usually perform differently and have different associated costs.

By contrast, the science team’s mitigation stream answers questions focused on measuring gas-leakage and the potential impact of those emissions. As mentioned above, to answer these questions the mitigation stream needs information on, and measurements of, biomass feedstock gas production and greenhouse gas emission. This information does not usually sit with industry but, at least in this case, with academia (specific universities or UKRI-funded university clusters) and publicly executive agencies (the MetOffice). In the context of the Biomass Strategy, unlike the engineering team, the mitigation stream therefore interfaces less with the private sector and more with academia and other public bodies.

5.3.4 Mitigation stream vs. engineering team: Combining evidence and mutual trust

As the mitigation stream, engineering team and biomass policy team gather evidence, they discuss their findings and conclusions together.

> *"We have **meetings with the science and engineering teams**, either separately or together to **discuss their findings** and **ask them further questions** if we need to. They **tell us what they did to arrive at the conclusions they did**, and **we discuss how to take it onboard** in the context of the [Biomass] Strategy." - Sci-Pol, 94, Medium*

> *"Well, I'm quite new so sometimes I **struggle with explaining technical, engineering details to** [Biomass Availability and Sustainability **policy team**]." – 22, Eng, Short*

> *"What we do is quite tricky sometimes because we have to **explain complicated science to policy people who don't know much about it**. And it's hard for us too because we're not necessarily used to it, at least if you've not worked in policy before." – 06, Sci, Long*

> *"**After a while you can develop rules of thumb, analogies and simplifications to more easily explain** stuff to non-scientific colleagues. Like this process produces these gases and if X quantity is released it can have Y effect, you see what I mean?" – 46, Sci, Long*

Throughout the project, the mitigation stream and engineering team meet with the policy team to discuss their work, the evidence gathered and how they are answering the initial question. This is also an opportunity for the biomass policy team to ask further questions to the mitigation stream and engineering team as well as provide them with an update on the broader policy project. As explored in the previous chapter (chapter 4, section 4.4.3), during their discussion with the policy team, engineers sometimes struggle to explain engineering information to policy officers without an engineering background. The scientists in the mitigation stream reported the same challenge, struggling to explain scientific information to policy officers without a scientific background, especially scientists that had limited policy experience. As is the case with engineers (see chapter 4, section 4.4.3), over time scientists develop techniques to more easily communicate scientific information to policy officers. As illustrated by the last quote above, this includes using analogies and simple "rules of thumb" to explain causality, scale, and effect in non-scientific, easy to understand terms.

Through those discussions and by explaining what they did to answer the initial policy question, the mitigation stream, engineering team and biomass policy team develop mutual trust.

> *"[**06, Sci**, Long] is really **good at explaining the work the science team does**. Like **how they came up with their results** and what is a sensible use of biomass and what really isn't viable. **I trust their advice** because they understand the underlying processes involved, it's their field." – 13, Pol, Medium*

> *"In this case [**22, Eng] did a good job at explaining how they came up with their taxonomy of different biomass technologies**. It really helps because you can **see [the engineering team's] expertise** and you know **you can believe what they say.**" – 94, Sci-Pol, Medium*

> *"[**94, Sci-Pol**] always asks us to review the briefings they write based on our input. But we generally don't have much to say, they **do a good job summarizing the outcome of our work together into very short briefings**" – 06, Sci, Long*

Policy officers in the biomass policy team valued the conversations they had with the mitigation stream as it allowed them to understand how the stream came up with an answer to the original policy question. This was facilitated by the mitigation stream's efforts to communicate the scientific information they gathered and analysed in simple terms. Being able to understand how the scientists came up with their answer meant that the policy officers in the biomass policy team trusted the mitigation stream's advice. As covered in the previous chapter and as the quote above, the same was true for the engineering team's advice. The engineer on the project explained the work carried out by his team to the policy officer, resulting in the policy officer trusting the engineers' biomass technology assessment. This trust also went the other way as scientists and engineers were able to see how their advice was taken into account by the policy team when drafting biomass policy briefings.

5.3.5 Mitigation stream vs. engineering team: Answers, narratives, and overall reflexions

The mitigation stream and engineering team's answers to the biomass policy questions were as follows:

> *"Without going into the finer details, we told the policy team that, **for the biomass idea to be worth it**, we would have to **keep biomethane emissions in general to under 24g of CO_2 equivalent per megajoule**." – Sci, 06, Long*

> *"We shared with [the policy team] a **table with different technologies, the corresponding [technology readiness level] and the approximate cost associated with each technology**. We then **ranked the options in order of preference, or at least what my team thinks is best** given the information we have."– Eng, 22, Short*

> *"The **information we got from the science team was straight forward**, they gave us a threshold on that particular question. The **work from the engineering team is a little trickier because it includes costs** and we need to have a wider conversation on the board about that." – 94, Sci-Pol, Medium*

As mentioned earlier, the policy team asked the mitigation stream a question on gas-leakage measurement and the potential environmental impact of those emissions. The mitigation stream's answer was to suggest keeping under a threshold of methane emission per megajoule of energy produced through biomass processing to ensure minimal impact on the environment. The mitigation stream's advice narrative rested on the causal link between methane production from biomass processing, potential atmospheric release of methane and methane's environmental impact as a greenhouse gas. The mitigation stream proposed a threshold based on methane emission measurement but did not suggest how to keep under that threshold; that is the engineers' remit.

Indeed, as we covered above, the policy team asked the engineering team what technological solutions exist to reduce greenhouse gas emissions from biomass production, by preventing gas-leakage and capturing emitted gas. The engineering team produced an assessment of biomass reactors and associated gas-capture technologies which included the performance of the technologies (gas-leakage and removal efficiency), their readiness levels (how soon they would be on the market) and the approximate costs each technology. The different technological options were then ranked by the engineering team based on the three factors above. The engineering team's advice narrative therefore focused on suggesting technological options to achieve a set goal: prevent and capture emissions from biomass reactors.

The biomass policy team noted that, unlike the advice from the mitigation stream, the engineering team's advice had a "trickier" economic component that warranted further discussion. As we noted above and the previous chapter (chapter 4, section 4.4.2), the cost of different technologies is often taken into account by engineers when weighing the evidence gathered and discussing their findings with policy teams. As we saw (ibid.), this can lead to potential clashes with policy officers when both teams' understanding of economic acceptability is not aligned. In the case of the Biomass Strategy, the policy officer quoted above wanted to discuss the strategy budget with the biomass policy board to get a better sense of what is economically acceptable in this space before acting on the engineering team's advice.

Reflecting on the Biomass Strategy and the interview questions, the mitigation stream, policy team and engineering team said the following about the differences between science and engineering advice in this context:

> *"Well, I mean **scientific advice for me relates to** things like climate science, land use science, forestry science. It's **how the earth system works** effectively, the interactions between the terrestrial ecosystem and the climate system. **Engineering to me is the application side of it**. Like **how we implement** things when it comes to **the technologies themselves that will deliver those mitigations**. So, it's very technology specific, **it's about that tech nature.**" – 94, Sci-Pol, Medium*

> *"I think that being a scientist taught me how to ask questions, construct experiments and then decide what conclusions you can and cannot draw. **Science is more of a process or a method, there is less focus on the outcome, in science the answer can be yes or no**" – 06, Sci, Long*

> *"**Engineers have a goal they are trying to reach**, we want a yes answer and until we get it we'll keep chiselling. Engineers are like 'I want to **build a bridge that strong and cheap** and **so what material is** just **strong enough** to be strong enough **and** just **cheap enough** to be cheap enough? I probably I won't get the cheapest and the strongest all in one so I'll have to compromise a bit. **Where is an acceptable compromise point**?'" – 22, Eng, Short*

The biomass policy lead stated that, in their opinion, science advice provided answers to ecosystem questions like how the terrestrial and climate system works. Engineering advice on the other hand was related to how and what technologies can help mitigate climate change. The mitigation stream's lead added that, unlike engineering, science was less focused on outcome, scientists were concerned with explaining situations and testing hypotheses, and hypotheses could be validated or not. As the last quote highlights, engineers on the other hand work towards a goal, and as such will keep compromising until the goal is achieved. This echoes what we have seen in this and the previous chapter, where scientists are asked questions that require explanation and measurement whereas the engineers are asked goal-oriented questions. As a result, scientists advice revolves around scenarios and thresholds based on causal explanations whereas engineering advice focuses on technological options and steps to follow to solve a policy problem. This neatly maps onto the epistemological differences between engineering and science explored in the literature (see literature review chapter, table 2.2) and McCarthy's point about science and engineering advice narratives (literature review section 2.2.5). This is further explored in the discussion chapter.

Table 5.3: Similarities and differences between the mitigation stream and the engineering team for each step of the advice process

Advice process step	Mitigation stream and engineering team similarities	Mitigation stream and engineering team differences
Policy questions and scientific/ engineering input	Both teams are asked for input by policy teams on policy board. Both teams had conversation with policy team to clarify the question asked.	Mitigation stream asked explanation-oriented question: measure possible gas leakage from biomass reactors and associated environmental impacts. Engineering team asked goal-oriented question: what technologies can be deployed to prevent gas leakage and reduce its impact.
Engaging stakeholders and gathering evidence	Both teams engage stakeholders to gather the evidence needed to answer the question asked.	Mitigation stream engaged academia and public bodies to gather information on feedstock types, gas production, emissions, and their impacts. The engineering team engaged industry and academics to gather information on different biomass technologies, market readiness and associated cost. Engineering interfaces with private sector more than mitigation stream because information they need sits with industry.
Combining evidence	Both teams discuss the evidence gathered and answer to initial question with policy team. Both teams have strategies to explain scientific/engineering information to policy officers.	Engineering team deals with costs, which can lead to potential clashes with policy officers when both teams' understanding of economic acceptability is not aligned. Mitigation stream work is not directly linked with costs, therefore clash with policy team is less likely.
Answers and narratives	Both teams answer policy question using simple narratives.	The mitigation stream answer expressed as an emission threshold. Advice narrative rested on the causal link between methane production, potential release of methane and methane's impact. Engineering team produced assessment of technological solutions ranked by performance, market readiness and costs.

5.4 A note on 'proper science'

A final point to note is that the science team does not feel like they are doing 'proper' science.

> *"In this bit of BEIS **we're not doing science** in a sense that the public would generally mean it **– like people in white coats**." – 46, Sci, Long*

> *"So **we don't do science… Actually**, it's not that we don't do science, but most of the time **it's working to define scientific challenges and then finding the appropriate scientists who can deliver** robust research projects to deliver against those **objectives rather than designing those experiments ourselves and conducting them**." – 06, Sci, Long*

> *"**We don't really specialise as most scientists would**, but that's the nature of the civil service too. As I said my background is in geology, but you know, **I touch on all areas of climate science here**." 26, Sci, Long*

The science team does not feel like they are doing science in the way that is commonly understood. As the quotes above suggest, the science team does not design and carry out scientific experiments (wear 'white coats') nor specialise as much as academic scientists would. Instead, because they work in policy, the scientists in the science advice team work at a higher, strategic level, helping define the climate science challenges faced by society and mobilise evidence to help solve them. The means delivering the UK's greenhouse gas inventory, working with policy teams to design, commission and understand scientific research and providing more direct advice on specific projects (like the Biomass Strategy). To cover different areas of climate and energy policy, and by virtue of working in the civil service, the scientists are relatively generalist, at least compared to academic scientists. This means touching on different areas of climate science and developing science communication skills for policy over time. This echoes a similar point made by the engineering team who stated that they do not do 'proper engineering' (see chapter 4, section 4.6).

6 *What are the impacts of the UK government's structure and the civil service culture on engineering advice at BEIS?*

This chapter details the results from the third phase of my research designed to understand the impacts of the UK government's structure and the UK civil service culture on engineering advice at BEIS.

The first section of this chapter presents a timeline of the engineering team's formation and evolution, highlighting how changes in government structure and ministerial vision have shaped the role of engineering advisers at DECC[12] then BEIS. Taking a historical perspective highlights the enablers and barriers to intra-ministerial engineering capacity development at DECC and then BEIS until November 2022 (end of data collection). As mentioned in the methodology (section 3.6), this section rests on interviews with senior civil servants who:

- Were involved in the creation of the engineering team at DECC.
- Oversaw the engineering team when DECC was merged with BIS to form BEIS.
- Still manage the engineering team and its directorate (SICE).

The second section of this chapter explores the impact of the civil service culture, and particularly its "generalist ethos" (see chapter 2, section 2.3.3), on engineering advice at BEIS. The generalist profile and high turnover of policy teams at BEIS can hinder collaboration between engineers and policy officers and creates knowledge retention issues within the ministry. As mentioned in the methodology (section 3.6), this section rests on interviews with senior civil servants who:

- Supervise the engineering team and its directorate.
- Supervise policy teams that collaborate with the engineering team.

[12] DECC was the Department of Energy and Climate Change from 2008 to 2016, after which it was merged with parts of the Department for Business, Innovation and Skills (BIS) to form BEIS. Changes in government structure leading to the creation of BEIS can be seen in figures 6.2 and 6.3.

This is complemented with quotes from engineering advisers and policy officers interviewed in phase 1.

Points raised in this chapter are accompanied by illustrative quotes from my participants along with their anonymised number, role types and time in role based on methodology tables 3.1 and 3.3. I have emphasised key parts of the quotes in bold. Historical points were also cross-referenced with publicly available policy documents, the documents are referenced in-text below and listed in appendix K.

6.1 Impact of government structure and ministerial vision on engineering advice at DECC then BEIS

This section takes a chronological look at the engineering team's formation and development, showing how changes in government structure (also known as machinery of government changes) and ministerial vision have shaped the role of engineering advisers. The section starts with the broader political context preceding the creation of DECC in 2008, then looks at the formation and evolution of the engineering team within DECC and ends with the team's integration into BEIS. Each of the historical events mentioned shed light on what has enabled or hindered the development of intra-ministerial engineering capacity, this is captured in figure 6.1 and detailed in the paragraphs below.

Figure 6.1: Timeline of the engineering team's creation and evolution. The figure shows how each event on the timeline links to an enabler or barrier to intra-ministerial engineering capacity development.

Year:	Event:	Impact on engineering advice :
1980s	Central government delegates infrastructure delivery to agencies and private sector.	Reduces central government engineering capacity.
1990s – 2000s	After mediatized public health scandals the government promises to strengthen its science advice system.	Capitalising on this impetus, the GCSA pushes for investment in specialist skills (includes science *and* engineering).
2008	Creation of DECC to "lead the global effort against climate change".	Fitting with context describe above above, DECC aims to be a scientifically and technically heavy department
2009	DECC's CSA asks for engineering input to achieve department's mission. Creation of engineering advice team.	Creation of engineering team to advise policy teams. Policy teams driving policy process with engineers in support.
2010	Commissioned solar feed-in tariffs model not properly reviewed within DECC. Leads to policy failure.	To avoid similar policy failures, engineering team tasked with being intelligent customer of outsourced research.
2010 – 2015	Increasing amounts of net-zero projects at DECC require engineering input. Leads to engineering team growth	Engineering team advising more policy teams and overseeing more commissioned projects. Justifies investments in team.
2016	DECC and BIS' differing aims lead to policy contradictions over carbon pricing. DECC and BIS merged to form BEIS, to resolve contradictions internally.	
2016	Engineering team moved into BEIS. BEIS' vision less focused on reducing emissions and more focused on supporting business and industry.	Engineering team remit stays the same. However, because vision of department changed, engineers work with policy officers increasingly concerned with cost of decarbonation. Creates tensions between engineering and policy teams
2021-2022	Engineering team at the **time of my research**. Same aim, size and issues as 2016, when it was moved into BEIS	All points above shaped the engineering team as I found it, the advice process it follows, and the issues it faces. This is covered in **chapter 4**.
2023	Dissolution of BEIS. The engineering team moves into the Department for Energy Security and Net Zero	Further machinery of government changes happened after I finished data collection.

6.1.1 1980s-2008: Political context and the creation of DECC

Before focusing on the formation of the engineering team, my participants flagged up the importance of the broader political context that preceded the creation of DECC.

> *"I think it's important to understand that **from the 80s onwards** you had a **movement to outsource infrastructure delivery**, the **central government got rid of a lot of its engineers** and instead delegated infrastructure projects to agencies and private actors. In the short-term that reduced government bills and played into the market-driven ideology of the time. In the **long-run that depleted the government's engineering capacity**." – 62, SCS, Long*

> *"You've got to remember that in the **90s and early 2000s** you had a **series of scandals** like BSE [Bovine Spongiform Encephalopathy] and the Foot-and-mouth epidemic which **generated striking emotional images and public attention**. This created a strong **impetus** to **improve government science advice** systems." – 15, SCS, Long*

> *"Later in the 2000s, **delivering on the government's promise to improve the uptake of scientific evidence**, the **GCSA** [Government Chief Scientific Adviser] of the time, John Beddington, **reinforced the science and engineering community**. He was very keen to work on the recognition of specialist skills and created the GSE (Government Science and Engineering profession)." – 62, SCS, Long*

As the quotes above suggest, by the late 2000s, the political context was quite favourable to strengthening the internal engineering capacity within the central government. Following mediatised public health scandals in the 1990s and early 2000s, the government promised to strengthen its science advice system (POST, 1996; DEFRA, 2002). Capitalising on this impetus, the Government Chief Scientific Adviser pushed for recognition of and investment in specialist skills including additional science and engineering roles across central government (GO-Science, 2013). Although the scandals previously mentioned were considered to be public health and scientific issues, science and engineering were grouped into a single profession within the civil service (Government Science and Engineering profession or GSE), meaning focus on and investments in science benefited engineering capacity as well (ibid). Additional investments in engineering skills and profiles were welcomed by the science and engineering profession, as the central government's engineering capacity had been depleted after infrastructure delivery was left to arms-length bodies and the private sector since the 1980s. This point is well documented in the academic literature (see literature review, section 2.2.4) and government reviews of the civil service science and engineering profession (GO-Science, 2013).

In 2008, within the context just described, DECC was created.

> *"**DECC** was originally Secretary of State (for Energy and Climate Change) Ed Miliband's idea. It was a **Labour initiative** and **then operated under a coalition government with a Lib Dem** head of state. Its original **mission** was to **reduce emissions**, **decarbonise the energy system** and **establish the UK as a leader in the fight against climate change**." – 70, SCS, Long*

> *"DECC was **set-up to be a scientifically and technically literate ministry**. When it was created it **took climate scientists from DEFRA** [Department for the Environment, Food and Rural Affairs] and **teams from BERR** [Department for Business, Enterprise and Regulatory Reform] **interested in energy efficiency**." – 43, SCS, Long.*

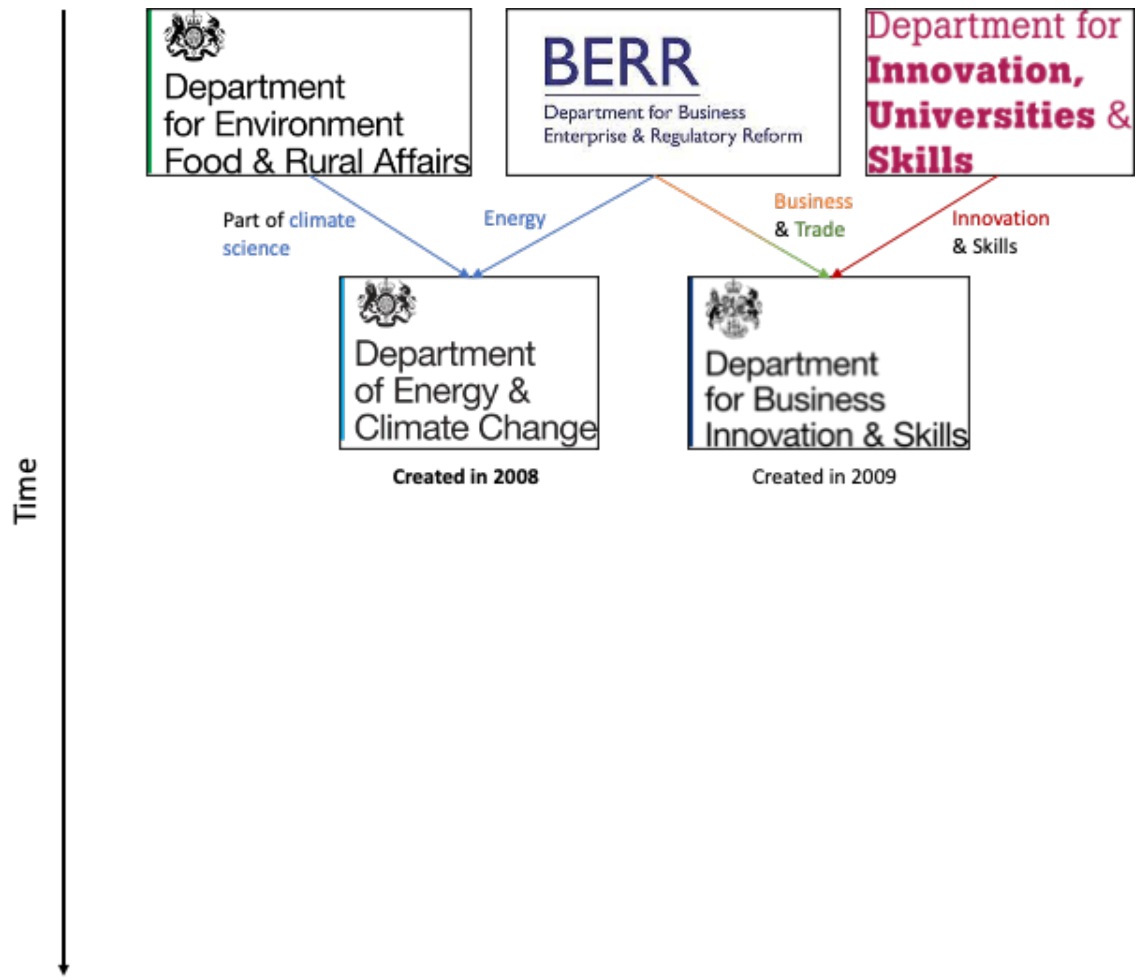
> *"A **year later BERR was merged with DIUS** [Department for Innovation, Universities and Skills] **to form BIS** [Department for Business, Innovation and Skills] by the way." – 43, SCS, Long.*

> *"Moira Wallace, who was appointed as DECC's permanent secretary insisted **to appoint the late David MacKay as DECC's CSA** [Chief Scientific Adviser]" – 62, SCS, Long*

DECC was formed under a Labour government and, as evidenced in the quote above and in its first annual report, it was set up to lead the "global effort against climate change", "reduce greenhouse gas emissions", and "ensure the supply of clean energy" (DECC, 2009). Fitting well within the political context described above, DECC aimed to be a scientifically and technically heavy department, taking over part of climate science from DEFRA and the energy efficiency policy portfolio from BERR (ibid). A year after DECC was created, BERR merged with DIUS to form BIS, the machinery of government changes leading to the creation of DECC are illustrated in figure 6.2 below. In 2009, DECC's permanent secretary appointed David MacKay as CSA, a Cambridge University physics professor who had just published a successful book on sustainable energy (DECC, 2010).

Please note that the fact that DECC was a Labour initiative and a relatively scientific and technical department without an explicitly economics-driven mission played a part in the 2016 machinery of government change that saw DECC merged with BIS to become BEIS. This change and its impact on the engineering team are explored in section 6.1.4 below.

Figure 6.2: Machinery of government changes leading to the creation of DECC



6.1.2 2009-2010: Formation and aim of the engineering team within DECC

One of David MacKay's first act as DECC CSA was to ask for more engineering input and capacity, establishing what would later evolve into BEIS' engineering advice team.

*"When David [MacKay] came in **he was adamant that DECC's vision could not be achieved without hiring more engineers** to support him. I remember he **was worried about the lack of engineers he initially met** at DECC." – 70, SCS, Long*

*"**David MacKay was a physicist** and **wanted more engineering input**. He **recruited Paul Hollinshead, an engineer**, who manage to **wrangle some budget** to get David [MacKay] more engineers." – 15, SCS, Long*

*"So Paul [Hollinshead] **built up a team of 5 engineers**, to support David. They were all recruited individually with selection tests outside of the standards of the civil service. You need to understand **how unusual it is for a CSA to be allocated a team and a budget**!" - 62, SCS, Long*

As a reminder, DECC's mission was to reduce the UK's greenhouse gas emissions, decarbonise the UK's energy system and establish the UK as a leader of the fight against climate change. David MacKay, who was a physicist and not an engineering by training, argued that in addition to scientific capability the ministry needed engineering capacity to deliver on its mission. Again, as noted in section 6.1.1, this happened in a political context where central government engineering capacity had been gradually depleted since the 1980s and where there was a general push to bring back some science and engineering skills in-house. Given the political context and department's mission, David MacKay was able to recruit an engineer, Paul Hollinshead, to provide him with engineering input level his role as DECC's CSA. David MacKay and Paul Hollinshead then worked together to hire five more engineers, supervised by Paul Hollinshead, to help DECC deal with engineering issues linked to decarbonisation and climate change.

Paul Hollinshead and the five engineers he recruited made up DECC's original engineering team, who's main aim was to advise policy teams within the department on engineering related issues.

*"Back in the day, [the ministry's] vision was to 'make the world green' and given the technical nature of the issue, they formed a **small team of engineers to advise the ministers on what's sensible and what isn't.** It was a **team to support the policy work, so what they did was driven by the policy teams, it is not driven by the engineers**." – 62, SCS, Long*

> *"We were involved quite down the policy chain if you see what I mean, we were* ***helping policy teams answer questions but not helping them with defining the question in the first place****. We did what we were told to do but not so much saying what should be done in the first place." – 15, SCS, Long*

> *"I would say that's* ***still true today****, and sometimes it's* ***a bit frustrating****. We're* ***helping policy teams figure out how to make the policy work but not really involved in policy direction setting****. I think it* ***constrains our options down the line*** *too you know." – 3, SCS, Long*

From the start, the engineering team's aim was to help policy teams within the ministry answer the engineering related questions they had in the context of the policy project they were working on (DECC, 2010). This created a dynamic where policy teams were driving the policy process with the engineers in support. The engineering team were not involved in setting the vision for the policy projects, which created a sense of frustration as engineers felt the engineering options to solve the issue at hand were limited by a policy direction they did not have a say in. As explored in chapter 4 and mentioned in the quote above, the engineering team's aim and set-up is still the same today, and engineering advisers still express some frustration at their limited influence on policy vision and direction setting.

The role of the engineering team also evolved in response to policy failure.

> *"The development of engineering team corresponded with a* ***solar feed-in tariffs policy issue****. The* ***model*** *that was being used to calibrate the spend on tariffs* ***had*** *a technical mistake in it, it had* ***wrong assumptions about the amount of solar projects across the country****. This was a* ***model that was commissioned and not properly [quality assured]****. The was a lot of* ***political fallout*** *from this issue and* ***DECC ended up with*** *high unforeseen liability in terms of the* ***money it had to pay over feed-in tariffs****." – 70, SCS, Long*

> *"It was a technical mistake in modelling which led to a review of business-critical models.* ***Anyone who had any real-world experience*** *in building solar PV projects, when they looked at the modelling,* ***knew it couldn't be right. But at the time we didn't have enough of those in the department****… So, the* ***aim of the engineering team*** *also* ***became making sure*** *that* ***this didn't happen again****." – 15, SCS, Long*

*"In the original days of DECC, **commissioning was not always done correctly**, and this wasn't just an engineering problem but a process problem. I remember a time when David [McKay] refused to use a commissioned piece of work because it wasn't rigorous. Anyway, **one of the roles of** the newly formed **engineering team** was to **act as an intelligent customer** and help with the commissioning process.' – 62, SCS, Long*

Starting in 2010, DECC ran into issues with its solar feed-in tariffs policy (DECC, 2011, 2012). The model that underpinned the policy, which had been commissioned, underestimated the potential number of commercial and residential solar panel installations across the UK. The mistakes in the model were not picked up within DECC, which, as the quotes suggest, did not have enough engineering capacity or clear quality assurance processes for commissioned business-critical work at the time. This led to DECC initially over-subsidising solar energy, then cutting down the subsidies, and having to settle disputes with businesses and resident associations who invested in solar energy based on the initial feed-in tariffs (Vaughan, Harvey and Gersmann, 2011; DECC, 2012; Vaughan, 2012). In reaction to this policy failure, one of the roles of the engineering team became to act as an intelligent customer of commissioned research, helping policy teams frame and review outsourced technical work. This is still one of the roles of the engineering team today, as explored in chapter 4, section 4.2.

6.1.3 2010-2015: Engineering team growth

From 2010 to 2015, policy needs at DECC drove the expansion of the engineering team.

*"The **more the engineering team worked with** the **policy teams** the **more gaps** were **uncovered**, the **easier** it became **to justify investment in** the **engineering team**." – 15, SCS, Long*

*"The **engineering team doubled its headcount** during that time. As I mentioned you had limited engineering capacity across the department at first, so **to deal with an increasing number of technical decarbonisation policies and more commissioned research** they hired more engineers." – 62, SCS, Long*

> *"**Go-Science** was also **pushing for more science and engineering representation within government departments** at that time, so **DECC got** Graig [Lucas], their **Head of Engineering**." – 43, SCS, Long*

As the quotes above suggest, from 2010 to 2015, in line with its mission, DECC oversaw an increasing amount of net-zero policy projects that required engineering input (DECC, 2015). This meant that the engineering team was advising an increasing number of policy teams and helping with a higher number of commissioned engineering research projects (ibid). This also created a feedback loop where the more the policy teams worked with the engineering team, the more policy teams realised that they needed engineering advice. All this combined made it easy for the CSA to justify investing in the engineering team which went from 5 to 10 staff members during that time. As pointed out in section 6.1.1, this also corresponded with the Government Office for Science's (GO-Science) efforts to increase in-house science and engineering capacity within government departments. This enabled DECC to appoint an additional engineer, Craig Lucas, as Head of Engineering to work under Paul Hollinshead and oversee the engineering team.

6.1.4 2016: Engineering team and the creation of BEIS

In 2016, after the Brexit referendum and Theresa May's appointment as Prime Minister, the Conservative government in power decided on a machinery of government change. This included the merging of DECC and parts of BIS to create BEIS which had a direct impact on the engineering team.

> *"One of **DECC**'s main aim was to reduce emissions, that included **putting carbon prices up to force industry to decarbonise**, right? But at the same time you had **BIS**, who's mission was to **support industry growth**, who was **issuing more carbon price subsidies to offset the increase in carbon prices**. [BIS] needed to make sure energy intensive industries in the UK were still economically competitive." – 15, SCS, Long*

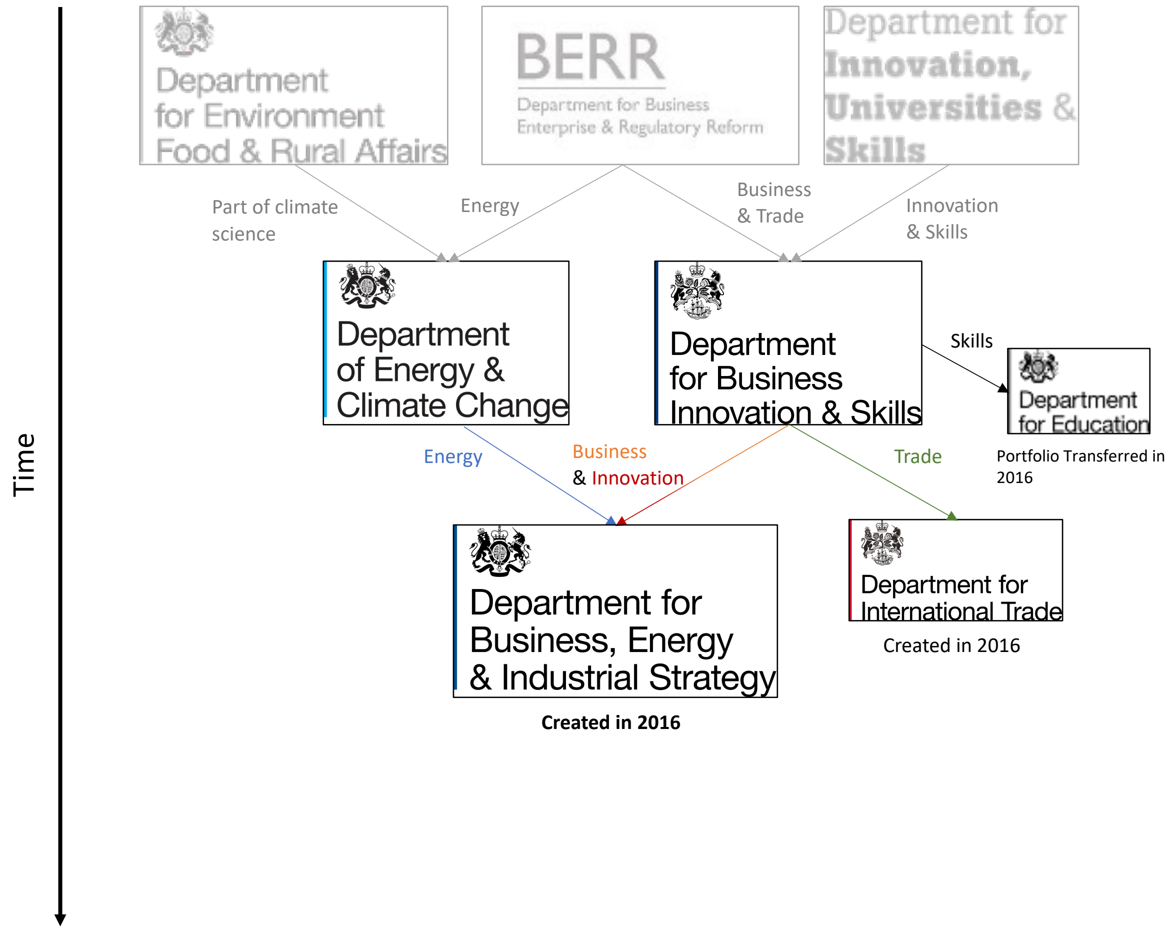
> *"**The vision and mission of DECC and BIS were very different and they got in each other's way**. So to try and **resolve this internally**, the PM [Prime Minister] office thought 'OK, let's **merge the two** and let them sort this mess out'. They gave BIS' skills portfolio to the Department of Education, took the*

trade portfolio to create the Department for International Trade, and fused the rest with DECC to create BEIS." – 70, SCS, Long

*"You have to remember that **DECC was a Labour initiative**, very **scientific and engineering heavy**, focused on **making** the **UK** a **climate change fight champion**. Whereas **BIS** was very **microeconomics heavy**, **focused** on **promoting business** and competitive advantage. In a way **BIS was a lot more aligned with the Conservative government's line** on new energy and climate technology, which was 'how can we use this for the UK's economic advantage'. So **when BEIS was formed, DECC and BIS** were **bolted together**, and **BIS vision came out on top** because it match the government's line." – 80, SCS, Long*

The 2016 machinery of government change included, as per the second quote above, moving BIS' skills policy portfolio to the Department of Education, using BIS's trade policy portfolio as the core for the newly created Department for International Trade and merging the rest of BIS with DECC to form BEIS. The government structure changes leading up to the creation of BEIS are illustrated in figure 6.3 below and listed in BEIS first annual report (BEIS, 2017).

Figure 6.3: Machinery of government changes leading to the creation of BEIS



One of the main reasons behind the merging of DECC and BIS was to resolve ongoing tensions generated by the competing aims of the two departments. As explored in section 6.1.1, DECC was a science and engineering heavy department established under a Labour government whose aim was to decarbonise the energy system and reduce national greenhouse gas emissions. This put the department at odds with BIS, a more economics focus ministry tasked with "supporting businesses […] and developing solutions that help industry […] and encourage innovation – both in products and skills" (BIS, 2016). These tensions manifested themselves around carbon prices for instance, with DECC increasing the prices to encourage decarbonation of industry and BIS simultaneously subsidising them to promote industry growth (DECC, 2015; BIS, 2016). By merging DECC and BIS into BEIS, a single entity, the government of the time hoped issues between DECC and BIS would be solved internally, avoiding public fallouts.

As the third quote above suggests, the Conservative government's policy vision on climate change was reflected in BEIS' mission statement. BEIS's aim was to "align economic and environmental objectives […] working with industry to show that investment in clean energy are investments in […] growth" (BEIS, 2017). BEIS was an economics-focused department, whose mission was to leverage investments in clean energy to create jobs, promote industry innovation and improve the UK's competitive advantage on the international scene. As we saw in the paragraph above, BEIS mission was therefore much closer to BIS mission statement than DECC's.

This had a direct impact on the engineering team.

> *"We [**the engineering team**] were **moved into BEIS** as we were, our **aim didn't change either.** The climate science team moved as well, we were grouped in the same directorate." – 5, SCS, Long*

> *"We **were still advising policy teams** within the department, but the **focus had shifted from decarbonising at all costs to protecting businesses and promoting growth.** It was a department vision thing. But it was really frustrating for us because it **marked a departure from DECC**, and we now had to deal with **policy teams over-concerned with costs and industry's response**. I'm sure you'll come across that still now." – 15, SCS, Long*

> *"I **wish we could have been involved in meetings where they set the vision for the department** or at least vision for the policies. We should have been able to make the case that reducing emissions is just as important as 'growth, growth, growth'!" – 70, SCS, Long*

The entirety of DECC's engineering team was moved into BEIS, alongside DECC's science advice team, forming what would later become the Science and Innovation for Climate and Energy directorate (SICE). As the quotes above suggest, the remit of the engineering team stayed the same but, because the overall vision of BEIS was less about reducing emissions (i.e. DECC's vision) and more focused on business and economic growth, the engineering team had to work with policy teams increasingly concerned with the cost of decarbonation to industry and consumers. This increased tensions between the engineering and the policy teams whose understanding of economic and political acceptability differed, tensions that can still be felt today (see chapter 4, section 4.4.2). Building on this, the engineers expressed frustration at not being able to influence BEIS' overall vision to make reducing emissions as core to the department's strategy as it was in DECC.

6.1.5 2016-2023: The engineering team at the time of my research and further machinery of government changes

When I started data collection in January 2021, the aim and remit of the engineering team was the same as it was in DECC and then BEIS (see chapter 4). The engineering team's role was to advise policy teams within the department on engineering related issues and act as an intelligent customer of commissioned engineering research. As was already the case at DECC, the policy teams were still driving the policy process with engineers in support, resulting in engineering advisers expressing frustration at their limited influence on policy direction setting (see section 6.1.2). The size of the engineering team was also the same as it was when the team was moved into BEIS, with 10 engineers overseen by a Deputy Director of Engineering and Research (previously "Head of Engineering"). In 2021, the mission of BEIS had not changed compared to 2016 either, with the department still focused on "driving growth, productivity and job creation across the UK […] putting the interests of consumers and businesses at the heat of everything [BEIS] does" (BEIS, 2022). As mentioned in section 6.1.4 above, this still generate tensions between engineering and the policy teams whose understanding of economic and political acceptability differed.

In February 2023, the government decided on another machinery of government change which saw the dissolution of BEIS and the creation of three new departments. Although these changes happened after the end of my data collection, meaning I have limited insight into their impact on the engineering team, it felt important to mention them here. The 2023 machinery of government changes, illustrated in figure 6.4 below, included the separation of BEIS policy portfolio into three:

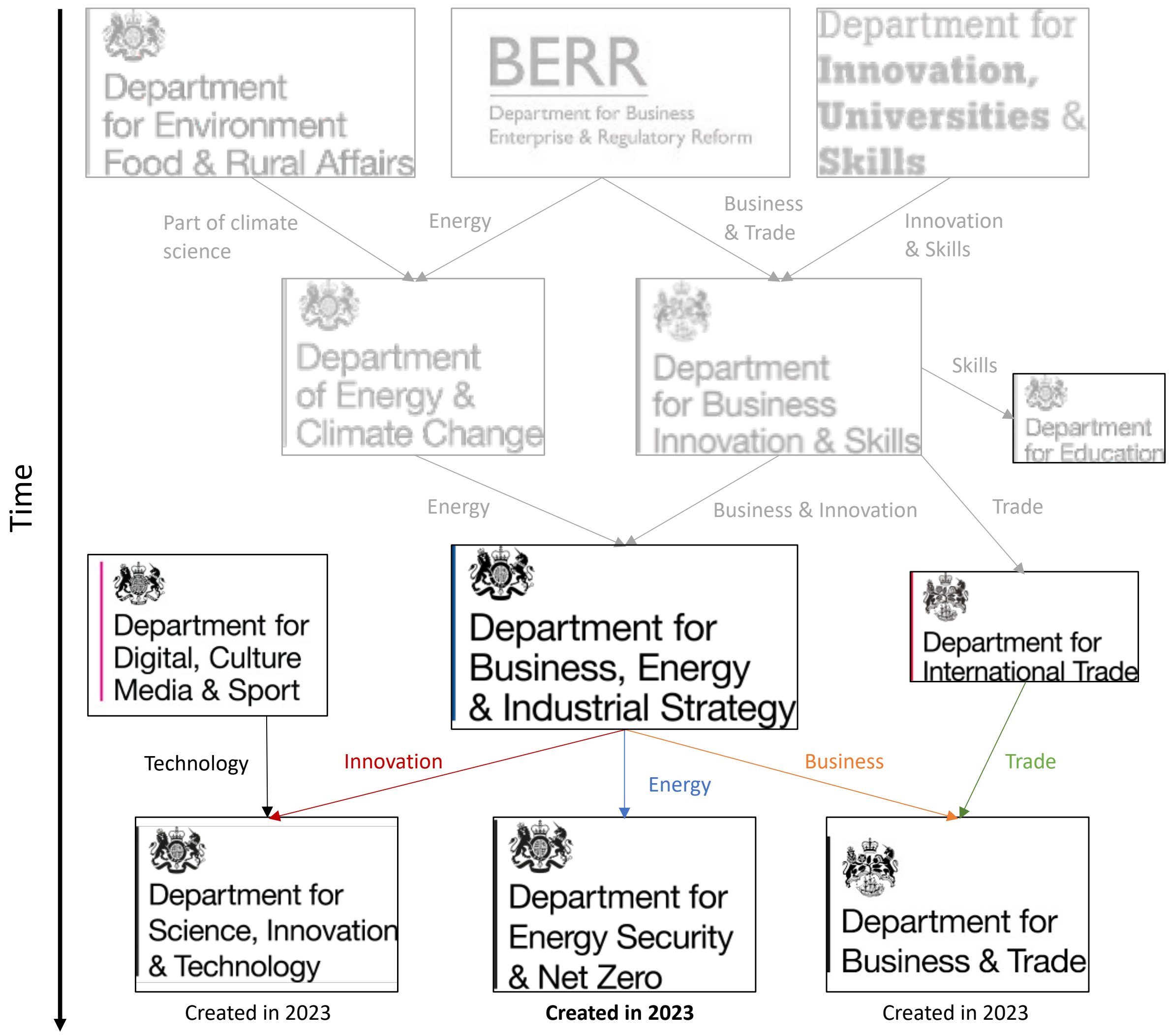
- The innovation portfolio served as the basis for the newly formed Department for Science, Technology, and Innovation (DSIT) which also took over some of the technology policy responsibilities from the Department for Digital, Culture, Media and Sport (DCMS).

- The energy portfolio was moved to the newly created Department for Energy Security and Net Zero (DSNZ).
- And the business portfolio was folded into the Department of International Trade to create the Department for Business and Trade (DBT).

The SICE directorate, including the engineering and climate science advice teams, was transferred to DESNZ who mission is "securing [the UK's] long-term energy supply, bringing down bills and halving inflation"[13]. As explored in the following discussion and conclusion chapters, it will be interesting to see how insights generated in this thesis apply to the new government structure and what can be learned ahead of future machinery of government changes.

[13] https://www.gov.uk/government/organisations/department-for-energy-security-and-net-zero, retrieved 31st January 2024

Figure 6.4: Machinery of government changes leading to the creation of DESNZ



6.2 *Impact of the civil service culture on engineering advice at BEIS*

The second section of this chapter explores the impact of the civil service culture, and particularly its "generalist ethos", on engineering advice at BEIS. As explained in the literature review (chapter 2, section 2.3.3), the civil service rewards exposure and experience of different policy areas, meaning policy officers move across teams and departments to further their career. Policy officers in the civil service are therefore encouraged to be "generalists", to learn how policy processes and procedures work rather than develop topical knowledge of a specific policy area.

As detailed below, this is the case at BEIS where turnover in policy teams is high. Engineers in the engineering advice team, on the other hand, do not move around as frequently as their policy counterparts. The difference in turnover speed between the engineering and policy teams hinders collaboration as incoming policy officers lack some of the knowledge their predecessors built overtime and have to rebuild a working relationship with the engineers. By virtue of staying in their role for longer, engineers can also become knowledge holders in their policy area, creating additional friction in the engineer-policy officer collaboration process.

Despite engineers staying in their role for longer than policy officers, the turnover in the engineering team is still around four years. The churn rate in both engineering and policy teams leads to knowledge retention issues in the department, exacerbated by the reliance on external consultants and commissioned research on many policy projects. This can lead to a lack of policy continuity and becomes an issue when it comes to long-term challenges like climate change.

How the civil service culture manifests itself at BEIS and its impact on engineering advice is captured in table 6.1 and detailed in the paragraphs below.

Table 6.1: How the civil service culture manifests itself at BEIS and impact on engineering advice

Civil service culture (chapter 2, section 2.3.3)	**How it manifests at BEIS (sections 6.2.1)**	**Impact on engineering advice (section 6.2.2 and 6.2.3)**
Civil service rewards exposure different policy areas, therefore policy officers move around to get promoted.	Policy officers I interviewed were in their role for an average of 18 months.	The high turnover in policy teams hinders engineering adviser and policy officer collaboration. Incoming policy officers lack some of the knowledge their predecessors built overtime. This includes the engineering knowledge underpinning the policy area and the “common language” developed by their predecessor and thee engineering adviser they worked with.
In order to switch teams and departments to gain exposure to different policy areas, policy officers develop a generalist skillset.	At BEIS policy officers focus on developing generalist skills like being quick-learners and communicating with different audiences. Policy officers are not expected to know about the policy area before they move into their new role, including engineering issues in that policy space.	
Complicated to recruit engineering specialists in the civil service because of the skills needed and salary differences between the public sector and industry.	This is true at BEIS and incentivises the department to keep engineering advisers in the engineering advice team. As a result, the engineering advisers I interviewed were in their role for an average of 4 years and 3 months.	The difference in turnover speed between the engineering team and the policy teams results in engineering advisers sometimes becoming knowledge holders in their policy area. This makes it harder for policy officers to push back against the engineers and grips the collaboration process. Despite engineers staying in the role for longer than policy officers, overall turnover at BEIS remains high. This creates knowledge retention issues for the department.

6.2.1 Policy officers and engineering advisers' turnover at BEIS

The "generalist ethos" of the civil service leads to a high turnover in policy teams at BEIS.

> *"[**Policy officers**] will **stay in their role for** what, a **year maybe two**. There's a **cultural thing** that if you come into a **policy profession**, you **need to move around** to get as broad experience as possible and **become a better generalist**, that's what **gets you promoted**." – 9, SCS, Long*

> *"If you want **to progress you have to change teams**. There is a big **emphasis** in government on working **on** different policy topics, so you need to switch teams to **get exposure to different [policy] areas**. Policy **priorities change quickly** too **so** it's **not hard to find a new team** to move to, or a team that's expanding." – 29, Pol, Medium*

> *"Policy people will try to **move to get a promotion**, so they'll move to a role at a **higher salary band or grade**. It's usually much **faster than** waiting to get **promoted in** the **team** they're **currently** in." – 5, SCS, Long*

According to the first quote above, policy officers at BEIS rarely stay in their role more than two years. This is in line with my limited sample of 10 BEIS policy officers who had been in their role for an average of 18 months and maps on to Page and Jenkins' sample of 140 policy officers who stayed in their role on average 17 months (chapter 2, section 2.3.3). Reasons given for this frequent change of teams are the same as the one listed in the literature review (ibid). The civil service rewards exposure to and experience of different policy areas, therefore policy officers move around to get promoted. Given policy priorities change, policy projects close and new ones start, policy officers can easily find policy roles in different teams and departments. As the quotes above suggest, policy officers generally try to move to a more senior role in another team or do a lateral move to gain experience in another policy area (and then get promoted).

In order to switch teams and departments to gain exposure to different policy areas, policy officers at BEIS develop a generalist skillset.

> *"Well, if you're in a policy role you're going to have* ***to move around*** *to climb the civil service ladder. So,* ***you're better off understanding how policy making works*** *in general* ***rather than*** *invest too much energy in understanding* ***a narrow policy area****." – 9, SCS, Long*

> *"****I don't*** *feel like I* ***have to know too much*** *about the policy area I'm going into* ***before I've moved*** *into the new role. It's* ***more important*** *for me* ***to*** *be able to* ***learn quickly on the job*** *and* ***understand*** *how to balance the* ***interests of*** *the different policy* ***actors in that space****." – 69, Pol, Short*

> *"Basically, your* ***job as a policy [officer]*** *is to know how to* ***create a convincing policy proposal****,* ***what the process is*** *and how to engage with different stakeholders in your area. It's an asset to have knowledge of your policy area beforehand but it's not a requirement. What you* ***need to be good at*** *though is learning on the job,* ***understanding what's expected of you and communicating*** *with various policy and business people." – 55, Pol, Med*

As the first quote suggests, policy officers know they have to change teams to get promoted and therefore have little incentive and time to develop deep knowledge about their policy area. Instead, policy officers develop "generalist" knowledge like how to navigate the policy making process, which they can rely on regardless of the policy area they work in. Echoing points raised in chapters 4 and 5, policy officers do not necessarily need knowledge of the policy area before they move into a new role, although it is seen as an asset if that is the case. Prior knowledge of a policy area, in the case of BEIS, can mean knowledge of the engineering and scientific issues underpinning a certain policy topic. Policy officers, however, need to be quick learners. Once on the job, they need to pick up on ministerial preferences and understand how to communicate with stakeholders in their policy area. As the third quote suggests, through their career, policy officers also develop knowledge of how to create convincing policy proposals. Again, the points above echo findings in chapters 4 and 5 and section 2.3.3 of the literature review.

By contrast, the turnover is slower in the engineering team.

> *"The* ***turnover*** *in* ***policy*** *teams is probably about* ***18 months****. The turnover* ***in [the engineering team]*** *is probably more like* ***4 years****." – 3, SCS, Long*

*"It can be **hard to find the right people**, they need to be **engineers**, know **about energy**, **but** also be **flexible** enough to adapt to many different policy projects. **And we can't pay them as well as industry** or consulting… of course."* – 15, SCS, Long

*"That's the thing with **specialist positions like engineering**, **we don't have many in the department**, and there is **a lot of work for them to do**. So usually, it's not too complicated to **promote them** at least **once to keep them in the team**."* – 5, SCS, Long

*"The thing about bringing technical people in is you're bringing them in because of their expertise. **There isn't lots of other places in the civil service for [the engineers] to go**, there's not multiple versions of [the energy engineering advice team]. **So they do tend to stay longer.**"* – 5, SCS, Long

As the first quote and my sample average suggests, engineers in the engineering team stay in their role on average around four years (four years and three months in the case of my sample). As the three following quotes show, this can be explained by different reasons. First, it can be complicated to recruit for specialist positions like engineering advisers because of the specific skills needed (see chapter 4, section 4.6) and because early-career engineers earn more in industry than in the civil service. It therefore makes sense to keep engineering advisers in the engineering team for as long as possible after they are hired. Additionally, given the small size of the team and the need for engineering advice across BEIS, engineering advisers contribute to many policy projects. As a result, the Director of SICE can easily make the case for their promotion. Finally, there are only few engineering adviser roles across the civil service for the engineering advisers to be promoted into. Unlike policy officers, engineering advisers therefore have less of an incentive to change teams to further their career.

With this said, there is still turnover in the engineering team.

*"We have **people come and go**. Members of the team tend to **leave for industry or delivery agents**, like National Grid. Most don't **stay in government**"* – 32, Eng, Long

*"Engineers leave for a **variety of reasons**, better **pay**, more **responsibility**, more attractive projects." – 5, SCS, Long*

*"Some engineers also move out [of the civil service] because **policy work, if you come from a technical background, is not always enjoyable**. Maybe you just **want to be a true specialist** you know, do something more focused like contribute to building something. The **high-level nature of policy work can be frustrating** for engineers." – 70, SCS, Long*

As my participants above suggest, engineers leave the engineering team for different reasons including better pay or more responsibility. Generally, engineers leave the civil service for the private sector including companies that were previously state-owned like National Grid. As the last quote suggests, some engineering advisers also leave because they do not find the high-level nature of engineering for policy work enjoyable. This maps on to points raised in chapter 4, section 4.6, where engineering advisers describe themselves as 'generalist engineers' as they have to switch between different areas of engineering depending on policy needs. This can be frustrating to some of the engineering advisers who prefer a more specialised, design-oriented job which, in many cases, align more with their education than an engineering adviser for policy role (again see chapter 4, section 4.6).

6.2.2 Impact on the collaboration between policy officers and engineering advisers

As established in section 6.2.1, turnover is high in BEIS' policy teams. This hinders engineering adviser and policy officer collaboration as incoming policy officers lack some of the knowledge their predecessors built overtime and have to rebuild a working relationship with the engineers.

*"One of the main **problems with the policy team churn** is that you constantly have **policy people** who work with us [engineering team], **pick up on some of the technical fundamentals** in the policy area, and **then leave**. And then they're replaced by someone who has to pick up on the engineering basics again." – 3, SCS, Long*

*"Every time a **new [policy officer] comes in, we need to work out how to communicate. It takes a bit of time** to learn their preferences and for me to communicate mine." – 85, Eng, Medium*

> *"It **took some time to build a relationship with [the engineering advice]** team, like what can they help with, how can we work together, when do they my input, **how can I use the evidence they provide** and so on…" – 29, Pol, Medium*

As explained in chapter 4 and section 6.2.1 above, policy officers often do not have an engineering background nor are they expected to know the engineering issues underpinning a policy area before they start their role at BEIS. Overtime policy officers pick up on some engineering knowledge by working with the engineering team, facilitating collaboration on energy policy projects. When a policy officer leaves and is replaced however, the cycle starts again, and newly appointed policy officer have to learn the engineering knowledge underpinning the policy area again. This slows down engineer-policy officer collaboration and, in-turn, policymaking.

As the quotes above state, the same logic applies to the communication preferences of both the policy officers and engineering advisers. Indeed, as detailed in chapter 4, section 4.4.3, engineers can struggle to communicate technical information to policy officers without an engineering background. Overtime, engineers and policy officers work out strategies to overcome their communication issues, often developing a "common language" to discuss the evidence they collected and weighed. By enabling better communication, this common language generates mutual trust and facilitates further collaboration (see chapter 4, section 4.4.3). However, every time a policy officer is replaced, the engineer and new policy officer have to rebuild a working relationship, including redeveloping their own common language and mutual trust. Again, this hinders engineer-policy officer collaboration and slows down the policymaking process.

As we noted in section 6.2.1, policy officers stay in their role for a year and a half on average whereas engineers tend to stay in their team for four years. This difference in turnover speed between the policy teams and engineering advice team affects the power dynamics between the engineers and policy officers and their ability to collaborate.

> *"Usually [the **engineering advisers**] have **been in place for longer** so they **bring the new policy officers up to speed**. That's **not just on the***

***engineering side** of things, **but** also on **what happened with** the **policies in that area before**." – 3, SCS, Long*

*"If [the **engineer**] constantly has someone in my policy role that hasn't been there for more than 18 months [they're] the one **keeping it together**. [**They've] got the institutional knowledge of what the thought processes were when designing the original policy**. It also means from a policy perspective that its **more complicated to disagree because they know a lot more**, and that can **lead to some tensions**." – 67, Pol, Short*

Because the engineers have been in their role longer than the policy officers they work with, they sometimes know more about the history of the policies in that area than their policy counterparts. This includes the engineering issues underpinning the policy area as we discussed above but also why and how some of the previous and ongoing energy policy projects came to be. This can be explicit or tacit knowledge of the initial problem the policy was trying to solve and the involvement and view of internal and external stakeholders on the policy. As a result, engineering advisers can become knowledge holders in their policy area and end up telling policy officers about the history and stakeholders' views on the policy they are working on. As the last quote suggests, this information asymmetry can lead to some tension as the policy officers feel they know less than the engineers and struggle to push back against the engineers' recommendations they might not agree with. The difference in turnover speed between the engineering and policy teams can therefore tilt the balance of power too much towards the engineers, leading to friction in the engineer-policy officer collaboration process.

6.2.3 Impact on knowledge retention

Despite staying in their role longer than the policy officers, engineering advisers often leave the civil service after four years (see section 6.2.1). Combined with the high turnover of policy officers at BEIS, this creates knowledge retention issues for the department.

*"Staff **churn is a real issue for the department**, with staff leaving, **corporate memory leaves** with them. And **new staff don't** always **know the history of the department and policies** they work on." – 5, SCS, Long*

> *"Turnover is a problem everywhere in the civil service, but I think it's worrying at BEIS because* ***if your people keep on leaving, how are you supposed to have climate change policy continuity?****" – 80, SCS, Long*

> *"If you ask me,* ***reliance on commissioned research is a big problem when it comes to knowledge retention****. Only the* ***consultants really know how the work is done****, well* ***maybe some of the engineers*** *who worked on the project* ***but what happens when they leave****…" – 9, SCS, Long*

As the quotes above suggest, overall staff turnover at BEIS is a challenge for institutional memory retention. Indeed, incoming staff in the department might not have the knowledge of BEIS' structure and history accrued by their predecessors over time. New staff might also lack insight into the background and previous work done on the policy projects they will be responsible for. As result they might change the original or intended direction of certain policy projects reducing policy continuity in that policy space.

Knowledge retention is further challenged by BEIS' (and the civil service more generally) reliance on outsourcing. As detailed in chapter 4, section 4.2, engineering research is often commissioned, with the engineering team acting as an intermediary between the consultants and the policy teams. As the third quote above suggests, this creates a situation where the consultants are the only ones who really know how the research was done although the engineers have an overview of the project. This is an issue for knowledge retention as no one within BEIS, even the engineering team, has a full view of how the work is carried out. However, this is made worse once the engineer who supervised the commissioned project leaves the department, as BEIS is left with very little knowledge about how the outsourced work was done.

To deal with knowledge retention issues, senior civil servants, policy officers and engineers at BEIS deploy different strategies.

> *"Sometimes we go to* ***"grey beards", the people who have been here for a while. But this is not a sustainable*** *strategy as they might end-up leaving too." – 9, SCS, Long*

> *"We try to **put all the research reports we produce on the government website**. As you know though, this is **only for publicly available final reports**, not for all the research and documents we produce along the way."*
> *- 3, SCS, Long*

> *"**Having big enough teams helps**. If a few people come and go at the same time the rest of the team can bring the new recruit up to speed and so on. **But, I mean, that's not really enough**." – 5, SCS, Long*

One of the strategies mentioned by my participants was asking "grey beards", civil servants who have been in the department for a long time, for their insights[14]. However, as the first quote shows, civil servants are aware that this is not a very sustainable strategy as experienced civil servants will eventually leave the department along with their institutional memory. The engineering team also mentioned putting the reports the team produces on the government website. This makes it easier for incoming engineering advisers and policy officers to find and refer to the engineering team's work done in their policy area. As the second quote points out, this only applies to publicly available documents and does not include the institutional knowledge contained in the drafts, memos and conversations that led to the final report. Finally, the last strategy mentioned was having large enough teams so that, at any given point, part of the team would share their corporate and policy knowledge with incoming staff. However, this might not always be possible due to project size, staffing constraints and budget restrictions in the civil service. Overall, despite the strategies motioned above, my participants noted that turnover and knowledge retention remained a problem at BEIS.

[14] Please note that the term "grey beards" is one used by my participant and might implicitly reflect the fact that the engineering-policy space has been, at least until now, relatively male-dominated. I have used the more inclusive term "experienced civil servant" in the rest of this thesis.

7 Discussion

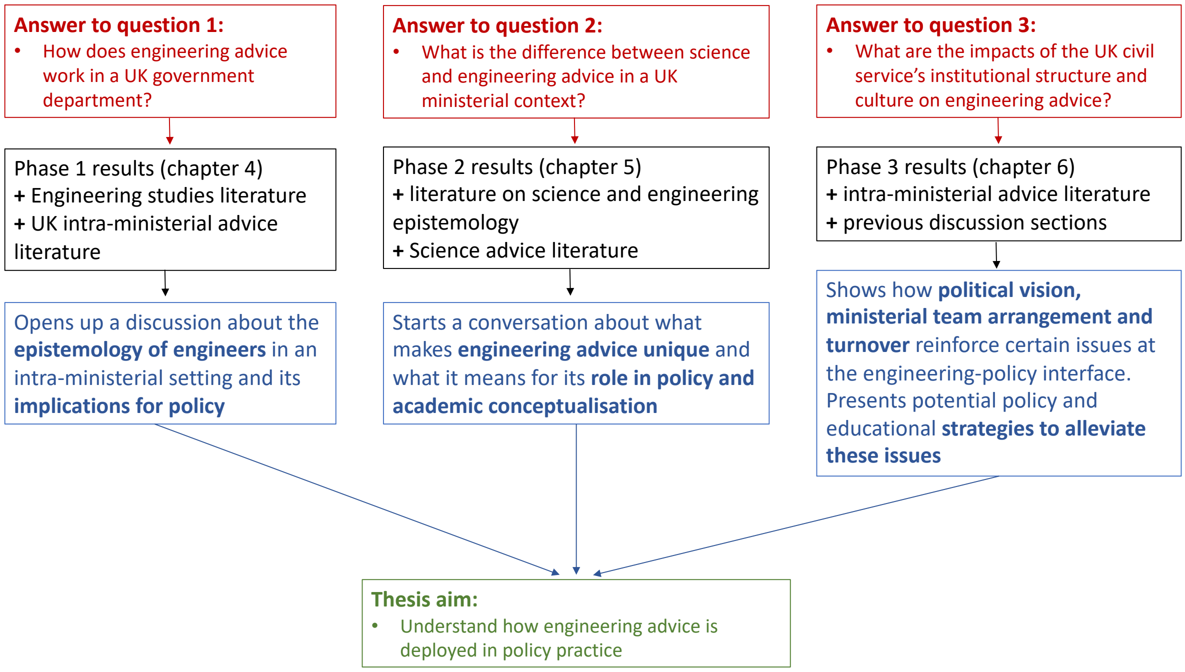
Now that I have detailed the results of my three research phases, this chapter creates a dialogue between my empirical findings and concepts introduced in the literature review. This chapter is organised around my three research questions and answers each of them in-turn to improve how engineering advice deployment is understood academically and in policy (see figure 7.1).

The first two sections answer my first research question: how does engineering advice work in a UK government department? These sections use the different themes from my first results chapter (chapter 4) to nuance and add to two bodies of literature: engineering studies and UK intra-ministerial advice literature. This opens up a discussion about the epistemology of engineers in an intra-ministerial setting and its implications for policy.

The next two sections answer my second research question: what is the difference between science and engineering advice in a UK intra-ministerial context? These sections link the results presented in chapter 5, literature on science and engineering epistemology and science advice literature. This starts a conversation about what makes engineering advice unique and what it means for its role in policy and academic conceptualisation.

Finally, the last section answers my third research question: what is the impact of the UK government's structure and civil service culture on engineering advice? This section ties together my phase 3 results (chapter 6), intra-ministerial advice literature and arguments made in previous sections of the discussion. Doing so shows how political vision, ministerial team arrangement and turnover reinforce certain issues at the engineering-policy interface. Potential policy and educational strategies to alleviate these issues and facilitate engineering advice deployment in policy practice are introduced throughout this section.

Figure 7.1: The discussion ties together my results and academic concepts to answer my research questions and meet the aim of my thesis



7.1 *How does engineering advice work in a UK government department: The 'generalist engineer' epistemology*

7.1.1 *Linking results back to the literature*

The first phase of my research was designed to gather the empirical data necessary to understand how engineering advice works in a UK government department. As explained in my methodology chapter (section 3.5) this consisted primarily of document analysis and ethnographic interviews of engineers working in BEIS' engineering advice team and the policy officers they work with. The results of this research phase are presented in chapter 4, where I detail how engineers and policy officers interface at each stage of the policy advice process (see figure 4.1).

The different themes explored in chapter 4 match, nuance and add to two bodies of academic literature identified in my literature review. The first one is engineering studies, which looks at engineering epistemology in the private sector (section 2.2.4). Studying the work of engineering advisers at BEIS helps us see if engineers in public policy share the same identity and practices identified by engineering studies authors in industry. Doing so also contributes to a second branch of academic literature, UK intra-ministerial policy studies, which focuses on middle-ranking officials in the civil service (section 2.3.3). Looking at the interface between engineering advisers and policy officers, all mid-ranking civil servants, sheds light on how engineering advice practice fits with intra-ministerial policy studies' concepts.

The remainder of this section explores how engineering advice work at BEIS by unpacking the links between the themes introduced in chapter 4, the engineering studies literature and intra-ministerial policy studies. Doing so opens up a discussion about the epistemology of engineers in an intra-ministerial setting and its implications for policy.

7.1.2 A landscape with distributed evidence

To understand the work and practices of engineering advisers at BEIS, one must start with the policy landscape they operate in. As we established in chapter 4 (section 4.3.2), energy policy requires both technical and socio-political evidence. Socio-political evidence is concerned with social and political views, like constituents' views or businesses' willingness to spend. Technical evidence, in this space, relates to engineering and its application and refers to energy generation data, standards or PV pricing. Of course, as highlighted in figure 4.3, the two types of evidence can overlap sometimes, and evidence of a more socio-political nature can contain technical elements and vice-versa.

The evidence needed to make energy policy is held by a wide variety of actors. Some hold socio-political evidence, some hold technical (engineering) evidence, some hold both, a point I will pick up below. From what I have seen, actors internal to BEIS include senior civil servants and policy teams, and external stakeholders include regulatory bodies, industry representatives and academia. On specific policies, constituents and businesses are more directly engaged through consultations. Additionally, in the case of policy projects where part of the work is commissioned, the consultant or consultant consortium is one of the main stakeholders involved. Engineering advisers and policy officers at BEIS therefore work in a policy landscape with distributed evidence, evidence of different types shared across multiple policy actors.

7.1.3 Gathering and processing different types of evidence requires different knowledge and skills

To paraphrase policy studies authors (chapter 2, section 2.3.2), engineering advisers and policy officers at BEIS adopt an 'open approach' to energy policy making, consulting with a wide range of stakeholders to collect and analyse the socio-political and engineering evidence needed to deliver policy. However, gathering and processing different types of evidence requires different knowledge and skills.

As explained in chapter 4 (section 4.3.2), policy officers' backgrounds and policy experience help them collect and analyse mostly socio-political evidence gathered through consultation with various stakeholders. Except for two who were trained engineers, most of the policy officers I interviewed had a background in political or social science and previous experience in the civil service. In line with what Page and Jenkins call the "generalist ethos" of the UK civil service (chapter 2, section 2.3.3), the policy officers I interviewed move across different policy areas and teams to further their careers. This equips them with a generalist skillset, meaning they are adaptable, quick-learners and sensitive to stakeholders' needs and communication preferences. As policy officers move around the civil service, they also gain knowledge of policy processes and procedures, they learn how to frame and phrase policies to increase their chances of being adopted (Page and Jenkins, 2005; Stevens, 2011 in section 2.2.3). With this skillset, policy officers at BEIS are therefore easily able to engage stakeholders and identify the socio-political evidence and trade-offs relevant to the policy project at hand. They also know, through experience, how to create convincing policy stories, how to frame the policy proposal to maximise its chances of going through.

However, as my results show, policy officers often do not have an engineering background and cannot fully understand, gather, or analyse the engineering evidence needed for the policy project. Policy officers, who oversee policy projects, therefore reach out to the engineering advice team to help them gather and process engineering evidence (the implications of this dynamic are explore in detail below). In line with McCarthy and Cooper's findings (chapter 2, section 2.2.6), the policy officers I interviewed ask engineers for input on the properties and performance of built systems (like the gas or electricity grids) and their components (for example charge points or solar panels).

Engineering advisers, as explained in chapter 4 (4.3.2), enter the policy process at this stage to collect and analyse mostly technical (engineering) evidence. Engineering advisers rely on their engineering backgrounds rooted in maths and physics to gather and review evidence focusing on different engineering trade-offs related to the policy problem and/or quantitative data and calculations (see chapter 4, section 4.3.2 and section 7.1.9 below). To do so, engineering advisers engage stakeholders mentioned in section 7.1.2 above, sometimes the same stakeholders simultaneously engaged by policy officers. Some stakeholders hold both socio-political and engineering evidence and policy officers will engage them to gather their views on a policy while engineers will communicate with them to collect engineering data.

As noted in my results, once the engineering advisers have collected engineering evidence, they work with policy officers to combine engineering and socio-political evidence to inform the policy project. This is a complicated and sometimes fraught process which I will discuss below. However, before I do so, a deeper look at the epistemology of engineering advisers is necessary as it heavily influences the engineering-policy interface.

7.1.4 Working in an intra-ministerial setting creates convergence in profiles

As mentioned, engineering advisers rely on their background to gather and process engineering evidence in response to the policy officers' questions. As my results show, the type of questions asked can be varied, therefore engineering advisers at BEIS explained that they try not to specialise in one area of engineering (chapter 4, section 4.6). Instead, they report having to adapt and learn quickly to cover different areas of engineering depending on policy needs. To do this, and in line with the UK civil service's approach to policy making, engineering advisers engage multiple internal and external stakeholders to gather the evidence they need. As engineering advisers noted, to engage different policy actors, they need to be able to communicate effectively, including with non-technical audiences (ibid).

The skills mentioned by engineering advisers to do their job effectively aligns perfectly with the generalist skillset of policy advisers outlined in section 7.1.3: being adaptable, being a quick-learner and being sensitive to stakeholders' preferences. Because engineering advisers are mid-ranking officials involved in policy making, they pick up the skills to do so effectively in the context of the UK civil service, skills typically associated with policy officers. This creates a convergence between the engineering adviser and policy officer profiles, where the engineering adviser displays some of the generalist skills of policy officers.

As noted in chapter 4 (section 4.6), this creates a situation where the engineering advisers perform some tasks and display practices in line with the view of the discipline developed in their studies. They still deal with engineering evidence, including quantitative data and standards, and provide input on built systems and their components. However, as they are mid-ranking officials involved in policy making, they also need and acquire generalist skills. As my results suggest, these skills are not typically foregrounded in their education, and include adapting to different areas of engineering and communicating with various stakeholders. Engineering advisers at BEIS therefore display what I call a 'generalist engineer' epistemology, which mixes practices and identities typically associated with both engineering and policy. The 'generalist engineer' epistemology, interestingly, shares some common characteristics with the epistemology of engineers working in industry identified by engineering studies authors. However, engineering advisers at BEIS also have unique practices and a sense of identity not reported in the literature. The following sections unpack the concept of 'generalist engineer' in more depth, highlighting its similarities and differences with engineering studies concepts.

7.1.5 The 'generalist engineer': Goal-oriented in an object world

As mentioned above, and in line with McCarthy and Cooper's findings, policy officers at BEIS call on the engineering advice team when they need input on the performance of built systems and their components. This echoes Bucciarelli's point about engineering working in "object worlds" (Bucciarelli, 1994; chapter 2, section 2.2.2). The built systems and the physical objects they are made of drive much of the engineering advisers' thinking and practice at BEIS, like engineers in industry in the case of Bucciarelli. To be able to answer these object-focused questions, engineering advisers need what Page labels "discipline-specific expertise", that is familiarity with the theories and concepts of a specific discipline, in this case engineering (Page, 2010; chapter 2, section 2.3.4). As I noted, engineering advisers do not specialise in a sub-area of engineering however they still need to be familiar and comfortable with many engineering concepts and processes. These include, for example: load factor in energy production, gas grid purge rates and standards for different types of technologies (as detailed in chapter 4, section 4.1).

Echoing a point made by engineering studies authors about engineers in industry, engineering advisers at BEIS are involved in how to do something, how to solve a particular problem (section 2.2.3). This can clearly be seen in the questions policy officers ask engineering advisers, for instance: can hydrogen be blended into the gas grid or what smart functionalities do EV charge points need and how can we implement them (see chapter 4, section 4.1). Not only are the questions object-focused, they also imply that that there is a specific engineering problem to be solved. As a result, engineering advisers operate in an "object world" and are strongly-goal oriented, the goal being solving the problem raised in the policy officer's question. This manifests itself in the way engineering advisers communicate back with policy officers, following the goal-driven narrative McCarthy observed (McCarthy 2021; chapter 2, section 2.2.5). These engineering narratives outline the tools and practical steps to take to reach a certain goal. This is clearly visible in the projects presented in chapter 4 (section 4.5.2), where the engineering advisers, for instance, have presented the policy officers with steps to take to understand if and how hydrogen can be blended into the grid and how to design smart EV charge points.

As engineering studies authors pointed out for engineers in industry (chapter 2, section 2.2.3), engineering advisers at BEIS often have to compromise to reach their goal. The most salient manifestation of compromise in my results has been around the costs. As I explained in chapters 4 and 5, engineering advisers often propose solutions that have a certain cost, like different options of biomass reactors and associated gas capture and storage technologies. However, the engineering advisers' preferred option might clash with what policy officers deem is politically and economically acceptable based on the views they have gathered. In this case the engineering adviser and policy officer compromise to find a solution that satisfies engineering constraints and is acceptable to the majority of policy stakeholders, especially the senior civil servants who will approve the policy (chapter 4, section 4.4.2). I will explore the consequences of engineering advisers or 'generalist' engineers' object-focus, goal-orientation and compromises for the engineering-policy interface in section 7.2 below.

7.1.6 The 'generalist engineer': Not directly involved in building objects and systems

One of the main differences between engineering advisers at BEIS and engineers in industry is their degree of involvement in the actual process of building physical objects and systems. As Vincenti points out, the engineers he studied in an aerospace company are involved in the design, construction and operation of objects that transform the physical world (Vincent, 1993; chapter 2, section 2.2.2). This is echoed by engineering studies authors who explain that that the engineers they observed in industry put together the plan from which an artifact will be built and oversee the manufacture of the artifact (chapter 2, section 2.2.3). To do so, engineers draw on scientific knowledge, follow standards and codes and prototype and test the artifact (ibid).

Engineering advisers at BEIS, as we noted above, also draw on scientific knowledge and follow standards and codes to answer policy officers' questions. However, by contrast to the observations of engineering studies authors, engineering advisers are not directly involved in putting together the plan from which the object or system will be built. The plan will be influenced by the standards chosen or developed by the engineering adviser and policy officers, in the case of the EV charge point project for example, but engineering advisers will not be the ones putting the plan together. Engineering advisers will not be directly involved in the manufacture of the objects either, keeping with the EV charge point example this will be left to private sector companies. Because engineering advisers are not directly involved in building objects and systems, they do not test the prototypes, this is left to the engineers working for the organisation manufacturing the object. Engineering advisers might have access to prototype testing data as evidence to inform a policy project but again, this is different from having their hands on the prototype.

This difference between my findings and those of engineering studies stem from the context in which the engineers are operating. In the case of the engineering studies literature, the engineers work in manufacturing companies. In my research engineering advisers work in public policy, which influences yet is removed from manufacturing, especially since a lot of manufacturing happens in the private sector (see chapter 2, section 2.2.4). As we have seen in chapter 4 (section 4.1), engineering advisers at BEIS work at a strategic level, they mostly work on regulations to encourage or enable different energy uses. Engineering advisers therefore occupy a space connected to the physical world as they deal with object-focused questions and influence the building of artefacts and systems through regulation and standards. However, as they work in policy, they are also removed from the direct planning and manufacturing of objects which is often left to industry. This duality is characteristic of the 'generalist engineer' epistemology.

7.1.7 The 'generalist engineer': Discipline-specific expertise and a generalist skillset

As I have established, engineering advisers at BEIS have discipline-specific expertise, they are familiar with the theories and concepts of engineering and use this expertise in their day-to-day work. However, as argued above, the type of engineering-related questions policy officers ask can be varied therefore engineering advisers try not to specialise in one area of engineering. Instead, engineering advisers adapt to policy needs and cover different areas of engineering, displaying skills associated with generalist policy officers in the process. These include being adaptable, being a quick-learner and being sensitive to the concerns of the stakeholders they work with. The last point about the concerns of stakeholders engaged include being sensitive to the preferences of policy officers at BEIS which implies an understanding of the wider policy context and processes that shape those preferences. As concluded earlier, engineering advisers are mid-ranking officials involved in policy making, therefore they pick up the skills and knowledge to do so effectively in the context of the UK civil service. Those are generalist skills and policy knowledge typically associated with policy officers. This generalist skillset and knowledge does not replace their discipline-specific expertise but complements it and constitutes the core of the 'generalist engineer's' identity.

The engineering advisers' policy knowledge manifests itself when they interact with policy officers and external stakeholders to clarify the original question, gather the evidence they need and process the evidence to answer the question. As engineering studies authors observed, engineers in the private sector take into account the client's specifications and deployment constraints when designing a product (chapter 2, section 2.2.3). Engineering advisers at BEIS engage in a similar exercise, but given they work in policy, this means taking into account the context and constraints of the policy project they are advising on. By doing so, engineering advisers display what Page calls "policy expertise" and "process expertise" (Page 2010, chapter 2, section 2.3.4). "Policy expertise" refers to familiarity with "policy lines and policy measures": specific strategies and instruments, past and present, aimed at addressing specific policy problems (ibid). "Process expertise" refers to the policy processes to be followed for a proposal to be put into effect (ibid). This is visible in some quotes presented in chapter 4 where engineering advisers explain that they "have to bear in mind the broader policy landscape" when gathering engineering evidence (section 4.3.2) and "turn engineering knowledge into something the higher-ups can make a decision with" when communicating their results (section 4.4.3). Again, these quotes show that engineering adviser use policy and process expertise in conjunction and not instead of their engineering-specific expertise.

Adding to the point above, engineering advisers' generalist skills and policy knowledge are clearly visible when they act as "mobilisers of expertise", when they engage with internal and external stakeholders to gather their views on the policy project at hand (Page, 2010; chapter 2, section 2.3.4). Engineering advisers, as shown in chapter 4 (section 4.3.2), do not specialise in a particular area of engineering and therefore engage with external stakeholders to gather the precise information they need to answer the policy officers' questions. Additionally, because the engineering advice team's capacity is limited, policy officers and engineering advisers will often work together to commission engineering research from external consultants. As we pointed out in the quotes above, engineering advisers are mindful of the policy context when they engage stakeholders, including from consultants. When "mobilising expertise", engineering advisers use 'generalist' skills like being sensitive to stakeholder concerns and display "policy and process" expertise (ibid).

As we will see below, the fact that engineering advisers are 'generalist engineers' has a big influence on the engineering-policy interface. Indeed, on top of discipline-specific expertise, engineering advisers act as mobiliser of expertise and display policy and process expertise. This creates an overlap with the skills, knowledge and expertise of policy officers, increasing the potential compatibility and conflict between the engineering advice and policy teams. This point and its consequences for the power dynamic between engineering advisers and policy officers is covered in section 7.2.

7.1.8 The 'generalist engineer': The importance of communication skills

As established above and shown in chapter 4, engineering advisers at BEIS engage with multiple internal and external stakeholders to gather and process evidence. This requires strong communication skills including an ability to adapt one's audience and summarise information. This often means communicating technical, or engineering, information to non-technical audiences. This was a challenge for many engineering advisers at BEIS who indicated that they initially struggled to communicate engineering information to policy officers. This echoes McCarthy and Cooper's findings that many engineers working in policy feel like policy makers fail to grasp the language of engineers, constituting a barrier to successful collaboration (Cooper et al., 2020; McCarthy, 2017; chapter 2, section 2.2.6).

As my results show, early-career engineering advisers reported that communicating with non-engineering audiences was a struggle as their academic training did not prepare them to do so. This is directly in line with engineering studies authors' findings, especially Trevelyan, who reported that young engineers in industry were surprised by the importance of communication in their job (Trevelyan, 2010; chapter 2, section 2.2.3). These young engineers therefore regretted the limited training they had in communication skills especially readjusting communication strategies depending on the audience (ibid). However, as both engineering studies authors and my results highlight, engineers in industry and engineering advisers in policy pick up these communication skills with experience.

Experienced engineering advisers at BEIS and engineers in industry, as they repeatedly interact with non-technical stakeholders, learn strategies to communicate engineering information to them. As shown in my results and observed by engineering studies authors, these include translating technical knowledge and limitations into layman's terms and using metaphors and simple diagrams (chapter 2, section 2.2.3).

This also echoes McCarthy's point about engineers and policy makers building "trading zones" to collaborate with each other (McCarthy, 2017; chapter 2, section 2.2.6). Within those trading zones engineers and policy makers develop their own shared language to interact and exchange on a specific project (chapter 4, section 4.4.3). As a result, engineering advisers in my case and engineers in industry in the case of engineering studies authors cite effective communication as one of the most important skill to do their job (chapter 2, section 2.2.3). The ability to communicate with a range of stakeholders, including non-technical audiences, is a defining trait of both engineering epistemology in the private sector and the 'generalist engineer' epistemology in policy.

7.1.9 The 'generalist engineer': Historically established versus practice generated knowledge

Engineering studies authors point out that engineers in industry express a tension between "historically established" and "practice generated" knowledge (chapter 2, section 2.2.3). Historically established knowledge refers to the profession's knowledge base, embedded in manuals and codes and taught in engineering university courses. By contrast, practice generated knowledge is constructed by engineers in the context of their work and reflects an understanding of the wider system they operate in. As Trevelyan explains, many young engineers coming into industry feel like they are "doing less engineering than expected" given how much communication work they do compared to "calculation, design and technical stuff" (Trevelyan, 2010; chapter 2, section 2.2.3). This expresses the tension between the predominantly technical view of the discipline engineers develop in their studies (historically established knowledge) and the amount of communication and coordination they are involved in in practice (practice generated knowledge).

As my results show, this tension is also expressed by engineering advisers at BEIS. Indeed, engineering advisers are reluctant to call themselves 'proper' engineers as their role is not in line with the view of engineering they developed in their academic training. As we have seen, engineering advisers are not directly involved in building objects and systems, they do not engage in design calculations and prototyping. Instead, engineering advisers adapt to cover different areas of engineering depending on policy needs and engage stakeholders to gather precise information on a specific engineering issue. To carry out this work, engineers rely on practice generated knowledge, and on policy knowledge and skills. As explained above, these include strong communication and stakeholder coordination skills as well as policy and process expertise.

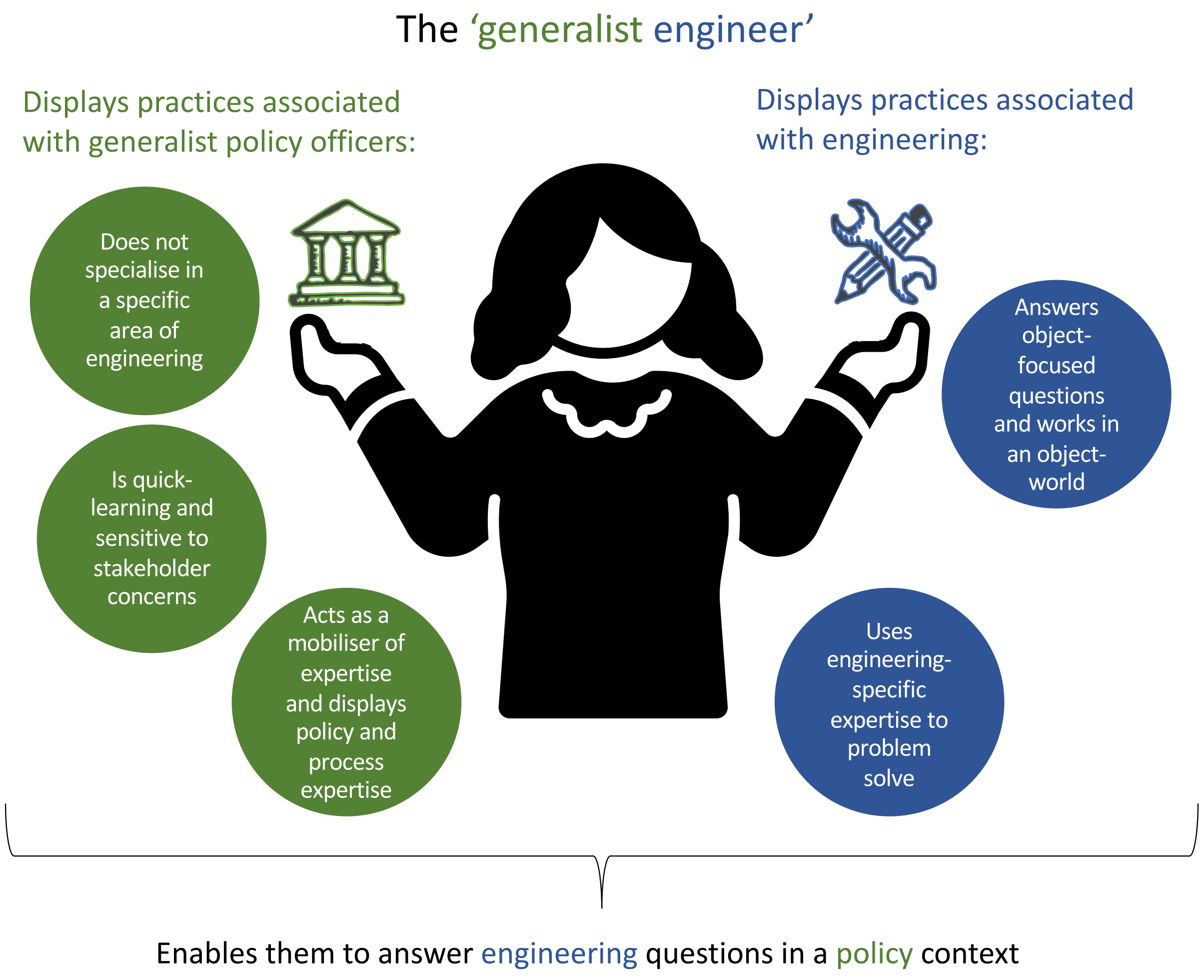
The tension between historically established and practice generated knowledge is probably felt even more strongly by engineering advisers at BEIS than the engineers in industry observed by engineering studies authors. Indeed, engineering advisers are less directly involved in building objects and systems than engineers in industry (at least the ones in the engineering studies literature). This means that engineering advisers do even less technical tasks requiring historically established knowledge, like completing design modifications using a CAD software, troubleshooting a circuit board, or machining a part for a test model (chapter 2, section 2.2.3). Instead, a large part of the role of engineering advisers requires practice generated knowledge, that is policy knowledge and skills. In their job, engineering advisers therefore seem to draw less on historically established knowledge and more on practice generated knowledge than the engineers in industry. Again, this in not to say that 'generalist engineers' do not use engineering-specific expertise in their role, they do. This signals that policy knowledge and skills are also a key part of engineering advisers' identity and enables them to do their work well.

7.1.10 The 'generalist engineer': Engineering problem-solving in a policy context

To conclude, engineering studies authors observe that, across countries and industries, engineers identify themselves as problem-solvers, recognising that problem-solving involves technical and social knowledge and skills (chapter 2, section 2.2.3). The same can be said for engineering advisers at BEIS, who, as we saw, are asked by policy officers to solve a problem. Problem-solving in their context entails a mix of engineering-specific expertise and policy knowledge and skills, knowledge and skills typically associated with generalist policy officers.

As we have seen in this section, this mix of engineering and policy skills is what makes up the core of the ‘generalist engineer’ epistemology and is illustrated in figure 7.2. In the following section I will explore the implications of the ‘generalist engineer’ epistemology for the engineering-policy interface.

Figure 7.2: The core of the ‘generalist engineer’ epistemology is made up of a mix of engineering and policy skills



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7.2 How does engineering advice work in a UK government department: Implications of the 'generalist engineer' epistemology for policy making

7.2.1 The 'generalist engineer' epistemology as both a source of tension and complementarity between engineering advisers and policy officers

The previous section introduces the concept of the 'generalist engineer' to reflect the practices and identity of engineering advisers I worked with. In this section, I will look at the implications this has for the engineering-policy interface at BEIS. In other words, what does the 'generalist engineer' epistemology mean for the relationship between engineering advisers and policy officers in a UK government department?

As explained above (section 7.1), engineering advisers are asked to answer object-focused questions that imply there is an engineering problem to solve. As a result, "generalist engineers" operate in an "object world" and are goal-oriented, the goal being solving the problem raised in the policy officer's question. As a result, and as Cooper suggests, engineering advice that "problem-solves in the physical world" might be valuable for "policy officers aiming to make policy that works" (Cooper et al., 2020; chapter 2, section 2.3.5). Equally, ministerial engineering experts might clash with policy officers "who are also trying to solve a policy problem in a different way" (ibid).

To problem solve in a policy environment, engineering advisers, on top of their engineering knowledge, also pick up policy knowledge and skills typically associated with generalist policy officers (section 7.1). This mix of discipline-specific, policy and process expertise is characteristic of the 'generalist engineer'. However, much to Cooper's point, this creates an overlap with the skills, knowledge and expertise of policy officers, increasing the potential compatibility and conflict between the engineering advice and policy teams.

The sections below therefore look across my results and intra-ministerial policy studies literature to highlight how engineering advisers' practices and identity create tensions and compatibility between them and policy officers. Points of tension and compatibility are treated in turn.

7.2.2 Tensions: Policy officers in charge, engineering advisers in support

The first point of tension I came across in my results, concerns the initial dynamic between the policy teams and the engineering advice team. As explained in chapter 4 and 6, the aim of the engineering advice team is to help policy teams answer the engineering related questions they have in the context of the policy project they are working on. This creates a dynamic where policy teams are driving the policy process with the engineers in support. This can be a source of frustration for engineering advisers who feel the engineering options they have are limited by a policy vision they did not have a say in. In other words, engineering advisers feel like the "object world" that is a key part of their identity (see 7.1.5), the systems and objects they can design or act upon, is constrained by a policy direction they have not been involved in from the start.

This is made worse by the fact that engineering advisers are aware of what Page labels the "policy principles" and "policy lines" that constrain their options (Page, 2006; chapter 2, section 2.3.3). "Policy principles" correspond to the current government's general views on how public affairs should be arranged and "policy lines" refer to the specific strategies aimed at addressing specific policy problems (ibid). As we mentioned above (section 7.1.7), 'generalist engineers', with experience, learn about political vision and policy strategies to problem-solve in an intra-ministerial policy context. However, engineering advisers only get brought into the policy process when "policy measures" are developed, when the instruments that give effect to the policy lines are created (Page, 2006; chapter 2, section 2.3.3). This is frustrating for engineers who are involved in developing policy measures without having a say in, yet being aware, of the policy lines that influence these measures.

7.2.3 Tensions: Fitting part of the policy issue into an "object world"

The second point of tension I observed occurred when engineering advisers clarified the policy advisers' questions (see chapter 4, section 4.1). As mentioned in the results and in section 7.1.3 above, policy officers generally do not have an engineering background and the initial questions they ask engineers are phrased in general and imprecise engineering terms. Engineers therefore need to have an initial conversation with the policy officers to understand what the question entails from an engineering perspective and how it can be answered. This includes, for instance, rephrasing the initial question to suggest modelling utility-scale solar facilities' land footprint or developing standards for EV smart charging. In the process, the engineering adviser fits the policy officer's questions, and therefore part of the policy project, into their "object-world". By rephrasing the initial question using engineering-specific expertise, 'generalist engineers' frame how part of the policy problem should be answered.

This puts engineering advisers in a strong position where they can shape part of what the policy project will look like, and policy officers lack the technical expertise to push back against the engineering advisers' points. At first glance, it might look like policy officers become the "servants" of engineering advisers, that internal advisers' discipline-specific expertise overshadows the policy making process (Page, 2010; chapter 2, section 2.3.4). However, as I will explore below, policy officers still have more exposure than engineering advisers to what policy stakeholders, including senior civil servants and ministers, consider politically acceptable. Additionally, policy officers are responsible for writing the final document and submitting the policy proposal for approval. Policy officers can therefore push back against engineering advisers' recommendations on the grounds that it would not be accepted by the senior civil servants approving the policy proposal. So, although engineering advisers fit part of the policy project into their "object world", this does not necessarily make policy officers the "servants" of engineering experts. This point is explored in more detail in section 7.2.5.

7.2.4 Tensions: Struggling to communicate engineering information

A point of tension between engineering advisers and policy officers running through my results was the difficulty in communicating and understanding engineering information. Indeed, new engineering advisers struggle to communicate engineering information to non-technical audiences, in particular policy officers. As mentioned in section 7.1.8, this can be traced back to the 'generalist engineer's' engineering academic training which do not prepare them well to readjust communication strategies depending on the audience. However, engineering advisers pick up this skill with experience as explored in section 7.2.6 below.

Equally, policy officers struggled to understand some engineering information because they lacked an engineering background. The policy officers who were trained engineers noted that their engineering background was a real asset in this case, helping them converse with engineers more easily. As with engineers and communication skills, policy officers pick up some technical knowledge on the job. As mentioned in chapter 6 however, policy officers stayed in their role on average 18 months, meaning they had limited opportunity to really deepen their technical understanding of the policy area. This creates a situation where policy officers have a limited ability to check if the engineering information provided by the engineering advisers is accurate. As I will explore in section 7.2.7 below however, engineering and policy officers can deploy strategies to get over this issue and create mutual trust.

Overall, for new engineering advisers and policy officers, communicating and understanding engineering information can be a barrier to collaboration, slowing down the policy making process. As mentioned above (section 7.1.8) and in the literature review (chapter 2, section 2.2.6), this is not uncharted academic territory. My point echoes McCarthy and Cooper's findings that many engineers working in policy feel like policy makers fail to grasp the language of engineers, constituting a barrier to successful collaboration (Cooper et al., 2020; McCarthy, 2017).

7.2.5 Tensions: Differing understanding of economic and political acceptability

The last major point of tension noted in my results is created by the differing understanding of economic and political acceptability between engineering advisers and policy officers. As noted above (section 7.1.7), "generalist engineers" take into account the context of the policy project they are advising on and as a result develop "policy and process expertise" (Page, 2010). Part of this includes engineering advisers being sensitive to stakeholders concerns when engaging them, when acting as "mobilisers of expertise" (ibid). As a result, the recommendations made by engineering advisers to policy officers partly reflect the engineering adviser's perception of what the stakeholders engaged consider acceptable.

The engineering advisers' understanding of what is acceptable in this policy context however can be at odds with what policy officers consider acceptable, creating friction in the policy making process as suggested in my results. Like engineering advisers, policy officers derive their understanding of political and economic acceptability from engaging with internal and stakeholders (section 7.1.3). As noted in my results however, although there is a lot of overlap between the stakeholders engaged by policy officers and engineering advisers, policy officers tend to engage a few more policy actors (see chapter 4, section 4.3.2). Importantly, policy officers engage these stakeholders to gather socio-political evidence, to gather their social and political views on the policy project at hand (section 7.1.3). In contrast to engineering advisers who engage stakeholders to gather technical evidence, policy officers have a more direct exposure to their socio-political views.

Additionally, policy officers have a better understanding of what the senior civil servants approving the final policy proposal want. As argued above, policy teams are responsible for policy projects and, as such, have representation on and input on policy boards where "policy lines" are selected (section 7.2.2). These boards where strategies to tackle the policy problem are selected give policy teams insight into what the senior civil servants expect. Engineering advisers however get brought into the policy project further down the line (ibid), and although they have an idea of what senior civil servants expect, they do not have as direct a view of it as policy officers do.

As seen in my results, policy officers therefore sometimes push back against engineering advisers' recommendations because they do not think that they would be politically and economically acceptable. As noted in the previous paragraphs, policy officers tend to have a better picture of what is acceptable in the context of the policy project as they engage more stakeholders, have a more direct view of their socio-political views and more direct insights into what senior civil servants expect. As a result, and as noted in chapter 4 (section 4.4.2), in the case where the policy officers push back on political and economic acceptability grounds, engineering advisers find it hard to argue and propose new solutions that are technically feasible and satisfy policy concerns.

Once the policy officer and engineering adviser find an agreement, the policy officer leads the write-up of the final policy proposal suggesting options that meet the project aims (examples in chapter 4, section 4.5.2). In line with Stevens' findings, policy officers turn the evidence into a coherent narrative, a policy story, leading the reader to the conclusion that the recommended policy option is the best course of action (Stevens, 2011; 2.3.3). Given that, in the UK civil service, having policy proposals accepted is a sign of success for policy officers, they try to increase its chances of being accepted (ibid). As my results and the literature show (ibid), to do so policy officers make sure that the story line of their policy discloses the balancing act between the different stakeholders' concerns. Additionally, they ensure that their policy story fits in with what the senior civil servants approving the policy find politically acceptable. This also explains why policy officers pay close attention to what different internal and external stakeholders find politically and economically acceptable and sometimes clash with engineering advisers about it.

As this section shows, despite 'generalist engineers' fitting a part of the policy project in their "object world" and possessing both "discipline-specific" and "policy process" expertise, policy officers cannot be considered their "servants" (Page, 2010; section 7.2.3). Policy officers have more exposure than engineering advisers to what policy stakeholders, including senior civil servants and ministers, consider politically acceptable. Additionally, policy officers are responsible for writing the final document and submitting the policy proposal for approval. This allows policy officers to push back against engineering advisers' recommendations on the grounds that it would not be accepted by the senior civil servants approving the policy proposal. Responsibility for initiating and closing the policy project and a good understanding of political acceptability grant policy officers' power in the policy process and by extension in their relationship with engineering advisers. The relationship between policy officers and engineering advisers is therefore more nuanced than one of "servant" to "expert" (ibid).

7.2.6 Compatibility: Learning to communicate

So far, I have only looked at how engineering advisers' practices can create tensions between them and policy officers. However, the engineering advisers' 'generalist engineer' epistemology is not just a source of tension, it also enables them to better collaborate with policy officers. The overlap in practices, knowledge and skills between ‘generalist engineers’ and policy officers makes it possible for them to communicate, understand each other’s role in the policy process and ultimately create trust as covered below. This increases the compatibility between the two roles and enables engineering advisers and policy officers at BEIS to collaborate and create energy policies.

The first point to note with regards to compatibility is the ‘generalist engineer’s’ ability to communicate engineering information to non-technical audiences (see section 7.1.8). As mentioned repeatedly in my work, engineering advisers did not feel like their academic training prepared them well to communicate engineering information to non-technically trained policy officers. However, with experience, engineering advisers pick up the skills and strategies to communicate technical information to policy officers. As detailed in chapter 4 (section 4.4.3), when communicating with policy officers, engineering advisers try to simplify engineering concepts and, relying on their awareness of policy context, focus mainly on the impact that changes to engineering systems might have for the policy project. As my results also show, communicating technical information often includes creating and collaborating on figures and diagrams leading to the development of a common language between engineering advisers and policy officers. As discussed above (section 7.1.8), this echoes McCarthy’s point about engineers and policy makers building a “trading zone”, a simple language to collaborate with each other on a specific project (McCarthy, 2017).

‘Generalist engineers’ experience working in policy and the process expertise and awareness of policy context they learn along the way therefore allows them to better communicate and work with policy officers. As hinted to above (section 7.2.4), this is also facilitated by the fact that policy officers gain some technical knowledge on the job, although this should be caveated as policy officers do not stay in their role for long; thus limiting the amount of technical information they learn[15]. The ‘generalist engineer’s’ academic background, as we saw, can create tensions in the policy making process as new engineering advisers struggle to communicate engineering information to policy officers. However, the fact that, over time,

[15] Note: the impact of turnover on the engineering policy interface is discussed in more depth in the final section of this chapter.

‘generalist engineers’ complement their engineering expertise with policy knowledge and skills enables engineering advisers and policy officers to collaborate.

7.2.7 Compatibility: Mutual recognition of expertise

The second point of compatibility ties into the fact that engineering advisers and policy officers perform a similar role with different types of evidence. ‘Generalist engineers’ engage stakeholders to gather and process the engineering evidence they need to inform the policy project (7.1.3). Simultaneously, policy officers engage policy actors to collect and analyse the socio-political evidence they need to inform the policy project (ibid). As my results show (chapter 4, 4.4.1), in the process, engineering advisers and policy officers handle conflicting evidence, sometimes because different stakeholders in that policy space have competing interests or sometimes because stakeholders disagree with the aim of the policy project. Either way, engineering advisers and policy officers try to reconcile and/or find compromises between the different stakeholder views they gathered in the context of the policy project. By doing so, they go beyond summarizing evidence and develop their own knowledge, that is their own understanding of the issues at hand within the context of the policy.

Engineering advisers and policy officers are therefore involved in the same stakeholder and evidence balancing exercise albeit with different types of evidence. As observed in chapter 4 (section 4.4.2), when engineering advisers and policy officers discuss the evidence they gather, they often disclose the contradicting stakeholder views they gather and how they reconciled/chose between them in the context of the project. As my results show, given both ‘generalist engineers’ and policy officers are involved in this balancing exercise, they understand and relate to each other’s role, provided the evidence trade-offs are disclosed. Additionally, by sharing how the evidence was analysed and weighed, the engineering advisers and policy officers become experts in the eyes of each other. Given the different type of evidence they handle, engineering advisers become the technical experts in the eyes of the policy officers and policy officers become socio-political experts in the eyes of the engineering advisers (chapter 4, section 4.4.2).

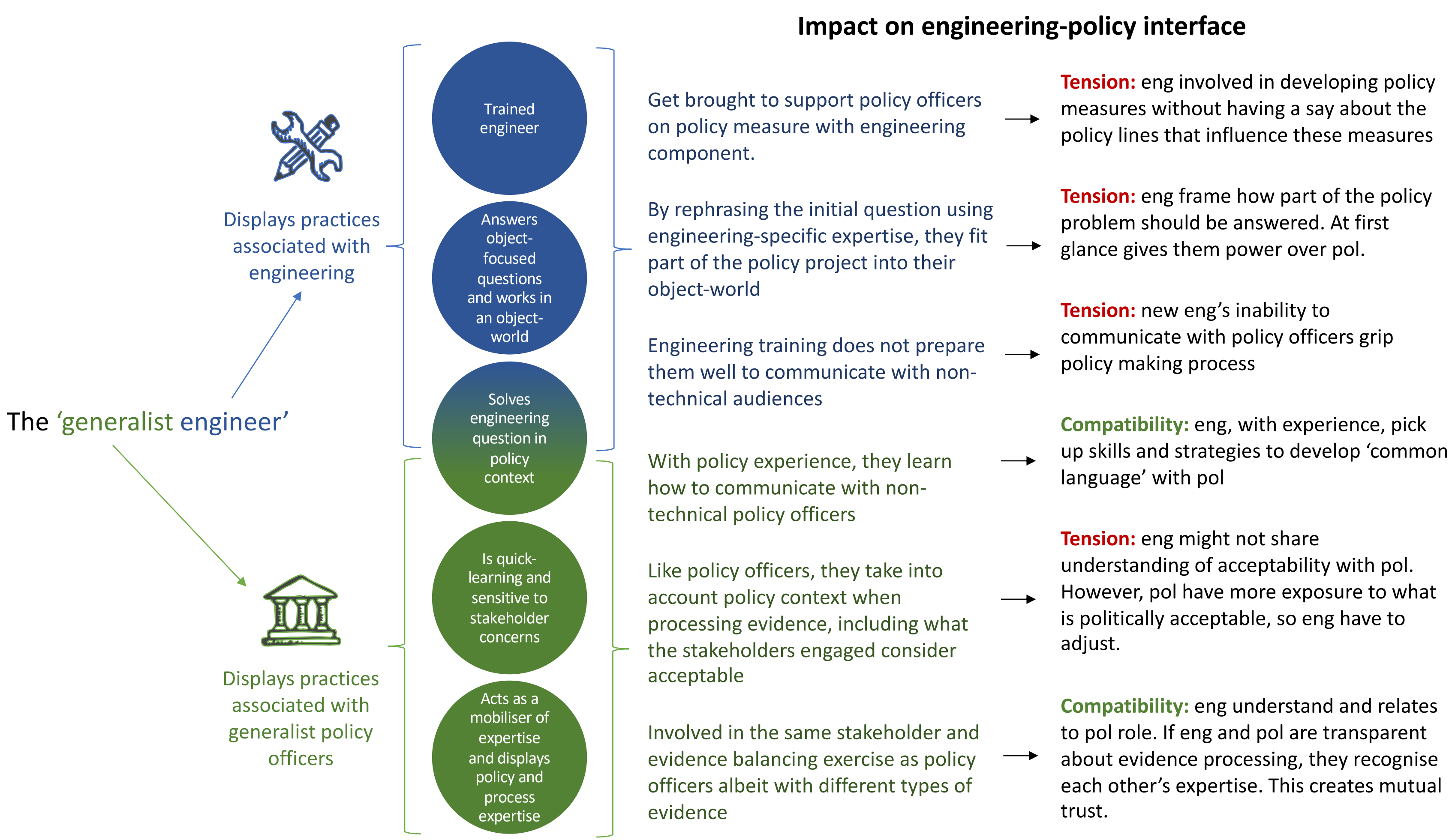
By balancing evidence in a similar way and disclosing it, the 'generalist engineer' and policy officer understand and relate to each other's role, becoming technical and socio-political experts (respectively) in the eyes of each other. When that is the case the compatibility of the two roles is obvious to all parties as energy policy, as we mentioned (section 7.1.2), requires both technical and socio-political expertise. This also illustrates the "relational" aspect of expertise in policy as described by Mieg, the notion that to be an expert, on has to be considered as an expert by others (Mieg, 2006; chapter 2, section 2.3.4). It is also worth pointing out, and we will come back to it later in this discussion, the importance of transparency between engineering advisers and policy officers. Transparency, or the disclosure of how the evidence was processed in this case, enables smooth collaboration between both parties, a point made in the science advice literature (chapter 2, section 2.1.6). Provided both parties are transparent about the way the evidence was balanced when discussing their recommendations amongst themselves, the overlap between practices of 'generalist engineers' and policy officers make the roles more compatible than conflicting.

7.2.8 Compatibility: Creating mutual trust

Taking the point in the section above even further, my results show that the recognition of mutual expertise between engineering advisers and policy officers leads to the development of mutual trust (chapter 4, section 4.4.2). Over time, as engineering advisers disclose how they collect evidence and what trade-offs are made when processing the evidence, policy officers explain that they trust the engineering adviser's research. Equally, as policy officers disclose how they balance different stakeholder views to the engineering advisers, engineers explain that they trust the policy officers' judgement. Mutual trust, combined with the 'common language' mentioned above (section 7.2.6), facilitates conversations between engineers and policy officers where both need to work together to suggest policy options that satisfies both engineering constraints and policy officers' concerns.

Figure 7.3 below concludes this section by summarising how the 'generalist engineer' epistemology can create both tensions and compatibility between the engineering advisers and policy officer roles. Policy recommendations to help ease some of the tensions mentioned and leverage the compatibility between the two roles will be suggested in the final section of this chapter when discussing the influence of the civil service structure and culture and engineering advice.

Figure 7.3: The 'generalist engineer' epistemology creates tensions and compatibility between the roles of engineering advisers (eng) and policy officers (pol)



7.3 What is the difference between science and engineering advice in a UK government department?

7.3.1 Linking results back with the literature

The second phase of my research was designed to gather the empirical data necessary to understand the difference between science and engineering advice in a UK intra-ministerial context. As outlined in my methodology chapter (section 3.6) this consisted of observation, document analysis, workshop data and ethnographic interviews of BEIS science and engineering advisers, and the policy officers they work with. The science advice team specialises in climate science and sits in the same directorate as the engineering team, allowing for comparison between engineering and science in this context. The results of this research phase are presented in chapter 5, where I detail the similarities and differences in work process and content between the engineering and science advice team (see tables 5.1 to 5.3).

The different themes explored in chapter 5 match, nuance and add to two bodies of academic literature identified in my literature review. The first one is the literature that distinguished between science and engineering epistemology and paved the way for the field of engineering studies (chapter 2, sections 2.2.1 and 2.2.2). Comparing the work of science and engineering advisers at BEIS helps us see how the epistemological differences identified in the literature manifest themselves in policy and influence science and engineering advice giving and receiving. Doing so also contributes to a second branch of academic literature, science advice, which gives the impression that concepts developed to understand science advice in collegial bodies and academies can be applied to intra-ministerial engineering advice (chapter 2, sections 2.1.8 and 2.1.9). Looking at the difference between science and engineering advice at BEIS sheds light on which science advice concepts applies to intra-ministerial engineering advice and, if not, whether it is because it is engineering or intra-ministerial advice.

The remainder of this section explores the difference between science and engineering advice at BEIS by unpacking the links between the themes introduced in chapter 5, the 'pre-engineering studies' literature and science advice literature. Doing so opens up a discussion about what makes engineering advice unique and what it means for its role in policy and academic conceptualisation.

7.3.2 Similarities: A landscape with distributed evidence

Before I go into more depth about the differences between engineering and science advice, let me mention the similarities between the roles of engineering and science advisers at BEIS. As we mentioned above, energy policy requires different types of evidence, socio-political and engineering (section 7.1.2). Sometimes, as detailed in chapter 5, energy policy also requires climate science evidence including estimations of UK greenhouse gas emissions, estimation of the amount of CO_2 to be captured to respect a climate target or what type of biomass feedstocks can be used to produce energy. Policy officers working in policy teams, as we saw (section 7.1.3 and chapter 5), have a generalist background, meaning most are not trained scientists. Policy teams therefore rely on the science advice team to gather and process scientific evidence to help answer scientific questions relevant to the policy project at hand. Science and engineering advisers are therefore in a similar position in the policy process, they support a policy project driven by the policy teams.

An associated issue with policy officers not having a science background is that they tend to phrase their questions to the science advice team in general and imprecise scientific terms. Science advisers therefore have a conversation with policy officers to clarify the information they need. This also applies when scientific research is commissioned, in which case science advisers translates the policy teams' needs into scientific terms for the consultants when drafting ITTs. As explored above (section 7.2.3), engineering advisers are engaged in the same exercise, rephrasing the policy officers' question into engineering terms.

Scientific and engineering advisers therefore intervene at a similar time in the policy process and are involved in the same 'rephrasing' exercise. As I will cover below however (sections 7.3.6 and 7.3.8), the questions asked of science and engineering advisers by policy officers have a different focus and orientation. The difference in the type of question asked generates a different answer and narrative and, in-turn, makes the relationship between policy officer and scientific advisers different from that of policy officers and engineering advisers.

7.3.3 Similarities: Engaging stakeholders

As is the case with engineering questions and as my results suggest (chapter 5, sections 5.2.1 and 5.3.2), the type of science-related questions policy officers ask can be varied. Science advisers therefore try not to specialise in one area of climate science and instead engage stakeholders to gather the evidence they need to inform the policy (chapter 5, sections 5.2.1 and 5.3.3). These stakeholders include consulting firms, the MetOffice, universities and academic consortiums (ibid). Like engineering advisers, science advisers rely on a mix of "discipline specific expertise" and "policy and process expertise" to engage stakeholders and collaborate with policy officers (section 7.1.7 above). Science advisers need to be familiar with climate science theories and concepts to gather scientific evidence but need to be familiar with the policy project and process to articulate this information "in a way policy officers would find useful" (chapter 5, section 5.2.1).

Both engineering and science advisers at BEIS therefore "mobilise expertise", they engage stakeholders to gather the evidence they require to answer the policy officers' questions (section 7.1.7 above). By doing so, they "mix discipline-specific" and "policy and process expertise" enabling them to gather engineering and scientific evidence (respectively) and frame their recommendation in a way they believe is relevant for the policy project at hand. Again, engineering and science advisers are involved in a similar stakeholder-engagement process however, as we will cover below (sections 7.3.6 to 7.3.9), the type of questions asked of them is different impacting the type of stakeholders they engage and the narrative of their advice. Despite a similarity in the advisory process, the difference in content and framing of the engineering and science advisers' recommendation results in a different relationship with policy officers.

7.3.4 Similarities: Importance of communication skills

My results show that science advisers, like engineering advisers, stress the importance of having good communication skills to do their job well (chapter 5, section 5.2.2 and 5.3.4). Throughout the policy projects, the science advisers meet with the policy teams to discuss their work, the evidence gathered and how they are answering the policy question. Science advisers report that this is not always easy as it can be a struggle to explain scientific information and terms (like 'CO_2 equivalent' or 'CO_2 sequestration') to policy officers without a scientific background, especially for science advisers that had limited policy experience (ibid). This is less of an issue when the policy officers they are interfacing with are trained scientists (ibid). This directly echoes comments made in the literature and by engineering advisers about the difficulty of communicating with non-technically trained policy officers and the tensions this creates for the policy-making process (section 7.2.4 above).

However, just like engineering advisers, over time scientific advisers develop techniques to communicate scientific information more easily to policy officers (chapter 5, section 5.3.4). This includes using analogies and simple "rules of thumb" to explain causality, scale, and effect in non-scientific, easy to understand terms (ibid). Science advisers also report that communicating with policy officers is also easier if the policy officer has been in their role for a longer period as they learn some scientific concepts on the job. Again, this directly echoes the strategies engineering advisers develop, with experience, to communicate engineering information to policy advisers (section 7.2.6 above). Engineering advisers also point out that this becomes easier the longer their policy counterpart stays in their role (ibid).

Policy officers value the conversations they have with science advisers as it allows them to understand how they come up with an answer to the original policy question (chapter 5, section 5.3.4). This is facilitated by the science advisers' efforts to communicate the scientific information they gather and analyse in simple terms. Being able to understand how the scientists come up with their answer means that the policy officers trust the science advisers' suggestions (ibid). Again, a similar point is made in relation to engineering advice above (section 7.2.8 above). When engineering advisers and policy officers disclose how they collect evidence and what trade-offs are made when processing the evidence, they realise the compatibility of their roles and start trusting each other.

7.3.5 Similarities: Historically established versus practice generated knowledge

As noted in chapter 5 (section 5.4), science advisers feel like they are not doing ‘proper’ science. By that they mean that they do not design and carry out scientific experiments nor specialise as much as academic scientists do. Instead, by virtue of working in policy, science advisers work at a strategic level, mobilising scientific evidence to inform policy projects. To do this, as pointed out in the previous sections, science advisers touch on different areas of climate science depending on policy needs and develop science communication skills. Science advisers are therefore reluctant to call themselves ‘proper’ scientists as their role is not in line with the view of scientific practice in an academic setting.

Just like science advisers, engineering advisers at BEIS say that they do not do ‘proper’ engineering (section 7.1.9 above). As we saw, this comment reflects a tension between the predominantly technical view of the discipline engineers develop in their studies (historically established knowledge) and the amount of communication and coordination they are involved in in practice (practice generated knowledge). Science and engineering advisers therefore both share and express the same tension between historically established knowledge and practice generated knowledge, between their academic training and the skills and knowledge needed to perform their role in a policy context.

As we saw, there are multiple similarities between the science and engineering advisers’ role at BEIS. They both intervene at a similar time in the policy process and ‘rephrase’ policy officers’ questions. Both “mobilise expertise” and to do so mix discipline-specific and policy expertise. Both initially struggle to communicate with non-technically trained policy officers but learn how to do so with experience. Being able to simply communicate scientific/engineering information, in-turn, helps policy officers understand and trust the advisers’ recommendation. As we saw, the amount of coordination and communication science and engineering advisers are involved in contrast with the more academic view of their discipline, prompting advisers to say that they are not doing 'proper' science or engineering.

All these similarities are linked to the way UK intra-ministerial policymaking works. In other words, science and engineering advisers' role share some similarities because they are embedded in the same policy space. As explored in the literature (chapter 2, section 2.3.3), working within a government department means interfacing with generalist policy officers in charge of the policy project, having to learn how to communicate with them and how to engage stakeholders to get the evidence needed to answer the policy question. However, as hinted at above and covered in the following sections of this discussion, differences appear when looking at the content of science versus engineering advice. The questions asked of science and engineering advisers are different and, consequently, so are their answers, influencing their relationship with policy officers.

7.3.6 Differences: Focus and question types

As highlighted in chapter 5, the questions policy officers ask science and engineering advisers have a different focus. As stated by policy officers at BEIS, science advice provides answers to ecosystem questions like how the terrestrial and climate system works (chapter 5, section 5.3.5). This includes, for example, advice on what type of biomass feedstock can be used to produce energy and what gases might be released from this process (chapter 5, 5.3.2). According to the same policy officers, engineering advice is related to what technologies can help mitigate climate change (chapter 5, 5.3.5). This reflects the difference in aim between engineering and science pointed out in the academic literature (chapter 2, 2.2.1), with science aiming to understand the world as it is and engineering looking to change the world. As my results show and backing up points made in the literature review (chapter 2, 2.2.5), policy officers therefore ask science advisers questions focused on the functioning of eco- and bio-systems. By contrast, as explored above (7.1.5), engineering advisers are asked object-focused questions on the performance of built systems and their components, implying a practical solution to a particular problem.

As a result of this difference in focus, the type of questions asked of science and engineering advisers are different. As illustrated in chapter 5 (section 5.3.2), the questions asked of science advisers are more explanation-oriented, for instance measuring the possible gas leakage from biomass reactors and the potential environmental impact of those leaks. On the other hand, the questions asked of engineering advisers are more goal-oriented, for instance what can be done to prevent gas leakage and reduce its potential impact (ibid). As science advisers explained, science advisers are concerned with explaining situations and rely on measurements and thresholds (chapter 5, section 5.3.5). Engineering advisers however, as explained above (section 7.1.5) work towards a goal, and as such will keep compromising until the goal is achieved. Again, this is a manifestation of the epistemological differences between science and engineering mentioned in the literature (chapter 2, section 2.2.1). Science aims to understand the world as it is and, as a result, answers explanation-oriented questions, including in a policy setting. Engineering aims to change the world and, as such, answers goal-oriented questions, including in a policy context.

7.3.7 Differences: Advice narrative

Answering these different types of questions results in a different type of advice narrative, in turn differentiating the relationship between science advisers and policy officers from that of engineering advisers and policy officers. As chapter 5 shows (section 5.3.5), science advisers at BEIS often answer explanation-oriented questions by defining thresholds based on specific measurements (CO_2 emissions for instance) and describing scenarios about what might happen if a threshold is exceeded or not. The narrative does not include what can be done to avoid exceeding the thresholds mentioned. The engineering team, by contrast, produces prescriptive narratives that propose solutions to a particular policy problem like what technological options should be selected to prevent and capture emissions from biomass reactors (ibid). This maps onto the epistemological differences between engineering and science explored in the literature (chapter 2, section 2.2.1) and McCarthy's point about science and engineering advice narratives (chapter 2, section 2.2.5). Indeed, my results support the claim that science is concerned with the world as it is and therefore science advisers construct descriptive narratives that explain causal relationships and processes to give an account of the evidence observed (McCarthy, 2021 in chapter 2, section 2.2.5).

Engineering on the other hand is concerned with bringing about change, therefore engineering advisers build prescriptive narratives that outline the steps to take to reach a goal (ibid).

As explored above (section 7.2.3), engineering advisers' goal-oriented, prescriptive narrative impacts their relationship with policy officers. This is particularly salient when engineering advisers rephrase the initial policy question using engineering-specific expertise, fitting part of the policy process into their object-world in the process (ibid). As we saw, by doing so, engineering advisers define the engineering goal to be reached and the steps to reach it, framing how part of the policy problem should be answered (ibid). This can create tensions with policy officers who might be trying to solve the "policy problem in a different way" (Cooper et al., 2020 in section 7.2.1 and 7.2.5 above). This often includes pushing back against engineering advisers' recommendations as they would not be acceptable to the senior civil servants approving the policy proposal (section 7.2.5). When that is the case, engineering advisers will propose new solutions until they find one that is technically feasible and satisfy policy concerns (ibid).

By contrast, science advisers provide policy officers with information about possible future climate scenarios based on current measurements and extrapolation. Science advice is therefore less constraining for policy officers, it is more informative and less prescriptive than engineering advice. Policy officers, as a result, tend not to push back against science adviser's input as it does not narrow down policy options as much as engineering adviser's recommendations. Because science advisers are presenting potential scenarios and not recommending a specific option, policy officers have more room to incorporate the science adviser's input into the policy proposal in a way that does not clash with what senior civil servants find acceptable. Tensions mentioned in the previous paragraph between engineering advisers and policy officers are therefore not felt between science advisers and policy officers.

However, as we saw (7.2.7), provided both engineering advisers and policy officers disclose and discuss how they balance evidence amongst themselves, compatibility between the two roles can be very high. Indeed, when the engineering advice satisfies both the technical and policy officer's concerns, it is particularly valuable for policy officers as it provides an acceptable solution to a policy problem (ibid). By contrast, science advice does not tell policy officers how to solve a problem, it provides information that can help problem-solving, but policy officers still have to come up with the different policy solutions. Science advice is therefore not as potent as engineering advice for policy officers trying to solve policy problems.

Interestingly, the difference in nature and narrative between science and engineering advice also makes both type of advice complementary for policy officers. As explored in chapter 5 (section 5.3), on certain projects like the Biomass Strategy, policy officers work with both science and engineering advisers to get the information needed to inform the policy project. Science advisers focused on measuring possible gas leakage from biomass reactors and the potential environmental impact of those leaks (chapter 5, section 5.3.2). Engineering advisers were tasked with recommending technological options to prevent gas leakage and reduce its potential impact (ibid). In line with arguments made in this section, policy officers relied on science advisers for an explanation of the phenomena at hand and on the engineering advisers for potential solutions to the issue. Science and engineering advice can therefore work in tandem, providing an explanation and better understanding of a policy issue and potential solutions to resolve the issue.

7.3.8 Differences: Economic and political acceptability

The final difference to note relates to the nature of the evidence collected by engineering and science advisers and how it connects with notions of political acceptability. As mentioned above (section 7.3.6) and in chapter 5 (section 5.3.2), the science advice team at BEIS answer explanation-oriented questions relying on climate models and measurements like greenhouse gas emissions. As my results show (chapter 5, section 5.3.3), this information usually sits with academia (specific universities or UKRI-funded university clusters) and public executive agencies like the MetOffice. The engineering team however, answers questions about technologies and built systems. As chapter 5 suggests (ibid) and mentioned in the literature (chapter 2, section 2.2.4), this information tends to sit with the private sector, often responsible for the manufacturing and delivery of technological systems. Dealing with industry to collect evidence on the performance and potential delivery of new technologies, implies looking at different options which usually perform differently and have different associated costs (chapter 5, section 5.3.5). As a result, engineering advice, unlike science advice, often carries cost implications that influence its political acceptability (ibid). Also, it is worth noting the close association of engineering and the private sector. Although this is not the focus of this thesis and very little empirical data was collected on this topic, this means that engineering advice for policy could potentially be overtaken by private interests. This point is picked-up in the 'avenues for future research' section of the conclusion.

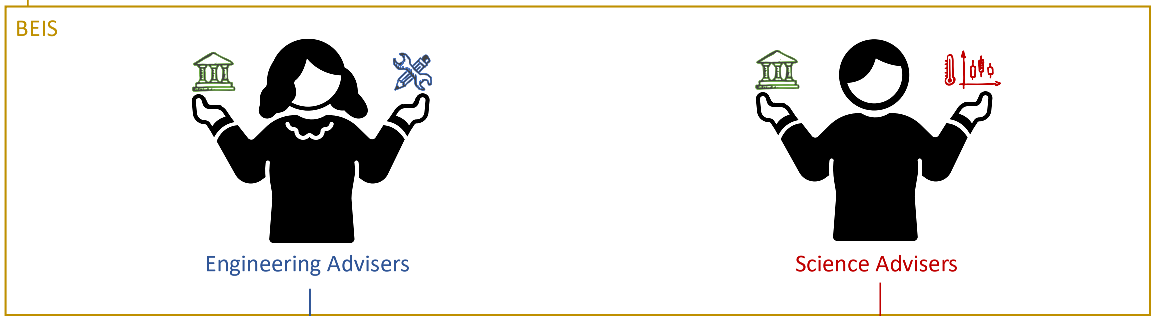
As illustrated in chapter 5 (ibid), policy officers reported that, unlike science advice, engineering advice has a "trickier" economic component that warrants further discussion. Policy officers in this case were referring to the cost implications of the engineering advisers' recommendation and needed to check it against what senior civil servants considered economically acceptable (ibid). Again, policy officers are concerned about engineering advice clashing with what their hierarchical superiors consider economically (and therefore politically) acceptable. As mentioned above (section 7.2.5) if the engineering adviser's recommendation does not align with what senior civil servants consider politically acceptable, policy officers push back against the advice creating tensions in the policy-making process. Those tensions are less likely to appear with science advice which does not carry cost implications like engineering advice does.

To sum-up this section, science and engineering advisers' role share some similarities because they are embedded in the same policy space. However, differences appear when looking at the focus and narrative of science versus engineering advice, impacting the advisers' relationship with policy officers. These similarities and differences are summarised in figure 7.4 below.

Figure 7.4: Similarities and differences between engineering and science advisers at BEIS

Both science and engineering advisers are embedded in the same policy space (BEIS), resulting in similarities between the roles. Both:

- Interface with generalist policy officers in charge of policy projects
- Learn how to communicate engineering and scientific information to policy officers
- Engage stakeholders to gather relevant information for the policy project



However, the focus and narrative of engineering and science advice differ, impacting the relationship between the advisers and policy officers

	Engineering advisers	Science advisers
Question Focus	Object-focused questions on the performance of built systems and their components	Questions focused on the functioning of eco- and bio-systems
Question Type	Goal-oriented	Explanation-oriented
Narrative	Prescriptive, suggest steps to reach solution	Descriptive, describing scenarios about what might happen if a threshold is exceeded or not
Impact on relationship with policy officer	Tensions with policy officers trying to solve the same policy problem in a different way High compatibility provided both parties disclose how they balance evidence	Science advice is less constraining for policy officers, it is not prescriptive. Less tensions. Science advice is not suggesting a solution. Less valuable for policy officers trying to problem-solve.

7.4 Science versus engineering advice in a UK government department: the application of science advice literature concepts to intra-ministerial engineering advice

7.4.1 Going back to the science advice literature

Results detailed in chapter 5 and the ensuing discussion of these results above (section 7.3) highlight the similarities and differences between science and engineering advice at BEIS. Points raised in the comparison of science and engineering advice, in turn, help us answer the following question running through the literature review (chapter 2): can science advice literature concepts be applied to conceptualise intra-ministerial engineering advice? The following sections answer this question by dividing science advice concepts into three sets:

- Science advice literature concepts that apply to both intra-ministerial science and engineering advice.
- Science advice literature concepts that do not apply to either intra-ministerial science or engineering advice. This is linked to the fact that science advice literature overlooked the intra-ministerial policy making context (chapter 2, section 2.1.8) and, as a result, some concepts do not apply to science or engineering advice in a UK government department.
- Science advice concepts that hold for intra-ministerial science advice but should be adjusted to conceptualise engineering advice. This is linked to the difference in focus and narrative between science and engineering advice highlighted above (section 7.3) and overlooked by the science advice literature (chapter 2, section 2.1.9).

7.4.2 Science advice literature concepts that apply to both intra-ministerial science and engineering advice

As explored in section 7.3.5 and illustrated in figure 7.4 above, there are multiple similarities between the roles of science and engineering advisers at BEIS. These similarities include interfacing with policy officers in charge of the policy project, learning how to communicate with them and how to engage stakeholders to get the evidence needed to answer the policy question. As stipulated in the literature review (chapter 2, section 2.2.7), these similarities map on to science advice literature concepts that broadly describe science advisers' role in policymaking; for instance: multidisciplinarity, boundary-spanning and knowledge brokerage. These concepts, as detailed below, therefore apply to both science and engineering advice at BEIS. To be clear, not all science advice concepts apply to an intra-ministerial setting as we will see in section 7.4.3, but some of the ones that do can be used to describe science and engineering advice in the context of my research.

The first of these concepts relates to multidisciplinarity. As explained in the literature review (chapter 2, section 2.1.3), post-normal and mode 2 science scholars argue that solutions to complex policy problems involve multiple disciplines and collaboration between the scientific, business, political communities, and society. As such, science advisers are part of a hybrid sociotechnical process where policy (socio-) is mixed with science (technical) (Jasanoff in chapter 2, section 2.1.1). According to the literature, the best scientific advisers can therefore interact with experts in fields peripheral to their own and understand their institution's policy agenda (ibid).

The same can be said of scientific and engineering advisers at BEIS. Indeed, as we saw (section 7.3.2), energy policy requires scientific, engineering, and socio-political evidence. Scientific and engineering advisers at BEIS are, as a result, part of a hybrid sociotechnical process where they gather 'technical' evidence (scientific and engineering evidence, respectively) and collaborate with policy officers more focused on socio-political evidence (ibid). To gather this evidence, science and engineering advisers mobilise expertise from different policy stakeholders using a mix discipline-specific and policy expertise (section 7.3.3). Echoing Jasanoff, advisers at BEIS therefore interact with experts and non-technical policy officers to gather information and frame their advice in a way they believe is relevant for the policy project at hand (ibid).

Concepts of knowledge brokerage and boundary-spanning applied to science advice by 'politics of expertise' authors (chapter 2, section 2.1.5) also hold for science and engineering advice at BEIS. Politics of expertise authors argue that science advisers act as knowledge brokers meaning they gather and synthesise information from the scientific and policy communities when making recommendations. This includes engaging with different knowledge sources and evaluating the information provided by these sources in the context of the policy project. Echoing Jasanoff and STS authors (chapter 2, section 2.1.4), politics of expertise authors also add that, as a result of the "coordination work" they perform between science and policy, scientific advisers develop a specific set of boundary spanning skills.

The same concepts can be used to describe the work of science and engineering advisers at BEIS. Both, as explained above (section 7.3.3), rely on a mix of discipline specific expertise and policy and process expertise to engage stakeholders and collaborate with policy officers. Science and engineering advisers need to be familiar with science/engineering concepts to gather scientific/engineering evidence but need to be familiar with the policy project and process to articulate this information "in a way policy officers would find useful" (ibid). To perform this knowledge-brokerage exercise efficiently, science and engineering advisers develop a set boundary spanning skills. As explored in sections 7.1.7 and 7.3.4, this includes being sensitive to policy officers and stakeholders concerns, and learning how to communicate scientific and engineering information to policy officers.

In addition to being knowledge-brokers, Jasanoff noted that science advisers are involved in a "negotiation" process between scientific claims and political context (chapter 2, section 2.1.1). The same could be said for science and engineering advisers at BEIS, who, as mentioned above (section 7.3.3), keep the policy context in mind when gathering and processing scientific and engineering evidence. BEIS' science and engineering advisers are also involved in a negotiation process with policy officers when discussing the information gathered. As we saw (section 7.2.7), while science and engineering advisers gather science/engineering evidence, policy officers engage policy actors to collect and analyse the socio-political evidence they need to inform the policy project. Science/engineering advisers and policy officers then get together to discuss their recommendations and how all the evidence gathered can fit together in the context of the policy project (ibid). At this stage, policy officers can push back against the advisers' recommendations as they might not be politically acceptable (section 7.2.5 and 7.3.7). This leads to a negotiation between all parties to find a solution to the policy problem that satisfies scientific/engineering constraints and policy officers' concerns. It should be noted however that push back from policy officer is more likely to happen with engineering advisers rather than science advisers (section 7.3.7), the implications of this point for science advice literature concepts are discussed in section 7.4.4 below.

Finally, the last key concept to mention in this section is science policy authors' notion of "transparency" (chapter 2, section 2.1.6). These authors argue that, when giving advice, science advisers should not try to obscure the complex negotiation process that precedes the recommendation but instead act with "professional humility" (ibid). Acting with "professional humility" means making transparent the limits of one's knowledge, the extent of uncertainty it is based on and, as a result, the different policy paths that might exist. As we noted in the literature review this concept is very similar to Pielke's famous concept of "honest brokerage" (ibid).

This echoes points made earlier in this discussion (sections 7.2.8 and 7.3.4) about the trust generated when engineering/science advisers and policy officers disclose how they collect evidence and what trade-offs are made when processing the evidence. As mentioned (ibid), when advisers and policy officers discuss the evidence they gather, they often disclose the contradicting stakeholder views they gathered and how they choose between them in the context of the project. By sharing how the evidence was analysed and weighed, or "acting with professional humility", advisers and policy officers are able to see how the other came up with their answer. This generates trust between advisers and policy officers and, in turn, enables them to collaborate more easily on policy projects (ibid).

7.4.3 Science advice literature concepts that do not apply to intra-ministerial science and engineering advice

Although some concepts from the science advice literature can be used to analyse the role of science and engineering advisers at BEIS, this is not the case for all science advice literature concepts. As explored in the literature review (chapter 2, section 2.1.8), science advice literature concepts were developed based on case studies that focus on organisations that advise yet sit outside of central government. In other words, science advice overlooked advice in ministries and, as a result, some of the literature's concepts do not apply in an intra-ministerial setting. Such concepts include "boundary work" and "stage management" which do not apply, at least in the sense meant in the science advice literature, to the role performed by either science or engineering advisers at BEIS.

As explained in the literature review (chapter 2, sections 2.1.1 and 2.1.4), Jasanoff and subsequent STS authors described part of science advisers' role as doing "boundary work". Boundary work here refers to the sharp boundaries between science and policy drawn by science advisers to reclassify their advice as "just science" and prevent non-scientists from challenging it (ibid). When this boundary holds, according to STS authors, political decision-makers accept the science advisers' recommendation, and their advice is "invested with unshakable authority" (ibid).

Although this might hold true for the EPA or FDA's advice to the US congress, science and engineering advisers at BEIS cannot be said to engage in this type of "boundary work". As we saw (section 7.2.2), science and engineering advisers at BEIS rephrase the policy officers' initial questions using scientific or engineering terms. However, advisers do not do this to create a separation between science/engineering and policy but to be able to correctly engage with stakeholders to gather the scientific/engineering evidence needed to inform the policy project (sections 7.2.2 and 7.2.3). In fact, scientific and engineering advisers at BEIS take into account policy context when gathering scientific/engineering evidence and often disclose how they weighed the evidence gathered based on policy consideration to policy officers (section 7.3.4). Doing so allows policy officers to incorporate the science/engineering advisers' suggestions more easily into the policy proposals (section 7.3.7). Alternatively, if the advice does not match the socio-political evidence gathered by policy officers (i.e. the advice is not politically acceptable), policy officers push back prompting advisers to find an alternative solution (ibid). Either way, at BEIS, scientific and engineering advisers do not reclassify their advice as 'just science/engineering' to prevent policy officers from challenging it. Instead, as noted in the literature review (chapter 2, section 2.3.2), they follow an open approach to policy-making representative of UK government departments focused on consensus and collaboration.

The other science advice literature concept that does not seem to apply to engineering and science advice at BEIS is what STS authors have labelled "stage management" (chapter 2, section 2.1.4). Stage management refers to the work advisers put in to maintain a division between "front and backstage", between what information is deliberately displayed and what is carefully concealed when a recommendation is given (Hilgartner in chapter 2, section 2.1.4). The concept refers to the way advisers "enclose and disclose information" to frame their advice to policy makers in a way that hides the vested interests that might seek to influence their advice (ibid).

At BEIS, contrary to what STS authors have extrapolated from their observations of the US National Academic of Science, science and engineering advisers are open about the vested interests that seek to influence their advice. As explored above (section 7.3.4), advisers handle conflicting evidence, sometimes because different stakeholders in that policy space have competing interests or sometimes because stakeholders disagree with the aim of the policy project. When advisers and policy officers discuss the evidence they gather, they often disclose the contradicting stakeholder views they gather and how they reconciled/chose between them in the context of the project (ibid). As we pointed out (section 7.2.7), this is facilitated by the fact that policy officers often engage the same stakeholders as the advisers and are therefore aware of, or struggle with, similar competing interests. Additionally, policy officers sometimes explicitly push back again the advisers' recommendations as they might not be acceptable to the senior civil servants (SCS) approving the policy proposal (section 7.3.7). In this case, science and engineering advisers will work with policy officers to find an alternative solution that satisfies engineering/scientific constraints and better aligns with the SCS' interests (ibid). As my results and discussion show, engineering and science advisers at BEIS do not seek to hide different policy actors' interests when framing their advice. Again, this can be attributed to the UK's intra-ministerial style of policy making where the focus is on collaboration with, and consensus between, multiple policy stakeholders and their views (chapter 2, section 2.3.2).

7.4.4 *Science advice concepts that hold for intra-ministerial science advice but should be refined to apply to engineering advice*

As we have seen, some science advice literature concepts do not apply in an intra-ministerial context, and some apply to both intra-ministerial science and engineering advice. This leaves us with one last set of concepts which apply to science advice at BEIS but need to be refined to apply to engineering advice. This goes back to the epistemological difference between science and engineering and its implications for policy highlighted above (section 7.3.6 to 7.3.8), implications overlooked by the science advice literature (chapter 2, section 2.1.9). As a consequence, science advice literature concepts of "negotiation" and "advice narrative" can be applied to science advice at BEIS but have to be adjusted to conceptualise engineering advice.

As mentioned above (section 7.3.6), science advice and engineering advice have different disciplines, science and engineering (respectively), at their core. Disciplinary differences are visible in the questions policy officers ask science and engineering advisers (ibid). In turn, this has a direct influence on the way science and engineering advisers answer policy officers' question and frame their advice (section 7.3.7). This impacts the advisers' relationship with policy officers (ibid), tying in with the literature's concept of "negotiation" (chapter 2, 2.1.1).

As STS authors noted, science advisers are involved in a "negotiation" process between scientific evidence and socio-political context (ibid). When negotiating with policy makers, science advisers create advice narratives that involve description and explanation with limited policy judgements (chapter 2, section 2.2.7). This applies in the context of my research where, to answer policy officers' questions, science advisers produce a descriptive, explanation-oriented narrative (section 7.3.7). As we saw (ibid), because science advice is framed in a more descriptive than prescriptive way, policy officers do not often push back against it as it does not significantly narrow down policy options.

By contrast, "negotiation" between engineering advisers and policy officers can be more complicated (ibid). When answering goal-oriented questions, engineering advisers produce prescriptive narratives outlining practical steps to solve part of the policy problem. This can create tensions with policy officers who pushing back against engineering advisers' recommendations as they would not be acceptable to the senior civil servants (ibid). This keeps the negotiation process going as engineering advisers propose new solutions until they find one that is technically feasible and satisfy policy concerns. Both science and engineering advisers at BEIS are therefore involved in a "negotiation" process. However, due to the difference in narrative between science and engineering advice, this process can be more conflictual in the case of engineering advice, a point not made in the literature.

To sum up this section, science advice concepts can be divided into three sets. The first set includes concepts like "multidisciplinary", "boundary-spanning" and "knowledge brokerage" that apply to both intra-ministerial science and engineering advice. The second set includes concepts like "boundary work" and "stage management" that do not hold in a UK intra-ministerial setting and therefore cannot be applied to either science or engineering advice at BEIS. The last set includes concepts like "negotiation" and "advice narrative" that apply to science advice at BEIS but must be nuanced to conceptualise engineering advice. The three sets of science advice concepts and their applicability to intra-ministerial science and engineering advice are summarised in figure 7.5 below.

Figure 7.5: Which science advice literature concepts can be applied to intra-ministerial science and engineering advice and why

	Science advice literature concepts	
Applies to both intra-ministerial science and engineering advice	• **Multidisciplinarity** • **Boundary-spanning** • **Knowledge brokerage** • **Professional humility**	Concepts general enough to describe the role of both science and engineering advisers at BEIS.
Applies to neither intra-ministerial science and engineering advice	• **Boundary work** • **Stage management**	Concepts developed based on case studies that focus on organisations that advise yet sit outside of central government. Do not apply in UK intra-ministerial context.
Applies to intra-ministerial science advice but not engineering advice	• **Negotiation** • **Advice narrative**	Concepts developed without looking at the epistemological differences between science and engineering. Applies to science advice at BEIS but needs to be refined to apply to engineering advice.

7.5 What are the impacts of the UK civil service's institutional structure and culture on engineering advice?

7.5.1 Linking results back to the literature

The last phase of my research was designed to gather the empirical data necessary to understand the impact of the UK government's structure and civil service culture on engineering advice. As explained in my methodology chapter (section 3.7), this consisted primarily of document analysis and ethnographic interviews of senior civil servants who used to or currently supervise the engineering advice team, its directorate, and the policy teams they work with. The results of this research phase are presented in chapter 6 where I detail how changes in government structure and ministerial vision have shaped the role of engineering advisers at BEIS (see figure 6.1). Chapter 6 also explores the impact of the civil service culture, and in particular its ‘generalist ethos’, on engineering advice (see table 6.1).

Analysing the different themes explored in chapter 6 with the intra-ministerial advice literature and previous discussion sections in mind surfaces key insights about engineering advice deployment in policy. This includes how political context and vision can help or hinder the development of intra-ministerial engineering capacity and advice. It also prompts a reflexion on how ministerial team arrangement impacts the engineering-policy interface resulting in the tensions between engineering advisers and policy officers explored in section 7.2. This, in turn, brings us to the influence of what intra-ministerial advice authors call the “generalist ethos” of the civil service on engineering advice (chapter 2, section 2.3.3). This includes a discussion of the negative impact of staff turnover on communication and knowledge retention at the engineering-policy interface. Potential policy and educational strategies to alleviate the issues raised and facilitate engineering advice deployment in policy practice are introduced throughout this section.

7.5.2 The impact of political vision on engineering advice

As we saw in chapter 6 (section 6.1), political vision, the ideological leanings and policy priorities of the party in power, has an impact on intra-ministerial engineering capacity and advice. My definition of political vision, inferred from my participants’ comments, mirrors that of Page (chapter 2, section 2.3.3) who explains that intra-ministerial policy making is shaped by “policy principles” and “policy lines”. “Policy principles” reflect the government’s views on how public affairs should be arranged and “policy lines” refer to the strategies prioritised to address specific policy problems. As detailed in chapter 6, Page’s point holds true at BEIS (and previously DECC) in two inter-connected ways. First, the government’s political vision influences the remit and mission of the department and, in turn, how it is staffed and how policy making works within it. Second, political vision influences what counts as politically acceptable which, as we established (section 7.2.5), policy officers take into account when drafting policy proposals. Through those two mechanisms, political vision therefore affects intra-ministerial engineering advice. As discussed in the paragraphs below, depending on the political vision, this can either mean enabling or hindering the development of engineering capacity and advice.

As shown in chapter 6, political context and vision can be favourable to the development of intra-ministerial engineering advice. Taking the example of the creation of DECC, I pointed out that the central government's engineering capacity had been depleted after the "policy principles" of the 1980s saw infrastructure delivery delegated to arms-length bodies and the private sector. Additionally, by the mid-2000s, a series of public health scandals in the 1990s and early 2000s brought governmental use of science and engineering evidence to the fore. As mentioned (chapter 6, section 6.1.1), although these were public health scandals, science and engineering were grouped together, meaning focus on science benefited engineering capacity as well. DECC was created in this context and, in-line with the Labour government's vision at the time was set-up to lead the "global effort against climate change", "reduce greenhouse gas emissions" and "ensure the UK's supply of clean energy". Given its' mission statement, DECC aimed to be a scientifically and engineering heavy department, and given the political context at the time, that meant hiring scientists and engineers back into the civil service and into DECC.

Within a certain political context and vision, key actors also play an important role in developing intra-ministerial engineering capacity. As pointed out in chapter 6 (section 6.1.2), David MacKay, DECC's first CSA, was an influential figure in creating and growing the department's engineering advice team. Again, given DECC was a newly created department with a stated focus on science and engineering and the calls for bringing back science and engineering capacity within central government, David MacKay was able to repeatedly make the case for hiring more engineers at DECC. In other words, wider political context and machinery of government (MoG) changes enabled and supported DECC's CSA push to hire more in-department engineers. This shows how the interplay between structural factors (political context, political vision, ministerial mission) and key individuals, especially during MoG changes, can be favourable to the development of engineering capacity and advice.

However, as explored in chapter 6 (section 6.1.4), political context and vision can also act as a barrier to the development of engineering advice. Taking the example of the creation of

BEIS, I pointed out that one of the main reasons behind merging DECC and BIS (to form BEIS) was due to the competing aims of both departments. DECC was a Labour initiative aiming to decarbonise the energy system whereas BIS was economics focused, tasked with supporting business growth and industry (ibid). Difference in aim between the two departments were visible around carbon pricing, with DECC wanting to increase the prices to encourage decarbonisation and BIS subsiding them to promote industry growth. As a result, the Conservative government merged DECC and BIS to resolve these tensions and created a single department, BEIS, instead. Reflecting the Conservative government's policy vision on climate change, BEIS's aim was to "align economic and environmental objectives and work with industry to show that investment in clean energy are investments in growth" (ibid).

During this MoG change, DECC's engineering team was moved to BEIS, however BEIS' remit and mission increased the tensions between the engineering advisers and their policy counterparts. As detailed in chapter 6 (ibid) and clear from the previous paragraph, the Conservative government's vision and by extension BEIS' vision was closer to BIS' mission than DECC's aim. Policy officers at BEIS, who, as we established (section 7.2.5), take into account political acceptability when drafting policy, were therefore more concerned with the cost of decarbonation to industry and consumers than they were at DECC. This proved challenging for the engineering advice team coming from DECC as policy officers were more likely to push back against their advice as it would not be acceptable to industry and consumers and therefore to the SCS approving the policy (ibid). This shows how political vision, by influencing ministerial remit and mission, can increase tensions at the engineering-policy interface, impacting the functioning of intra-ministerial policy making.

This section highlights how political context and political vision impact intra-ministerial engineering advice deployment. Sometimes context and governmental vision influence ministerial missions in way that enables engineering capacity and advice development, as was the case with DECC. Sometimes, they can affect notions of political acceptability and increase tensions at the engineering-policy interface, as was the case with BEIS. It is hard to draw further political or policy recommendations from this analysis as political context and vision are influenced by a wide array of factors and their impact will vary from department to department let alone from country to country. However, I make this point to stress the importance of looking at the wider political landscape and its' evolution when exploring engineering advice for policy beyond BEIS. Additional contexts of interest for analysing engineering advice deployment in policy practice are presented in this thesis' conclusion, under 'avenues for future research'.

7.5.3 The importance of intra-ministerial teams' arrangement and profiles

Besides looking at the importance of political context and vision, chapter 6 (section 6.1.2) also highlights how the engineering team's set-up influences the way engineering advice is given and received. The engineering advice team was set-up, from its creation at DECC until my fieldwork, to help answer policy teams' engineering-related questions in the context of specific policy projects. This includes advising on internal projects and, following policy failures, acting as an intelligent customer of commissioned research, helping policy teams frame and review outsourced technical work (ibid). As discussed in section 7.1 and 7.2, this set-up results in engineering advisers becoming 'generalist engineers' creating both tensions and compatibility when interacting with policy officers. Tensions include engineering advisers not being able to influence 'policy lines' (section 7.2.2), engineers and policy officers struggling to communicate and understand engineering information (section 7.2.3 and 7.2.4), and engineers and policy officers having different understanding of political acceptability (section 7.2.5). However, provided engineering advisers and policy officers are able to communicate how they processed engineering and socio-political evidence, they develop mutual trust and collaborate more easily on policy projects (sections 7.2.6 to 7.2.8). The rest of this section therefore looks at how intra-ministerial team arrangement and profiles can be tweaked to promote compatibility and avoid tensions at the engineering-policy interface.

Drawing on chapter 6 and section 7.2 above, engineering advice deployment at BEIS could be facilitated by assisting the engineering advice team in the following ways. Continuing professional development (CPD) modules could be designed and offered to help engineering advisers communicate engineering information to non-technical policy advisers. This training could be developed in collaboration with more experienced engineering advisers and policy officers to leverage the communication best practices they acquired with experience (examples in section 7.2.6). Additionally, training modules could be developed to familiarise engineers with the policy officers’ ways of thinking and approaching socio-political evidence. Again, this could be designed by leveraging the insights of experienced engineering advisers and policy officers who are working together or have collaborated in the past (examples in section 7.2.7 and 7.2.8). Going beyond CPD, higher education institutions are developing new engineering education programmes, at undergraduate and postgraduate level, combining technical training and skills with social-scientific and policy knowledge (Lazar, Liote and Cooper, 2023; Liote, 2023). The engineering advice team would benefit from hiring graduates from such programmes who will be familiar with engineering issues and practice in a policy context. The CPD and university training described above would help engineering advisers, especially ones with less experience, communicate with policy officers more easily. As mentioned above (sections 7.2.6 to 7.2.8), this would help foster mutual trust and facilitate collaboration between engineering advisers and policy officers.

Besides education and training implications, chapter 6 and section 7.2 also hint to two structural points related to the engineering team. First, the engineering advice team has an important role to play in policy making even when the engineering research is commissioned. As we saw, following an issue with solar feed-in tariffs modelling (chapter 6, section 6.1.2), the engineering team acts an intelligent customer of commissioned research. This observation should serve as a reminder that, even if public administrations outsource technical research, there is still a need for internal engineering advisers to help policy teams set-up and review the consultants’ work and avoid policy failures. The second structural point relates to engineering advisers not being able to influence ‘policy lines’, restricting their options when developing ‘policy measures’ (section 7.2.2). Administrations wishing to fully leverage engineering advice should find a way for their engineering advisers to feed-in when the policy course of action is debated and selected. Of course, the way this is enabled in practice depends on context and further research is needed to understand how this could work at DESNZ and elsewhere (see conclusion section on ‘avenues for further research’).

Observations and analysis made in chapter 6 and the discussion so far also have implications for policy teams working on projects requiring engineering input. The point made about CPD and higher education programmes made above also holds for policy teams. Indeed, policy teams would benefit from training helping them understand engineering evidence, engineering ways of thinking and how to communicate with engineering advisers. This training could also include the best practices mentioned in sections 7.2.6 to 7.2.8 above. This would enable better communication between policy officers and their engineering counterparts, creating trust and enabling good cooperation. Additionally, policy teams would benefit from more systematically having policy officers that have an engineering background. The new engineering education programmes that combine engineering and socio-scientific skills and knowledge mentioned above would produce the ideal graduates for these positions. Echoing points made in the literature (chapter 2, section 2.2.6), engineering-trained policy officers could act as a point of contact for engineering advisers, further enhancing communication between the engineering advice and policy teams. As McCarthy suggests, a 'systems architect' role could be added at a to "see where communication could break down, and where and why divergent expectations emerge" between engineers and policy advisers (ibid). Again, these suggestions are based on the context of my research and different ways of organising intra-ministerial engineering and policy capacity might be possible. Uncovering these and the benefits they might bring however requires further research; this is covered in the conclusion.

7.5.4 The impact of staff turnover on communication at the engineering-policy interface

In addition to political vision and team arrangement, the civil service culture creates friction at the engineering-policy interface. As explored in the literature review (chapter 2, section 2.3.3) and in chapter 6 (section 6.2.1), the UK civil service rewards exposure to and experience of different policy areas, meaning policy officers do not specialise and move around to further their career. This is also referred to as the "generalist ethos" of the civil service (ibid). In the case of my research, policy officers at BEIS rarely stay in their role for more than two years. Engineering advisers however stay in their role for an average of four years (ibid). Reasons for this are covered in chapter 6 and include the difficulty of recruiting for specialist positions hence the incentive to keep engineering advisers in their role for longer, and the low number of engineering advice teams across the civil service for the engineering to get promoted into. The civil service culture therefore encourages turnover in policy teams, less so in the engineering team, although engineering advisers also leave on average after being promoted once (ibid).

This amount of turnover, especially in the policy teams, negatively impacts communication at the engineering-policy interface. As explained in chapter 6 (section 6.2.2) and discussion section 7.2.4, overtime non-technically trained policy officers pick up on some engineering knowledge by working with the engineering team, facilitating collaboration on energy policy projects. When a policy officer leaves and is replaced however, the cycle starts again, and newly appointed policy officers have to learn the engineering knowledge underpinning the policy area again. The same logic applies to the communication preferences of both the policy officers and engineering advisers. Overtime, engineers and policy officers work out strategies to overcome their communication issues, often developing a 'common language' to discuss the evidence they collected and weighed. However, every time a policy officer is replaced, the engineer and new policy officer have to rebuild a working relationship, including redeveloping their own common language. Turnover therefore limits good communication between the engineering advice and policy teams, in turn reducing the mutual trust between actors necessary for good policymaking in this space as explained in section 7.5.3 above.

Reducing turnover in policy teams seem particularly complicated as it would require a large cultural, structural and human resources shift in the civil service. Some of the policy suggestions mentioned above (section 7.5.3) however, could help alleviate the communication problems triggered by staff turnover. Running a CPD module for engineering advisers and policy officer who just joined their team might help them figure out how to work together faster. Hiring engineering advisers and policy officers already trained (while at university for instance) to communicate with one another could also be helpful. More systematically having policy officers with an engineering background in policy teams would have the same effect. Although it does not tackle the root cause of the problem, implementing some of these suggestions could improve communication between engineering advisers and policy officers including the ones who recently joined their team.

7.5.5 The impact of turnover on knowledge retention at the engineering-policy interface

As established in chapter 6 (sections 6.2.2 and 6.2.3), turnover also creates knowledge retention issues at the engineering-policy interface. The high amount of turnover in policy teams means that experienced policy officers leave and are replaced by new team members who might not know as much about the history of the policies in that area. This includes why and how some of the previous and ongoing energy policy projects came to be, the initial problem the policy was trying to solve and the view of stakeholders on the policy. Engineering advisers, by contrast, tend to stay in their role for longer and become the knowledge holders in their policy area. As explored in chapter 6 (section 6.2.2), this information asymmetry can lead to some tension as policy officers feel they know less than the engineers and struggle to push back against the engineers' recommendations they might not agree with. This is made worse by fact that engineering advisers' advice narrative is prescriptive (see section 7.3.7 above), and without a way to push back, policy officers can feel like they have to do as the engineering advisers say. The difference in turnover speed between the policy teams and engineering advice team can therefore make policy officers "servants of the [engineering] experts" (Page 2010 in chapter 2, section 2.3.4).

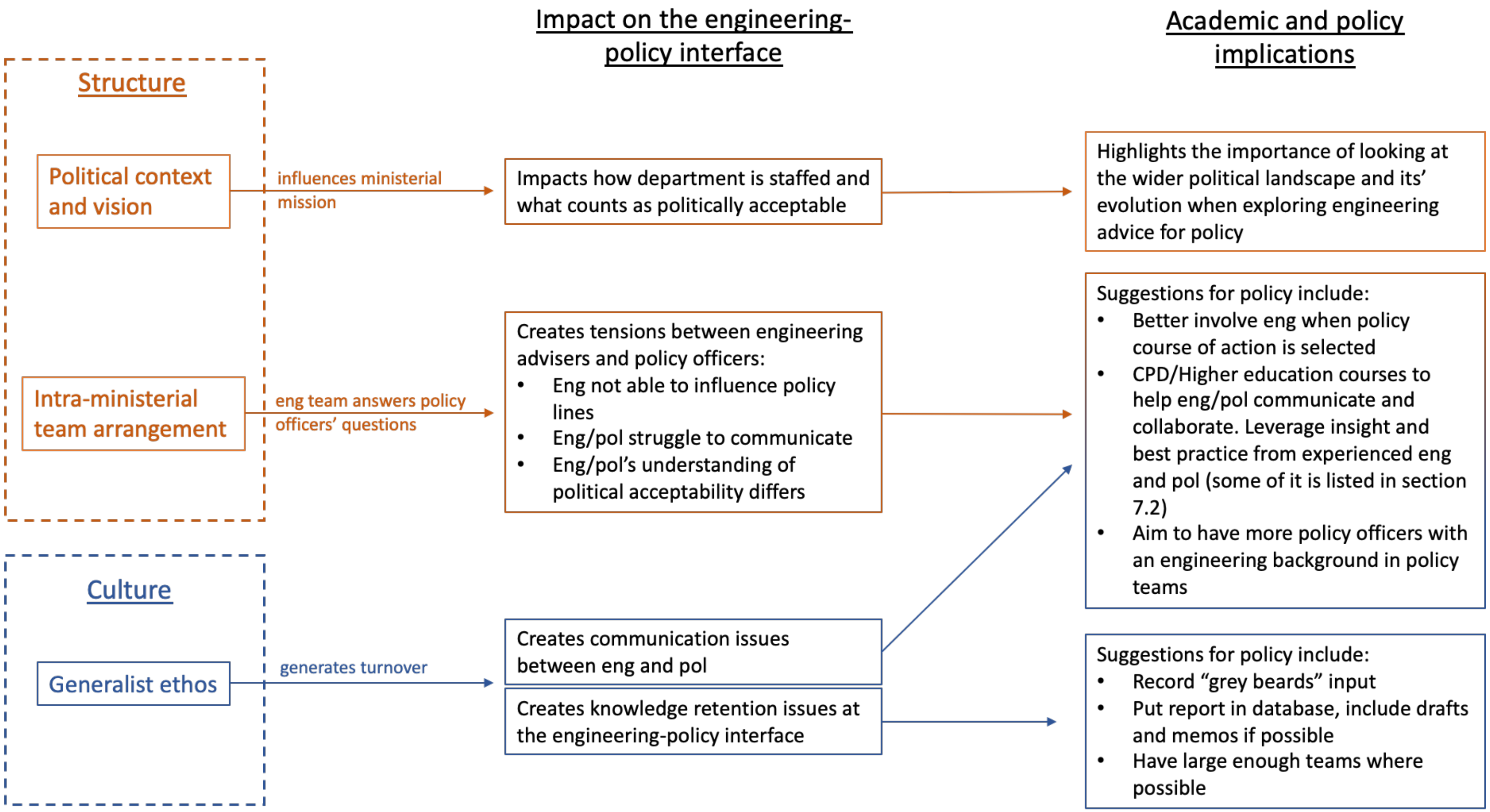
On top of impacting the balance of power at the engineering-policy interface, turnover in both the engineering and policy teams is a challenge for institutional memory retention. Indeed, as observed in chapter 6 (section 6.2.3), incoming staff in the engineering advice and policy teams might not have the knowledge of BEIS' structure and history accrued by their predecessors over time. New policy officers and engineering advisers might also lack insight into the previous work done on the policy projects they will be responsible for. As a result, they might change the original or intended direction of certain policy projects reducing policy continuity in that policy space.

As pointed out in chapter 6 (ibid), this is also worsened by BEIS' reliance on commissioned research, which creates a situation where the consultants are the only ones who really know how the research was done. Even if the engineers act as intermediaries between the consultants and the policy teams, no one within BEIS (even engineering advisers) has a full view of how the outsourced work is carried out. Additionally, once the engineer who supervised the commissioned project leaves the department, BEIS is left with very little knowledge about how the outsourced work was done.

As mentioned above (section 7.5.4), reducing turnover in the civil service is extremely hard. However, strategies exist to help retain knowledge at the engineering-policy interface, some were mentioned by my participants in chapter 6 (section 6.2.3). These include asking civil servants who have been in the department for a long time, for their insights. Policy officers and engineering advisers could record their answers to retain this institutional memory after these experienced civil servants leave. Participants also mentioned putting the engineering team and policy teams' public reports on a dedicated database. This enables incoming engineering advisers and policy officers to find and refer to the previous work done in this policy area. This could be expanded to include the drafts, memos and conversations that led to the final reports, although this information would have to sit behind a portal that is not publicly accessible. Finally, the last strategy mentioned was having large enough teams so that, at any given point, part of the team would be able to share their institutional and policy knowledge with incoming staff. This should be done as much as possible within project size, staffing and budget constraints. Implementing these strategies would help retain institutional memory and knowledge within the engineering and policy teams, maintaining a balance of power at the engineering-policy interface that enables smooth cooperation in this policy space. Doing more ethnographic research on engineering advice in different contexts (see conclusion) might also surface additional knowledge retention strategies.

To sum-up, the UK government's structure and civil service culture impact engineering advice in multiple ways (see figure 7.6 below). Political vision, by influencing ministerial missions, can affect how a department is staffed and what counts as politically acceptable, in-turn facilitating or hindering engineering advice deployment. Team arrangement within a ministry also has an impact on engineering advice. Indeed, the way the engineering and policy teams were set-up at DECC then BEIS created some of the compatibility and tensions at the engineering-policy interface covered in discussion sections above. Finally, the turnover resulting from the civil service's "generalist ethos" creates knowledge retention and communication issues between engineering advisers and policy officers. Throughout this section I have also outlined potential strategies to alleviate some of engineering-policy interface issues created by the civil service structure and culture. These strategies can be seen in figure 7.6 below.

Figure 7.6: How the civil service's structure and culture impact engineering advice and related academic and policy implications



8 Conclusion

8.1 How is engineering advice deployed in energy policy practice?

This thesis set out to investigate engineering advice deployment in energy policy practice. As established in the introduction, engineering advice had never been systematically examined in the academic literature. The literature review (chapter 2) therefore explored and combined three adjacent fields of study to create a theoretical picture of engineering advice in a UK intra-ministerial context. The review of the science advice, engineering studies and UK intra-ministerial literature generated three research questions (**RQs**) to be empirically tested to further the understanding of engineering advice for policy:

- **RQ1.** How does engineering advice work in a UK government department?
- **RQ2.** What is the difference between science and engineering advice in a UK intra-ministerial context?
- **RQ3.** What are the impacts of the UK government's structure and civil service's culture on engineering advice?

The methodology (chapter 3) explained how the methods were chosen to gather and analyse the data needed to answer these three questions. Data collection was divided into three phases, each ethnographically investigating one of the research questions. The results of each research phase are presented in chapters 4 to 6, along with fragments of raw data including participant quotes and extracts from policy documents. The **results chapters** detail:

- **Chapter 4.** How engineers and policy officers interface at each stage of the policy advice process.
- **Chapter 5.** The similarities and differences in work process and content between the engineering and science advice team.
- **Chapter 6.** How changes in ministerial vision have shaped the role of engineering advisers at BEIS and the impact of the civil service's generalist ethos on engineering advice.

The discussion (chapter 7) combines insights from the literature review and empirical data from the results chapter to answer the three research questions. These answers, based on the ethnographic study of BEIS' engineering team, highlight **three key elements to look out for when conceptualising engineering advice deployment in policy practice** (illustrated in figure 8.1 below).

1. Look at who gives the advice and who receives it. This means examining the epistemology of engineering advisers in policy and its implications for the engineering-policy interface. My research suggests that, to answer engineering questions in a policy context, engineering advisers display practices and skills associated with both engineering and policy makers. In my context, engineering advisers possess traits typically linked with policy officers: they do not specialise in a specific area of engineering, they are quick learners and sensitive to stakeholder concerns, and they act as mobilisers of expertise displaying policy and process expertise. At the same time, engineering advisers display practices typically associated with engineering: they answer object-focus questions and work in an object-world, and they use engineering-specific expertise to problem solve.

This overlap in skills, expertise, and desire to problem-solve increases both the potential conflicts and compatibility between engineering advisers and policy makers. At BEIS, tensions can arise because engineering advisers frame how part of the policy problem should be answered, which, as Cooper (2020) noted, policy officers feel is their job. Policy officers however have more exposure to SCS and policy stakeholders' views and can therefore push back against engineering advice if they do not feel it is politically acceptable. These tensions are exacerbated by communication difficulties as engineering advisers struggle to communicate engineering information and policy officers struggle to understand it.

With experience however, engineering advisers and policy officers learn how to communicate with each other and see the complementarity of their roles. When engineering advisers and policy officers develop a 'common language' they realise that they are engaged in a similar stakeholder and evidence balancing exercise albeit with different types of evidence. At this point, engineering advisers and policy officers understand and relate to each other's role. Using the common language, they have developed, they are able to disclose the evidence trade-offs they are confronted with and recognise each other's expertise. This creates mutual trust and enables engineering advisers and policy officers to reach an agreement. With this said, an agreement between the two parties allows the creation of a policy proposal but does not guarantee the success of the policy created. Given all the challenges that exist at different stages of policy delivery, policy failure is still possible despite an initial agreement at the engineering-policy interface, and more research is needed to understand why that might be (see section 8.4 below).

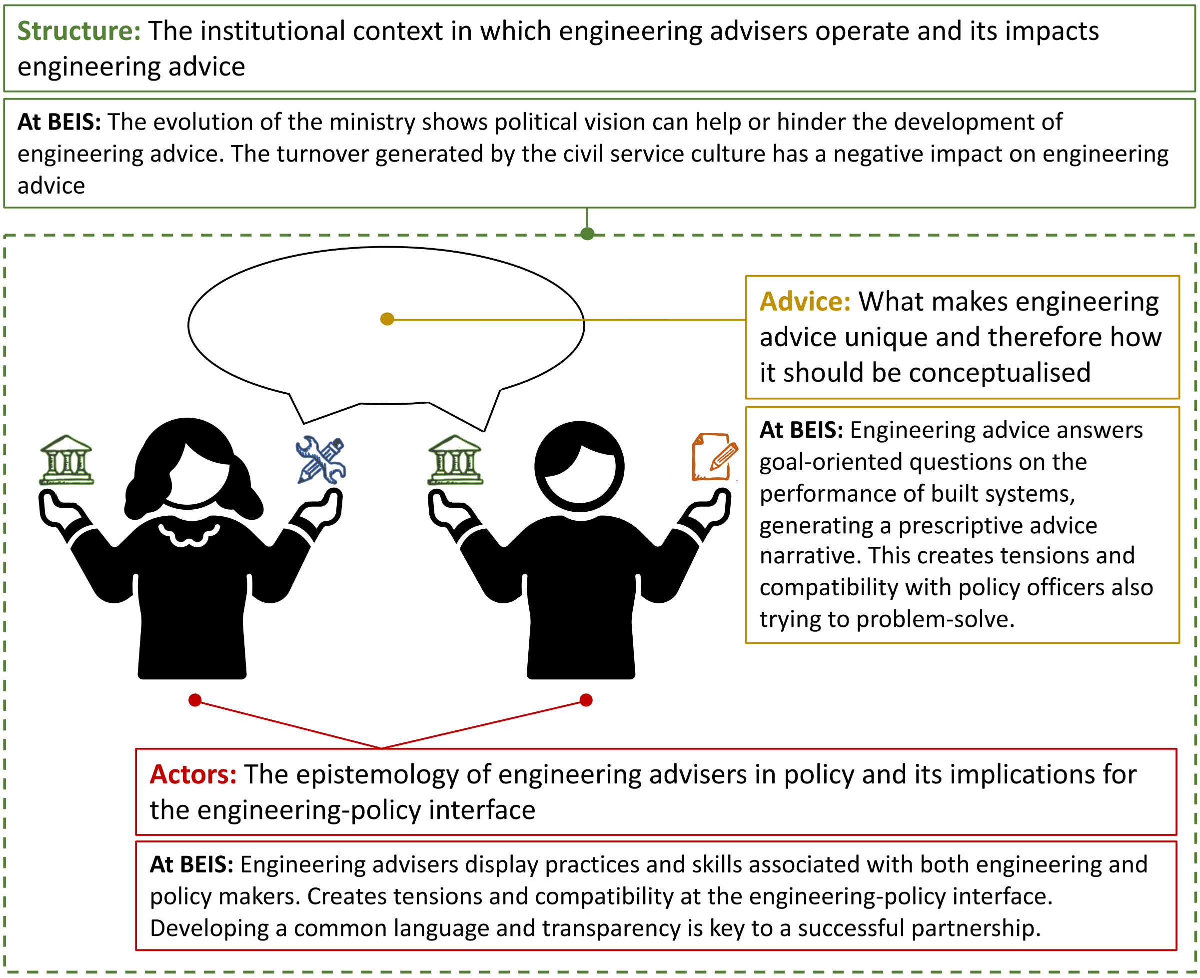
2. Look at the narrative and content of the advice. This means exploring what makes engineering advice unique and therefore how it should be conceptualised. In this thesis, this is done by contrasting engineering advice with science advice at BEIS, pointing out the differences between the two. My research suggests that the question type and therefore advice narrative differ between the two, resulting in different relationships with policy officers. Engineering advice answers goal-oriented questions on the performance of built systems and their components, generating a prescriptive advice narrative. As mentioned, this creates tensions with policy officers trying to solve the same policy problem in a different way or compatibility provided both parties disclose how they balance evidence. By contrast, science advice answers explanation-oriented questions on eco- and biosystems generating a descriptive advice narrative. Unlike engineering advice, science advice is less constraining for policy officers and creates less tensions. Equally, science advice does not suggest a solution and can therefore be less valuable for policy officers trying to problem solve.

These findings are useful for the conceptualisation of engineering advice, highlighting which concepts from the science advice literature can be applied to intra-ministerial engineering advice. My research suggests that concepts from the literature that are general enough, like "boundary-spanning" and "knowledge brokerage" apply to engineering advice. These concepts map on to points made when looking at how advice is given and received, with engineering advisers relying on a mix of discipline-specific and policy expertise to engage stakeholders and collaborate with policy officers. Additionally, as noted in the science advice literature, engineering advisers and policy officers that are transparent and "act with professional humility" collaborate more easily on policy projects.

Some science advice concepts however do not apply to intra-ministerial engineering advice. These include “boundary work”, “stage management” and “negotiation”. “Boundary work” and “stage management” do not apply in a UK intra-ministerial setting, to either science or engineering advice, as advisers follow an open approach to policymaking and do not prevent policy officers from challenging their advice. The concept of “negotiation”, closely tied with advice narrative, happens differently for science and engineering advisers at BEIS. Indeed, as explained, the negotiation between engineering advisers and policy officers surfaces tensions and compatibility between the two roles. This is not the case with science advice in the literature or at BEIS and needs to be considered when conceptualising engineering advice.

3. Look at the structure in which the actors are embedded. This means understanding the institutional context in which engineering advisers operate and how it impacts engineering advice. In my case, this includes analysing the political context that led to the formation of BEIS’ engineering team and its evolution, as well as the culture of the UK civil service. This shows that political vision can influence ministerial missions in way that enables engineering capacity and advice development. Alternatively, it can also affect notions of political acceptability and increase tensions at the engineering-policy interface. Additionally, intra-ministerial team arrangement also impacts engineering advice. Indeed, tensions at the engineering-policy interface can be traced back to the engineering team’s initial set-up at DECC, set-up that had not changed at the time of my research. Finally, the turnover generated by the civil service’s generalist ethos hinders communication and knowledge retention at the engineering-policy interface, exacerbating the tensions aforementioned.

Figure 8.1: Understanding engineering advice deployment in policy practice means looking at who gives and receives the advice, the narrative and content of the advice and structure in which the actors are embedded



8.2 Policy insights

My analysis of engineering advice deployment at BEIS yields **two sets of policy insights**: the first relates to education and training, and the second to organisational structure. The points below are extracted from discussion section 7.5.

1. Education and training. Engineering advice deployment at BEIS could be facilitated by developing the following education and training programmes for both engineering advisers and policy officers. Continuing professional development (CPD) modules could be designed to help engineering advisers communicate engineering information to policy officers and help policy officers understand it. This training should be developed with experienced engineer advisers and policy officers to leverage the communication best practices they acquired with experience. Additionally, CPD modules could be developed to familiarise engineers with policy advisers' approaches to evidence and vice-versa. Again, this should be designed by leveraging the insights of experienced engineering advisers and policy officers who work/have worked together. These CPD modules would be particularly beneficial to new joiners on both sides of the engineering-policy interface to help them figure out how to work together faster. Overall, this training would enable better communication between policy officers and their engineering counterparts, reducing tensions and increasing compatibility between the two roles.

Going beyond CPD, these insights are also valuable for higher education institutions. My research shows a need for graduates who are technically trained and possess social-scientific and policy knowledge. Both the engineering advice and policy teams would benefit from hiring graduates from such programmes who will be familiar with engineering issues and practice in a policy context. Such graduate would be able to pick up on both engineering and policy concerns at the engineering-policy interface, easily collaborating with their engineering or policy counterpart (depending on which team they are on) quickly after they start.

2. Organisation structure. Engineering advice deployment could be facilitated by considering the following organisational adjustments. On the engineering team side, implicating engineering advisers to act as 'intelligent customers' when policy teams commission engineering research avoids policy failures. This point serves as a reminder that, even if public administrations outsource technical research, there is still a need for internal engineering capacity to assess the commissioned work. Additionally, administrations wishing to fully leverage engineering advice should find a way for their engineering advisers to feed-in when the policy course of action is debated and selected. Of course, the way this is enabled in practice depends on context and further research is needed to understand how this could work at DESNZ (BEIS' successor) and elsewhere (see section 8.4).

On the policy team side, policy teams would benefit from more systematically having policy officers that have an engineering background. The new engineering education programmes mentioned above would produce the ideal graduates for these positions. Engineering-trained policy officers could act as a point of contact for engineering advisers, further enhancing communication between the engineering advice and policy teams. Echoing McCarthy's recommendation, my research also suggest that creating a 'systems architect' role would be beneficial to engineering advice deployment. The systems architect's job would be to "see where communication could break down, and where and why divergent expectations emerge" between engineers and policy advisers (McCarthy, 2017).

Several strategies to retain knowledge at the engineering policy interface would also help engineering advice deployment. This includes asking civil servants who have been in the department for a long time for their insights and recording them. This would help retain institutional memory after these civil servants leave. Additionally, on top of the public reports produced, engineering advisers and policy officers could save the drafts, memos and conversations that led to the final reports on a non-public database. This would enable engineering advisers and policy officers to find and refer to the previous work done in this policy area. Finally, having larger teams – within project size, staffing and budget constraints – would help retain knowledge. This would mean that, at any given point, part of the team would be able to share their institutional and policy knowledge with incoming staff.

8.3 Limitations of study

My research is not without its limitations, all of which are listed in the methodology chapter (chapter 3, section 3.8.2) but worth repeating here. As with all qualitative studies, biases can affect the data collected, including social desirability effect and researcher's selective interpretation. In other words, participants can tell the researcher what they think is the socially accepted behaviour instead of what they think or do. And researchers might construct their version of what happened instead of capturing the participants' accounts. I tried to mitigate these biases in my research as much as possible by cross-referencing the data collected, practicing reflexivity and providing enough raw data to show how I developed my theoretical arguments. **Despite my best efforts however, it is possible that some biases could have affected parts of this study.**

Secondly, as with all ethnographic research, my work can only provide a picture of a limited range of reality. **This study focuses on a specific team within BEIS, the points made in the discussion and the policy insights derived from it have been developed in that context.** I cannot claim that the data I obtained are representative of the entire body of British civil servants, let alone of other actors (inside and outside government, in the UK and abroad) who play a part in engineering advice in policy. Although my approach can be reproduced in other contexts and points raised can guide further research, more work is needed to generalise many of the arguments presented in this thesis.

8.4 Avenues for future research

My research has been focused on BEIS' engineering advice team, this means that my findings have:

- Been developed by looking at roles and practices at the engineering-policy interface, not by following policy projects from inception to implementation
- Been developed in a specific ministry focused on a specific policy area (energy)
- Been developed in a central-government setting
- Used BEIS' science advice team as a contrast to the engineering team
- Been developed in the UK

To **further understand engineering advice deployment** in policy practice, future research could therefore ethnographically look at:

- The epistemology of engineering advisers in policy and its implications for the engineering-policy interface
- What makes engineering advice unique and how it should be conceptualised
- The institutional context in which engineering advisers operate and how it impacts engineering advice

in different contexts (see figure 8.2 below).

Focus on policy projects. One way to further our understanding of the engineering-policy interface would be to follow specific engineering-informed policy projects from their inception to their implementation. Depending on the project, this would foreground specific tools used by engineering advisers to inform policy, for instance how standards or models are used in policy making, which are mentioned but not analysed in depth in this thesis. Looking at particular policy projects would also highlight if and how private sector[16] and public sector values clash in engineering-informed policy projects. This would show if and how engineering advice can be taken over by private sector interests and what this means for engineering advisers. Additionally, analysing projects that were deemed policy successes and policy failures could help us identify what engineering-policy challenges have to be overcome to create successful policies.

Research a different ministry and policy area. Another way to expand on this research would be to use the methodology introduced in this thesis to look at engineering advice in another government department. The Department for Transport (DfT) for instance would be a good candidate as it covers an engineering heavy policy area. Doing a similar study at DfT would generate comparative ethnographic insights of the engineering-policy interface across ministries (BEIS vs. DfT) and across policy areas (energy vs. transport).

Study a different type of organisation. A third way to build on this thesis would be to ethnographically study engineering advice in an organisation outside of central government. Sticking with transport policy, this could mean looking at the engineering-policy interface at National Highways or in transport-focused select committees in Parliament. This would generate comparative insights across institutions: central government vs. arms-length agency in the case of National Highways, and executive vs. legislative branch in the case of Parliament.

Use a different contrasting discipline. A fourth way to expand on my findings would be to contrast engineering advice with something other than climate science advice. I used science as a contrasting discipline as the literature often groups science and engineering together and

[16] closely associated with engineering, see chapter 7, section 7.3.8

because BEIS' climate science team provided a good comparison point. Looking at other discipline-specific advice however might surface additional insights, like tensions or compatibility with engineering advice. Based on my findings economic advice could be a good candidate as engineering advice and cost are often mentioned together.

Look at a different country. Finally, this study could be the start of an international comparison of engineering advice for policy. Using a similar methodology to investigate the engineering-policy interface beyond the UK would likely touch on national preferences or styles of engineering advice. Comparing engineering advice internationally would also reveal how cultural context influences how the advice is given and received which would fit well with my anthropological methods.

Overall, looking at engineering advice in different contexts might reinforce some of my points and nuance some of my findings. This would also enable future researchers to share best practices and insights from this thesis with other organisations and find new organisational strategies to improve engineering advice deployment in policy.

Figure 8.2: Avenues for future research include looking at engineering advice deployment in different contexts

My thesis looks at engineering advice deployment at BEIS	**Focus:** Teams' role and practices	**Department:** BEIS **Policy area:** Energy	**Organisation type:** Central government	**Contrasting discipline:** Climate science	**Country:** United Kingdom
	+	+	+	+	+
Future research could look at engineering advice deployment in other contexts	**Other focus:** Projects end-to-end	**Other department:** DfT **Other policy area:** Transport	**Other organization types:** Arms-length bodies, Parliament	**Other contrasting discipline:** Economics	**Other countries:** International comparison
	=	=	=	=	=
This would expand the understanding of engineering advice by:	**Surface** additional insights like: **tools used by engineering advisers, role of the private sector** and **avoiding policy failure**	Generate **comparative insights** of the engineering-policy interface **across ministries and policy areas**	Generate **comparative insights** of the engineering-policy interface **across institutions**	**Surface** additional insights, like **tensions or compatibility with engineering advice**	**Explore national** preferences or **styles of engineering advice**

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Appendix A: Interview Information Sheet Template

Participant Information Sheet For Research Participant
UCL Research Ethics Committee Approval ID Number: 18261/002

YOU WILL BE GIVEN A COPY OF THIS INFORMATION SHEET

Title of Study: Understanding how engineering advice is deployed in energy policy practice

Department: Science, Technology, Engineering and Public Policy (STEaPP)

Name and Contact Details of the Researcher(s):
Laurent Liote, PhD Candidate at UCL STEaPP, <email>

Name and Contact Details of the Principal Researcher:
Dr. Adam Cooper, Associate Professor at UCL STEaPP, <email>

1. Invitation

You are being invited to take part in an interview for a research project. Before you take part, it is important for you to understand why the research us being done and what participation will involve. Please take time to read the following information carefully and discuss it with others if you wish. Ask us if there is anything that is not clear or if you would like more information. Take time to decide whether or not you wish to take part, participation is on an entirely voluntary basis.

2. What is the project's purpose?

I am trying to understand how engineering advice is generated and used when making energy policy decisions. I hope that this project:

- Contributes to a wider debate on the use of evidence in policy
- Contributes to a growing body of research on the often-neglected engineering advice
- Helps identify best practices leading to effective policy making

3. Why have I been chosen? (Inclusion Criteria)

I am asking you if you wish to take part in this study because you are an integral part of the engineering advice process within the Department of Business, Energy & Industrial Strategy.

4. Do I have to take part?

It is up to you to decide whether or not to take part. If you do decide to take part you will be given this information sheet to keep and be asked to sign a consent form. You can withdraw at any time until the final 'upgrade' report is written in September 2021 without giving a reason and without it affecting any benefits that you are entitled to. If you decide to withdraw you will be asked what you wish to happen to the data you have provided up that point.

5. What will happen to me if I take part?

If you decide to take part in this study you will be asked to participate in an interview. I will ask you questions about your career and role within your organisation as well as some of the projects you are working on. Interviews should last at least 60 minutes.

Consent will be obtained before each interview. Your data can be withdrawn from the study at any point after you have participated in a focus group or interview, until the final report is written in September 2021. I, Laurent Liote, will be the one conducting the interviews. Names, email address and job titles will be collected but the data will be pseudonymised when stored on a secure drive. The research report will be completed by September 2021 and will not feature any personal information, or details that could identify you. I might contact you via email to a clarify details from the initial interview and/or request a second, follow-up interview.

6. Will I be recorded and how will the recorded media be used?

The audio recordings of your activities made during this research will be transcribed. The audio files will then be deleted immediately, and transcriptions will be stored on a secure drive. Anonymised quotes may appear in any research outputs, such as papers or presentations at conferences.

7. What are the possible disadvantages and risks of taking part?

There are no anticipated risks to taking part in this project.

8. What are the possible benefits of taking part?

There are no direct benefits. However, the learnings from this research will help identify best practices leading to effective infrastructure policy making, which I believe will benefit the both the academic and policy community.

9. What if something goes wrong?

Should something go wrong during the research you should raise a complaint by contacting this project's principal investigator:

Dr. Adam Cooper, Associate Professor at UCL STEaPP

Email: <email> | Phone Ext: <phone>

This includes complaints regarding your treatment by the researcher and something serious occurring during or following your participation in the project (e.g. a reportable serious adverse event).

Should you feel your complaint has not been handled to your satisfaction by the principal investigator, you can contact the Chair of the UCL Research Ethics Committee – ethics@ucl.ac.uk

10. Will my taking part in this project be kept confidential?

All the information that we collect about you during the course of the research will be kept strictly confidential. The data will be anonymised and you will not be able to be identified in any ensuing reports or publications.

11. Limits to confidentiality

Confidentiality will be respected subject to legal constraints and professional guidelines.

12. What will happen to the results of the research project?

I will:

- Write a research report, where any personal data will be fully anonymised
- The research report will be sent to all participants via email
- Present the findings of the report during my PhD upgrade
- Write academic articles based on the study findings
- Present the findings in conference papers/at conferences
- Use the finding in my PhD thesis and related articles and presentations

13. Local Data Protection Privacy Notice

The controller for this project will be University College London (UCL). The UCL Data Protection Officer provides oversight of UCL activities involving the processing of personal data, and can be contacted at data-protection@ucl.ac.uk

This 'local' privacy notice sets out the information that applies to this particular study. Further information on how UCL uses participant information can be found in our 'general' privacy notice: https://www.ucl.ac.uk/legal-services/privacy/ucl-general-research-participant-privacy-notice

The information that is required to be provided to participants under data protection legislation (GDPR and DPA 2018) is provided across both the 'local' and 'general' privacy notices.

The categories of personal data used will be as follows: name, email address, job title and organisation

The lawful basis that would be used to process your *personal data* will be performance of a task in the public interest

Your *personal data will be processed so long as it is required for the research project* and will be pseudonymised before it is stored.

If you are concerned about how your personal data is being processed, or if you would like to contact us about your rights, please contact UCL in the first instance at data-protection@ucl.ac.uk

14. Who is organising and funding the research?

The UK's Engineering and Physical Science Research Council (EPSRC): https://epsrc.ukri.org/
University College London (UCL): https://www.ucl.ac.uk/

16. Contact for further information

Laurent Liote: <email>

Thank you for reading this information sheet and for considering taking part in this study.

Appendix B: Interview Consent Form Template

CONSENT FORM FOR INTERVIEW/FOCUS GROUP PARITICIPANTS IN RESEARCH STUDY

Please complete this form after you have read the Information Sheet and/or listened to an explanation about the research.

Title of Study:
Understanding how engineering advice is deployed in energy policy practice

Department:
STEaPP

Name and Contact Details of the Researcher:
Laurent Liote: <email>

Name and Contact Details of the Principal Researcher:
Dr. Adam Cooper: <email>

Name and Contact Details of the UCL Data Protection Officer:
Alexandra Potts: data-protection@ucl.ac.uk

This study has been approved by the UCL Research Ethics Committee: Project ID number: 18261/002

Thank you for considering taking part in this research. The person organising the research must explain the project to you before you agree to take part. If you have any questions arising from the Information Sheet or explanation already given to you, please ask the researcher before you decide whether to join in. You will be given a copy of this Consent Form to keep and refer to at any time.

I confirm that I understand that by ticking/initialling each box below I am consenting to this element of the study. I understand that it will be assumed that unticked/initialled boxes means that I DO NOT consent to that part of the study. I understand that by not giving consent for any one element that I may be deemed ineligible for the study.

		Tick Box
1.	*I confirm that I have read and understood the Information Sheet for the above study. I have had an opportunity to consider the information and what will be expected of me. I have also had the opportunity to ask questions which have been answered to my satisfaction *and would like to take part in an individual interview*	
2.	*I understand that I will be able to withdraw my data up until the final report is written in September 2021	

3.	*I consent to participate in the study. I understand that my personal information *(name, email address, job title and organisation)* will be used for the purposes explained to me. I understand that according to data protection legislation, 'public task' will be the lawful basis for processing.	
4.	**Use of the information for this project only** *I understand that all personal information will remain confidential and that all efforts will be made to ensure I cannot be identified. I understand that my data gathered in this study will be pseudonymised and stored securely. In the research report (please circle one of the following two options): (a) I request that my comments are presented anonymously but give permission to connect my role/affiliation with my comments (but not the title of my position). (b) I request that my comments are presented anonymously with no mention of my role/affiliation.	
5.	*I understand that my participation is voluntary and that I am free to withdraw at any time without giving a reason, without the care I receive or my legal rights being affected. I understand that if I decide to withdraw, any personal data I have provided up to that point will be deleted unless I agree otherwise.	
6.	I understand the potential risks of participating and the support that will be available to me should I become distressed during the course of the research.	
7.	I understand the direct/indirect benefits of participating.	
8.	I understand that the data will not be made available to any commercial organisations but is solely the responsibility of the researcher undertaking this study.	
9.	I understand that I will not benefit financially from this study or from any possible outcome it may result in in the future.	
10.	I understand that my anonymous research data present in the final research report may be used, by the researcher only, for future research (i.e. PhD thesis and related article, papers and presentations). No one will be able to identify you when this data is shared.	
11.	I understand that the information I have submitted will be published as a report and I wish to receive a copy of it. Yes/No	
12.	I consent to my interview being audio recorded and understand that the recordings will be destroyed immediately following transcription. To note: If you do not want your participation recorded you can still take part in the study.	
13.	I hereby confirm that I understand the inclusion criteria as detailed in the Information Sheet and explained to me by the researcher.	
14.	I am aware of who I should contact if I wish to lodge a complaint.	
15.	I voluntarily agree to take part in this study.	
16.	Use of information for this project and beyond	

	I would be happy for the data I provide, follow pseudonymisation, to be archived at the secure and encrypted UCL N: Drive. I understand that only this researcher (Laurent Liote) will have access to my pseudonymised data.	

If you would like your contact details to be retained so that you can be contacted in the future by UCL researchers who would like to invite you to participate in follow up studies to this project, or in future studies of a similar nature, please tick the appropriate box below.

	Yes, I would be happy to be contacted in this way	
	No, I would not like to be contacted	

__________________________ _________________ ____________________

Name of participant Date Signature

__________________________ _________________ ____________________

Researcher Date Signature

Appendix C: Interview Topic Guide Phase 1

Before I start, make sure the participant has read and understood the participant information sheet and signed the consent form.

Record

Questions to lead the discussion can include**:**

1. Questions about the organisation/team:

Tell me more about the work your organisation does as a whole

Tell me more about the work your team does and how that fits within the wider organisation

Could you tell me more about how your organisation/team is structured?

2. Questions about the role/position:

Tell me more about your role, your day-to-day?

Can you show me/walk me through what you work on?

Tell me more about your background and how you got into the role you are in

Did you have to go into a different area of engineering than the one you trained in?

Do you frequently jump from one engineering subdiscipline to another?

Do you get continuous training/learning to help with your work?

How is the work you do considered in your team/organisation?

Are you considered an expert in your organisation/team?

Do you often work with people outside of your team/organisation?

How are your objectives communicated?

Do you ever have to explain the work you did? To whom? How do you go about it?

What do you think is the end goal of the work you do? What is the impact of your work?

Appendix D: Interview Memo Example

Informant is concerned about giving me ‘helpful’ answers, will have to make sure this is not ‘what I want to hear’. *Added post coding*: it aligns well with other interviews.

Informant has read and referred to the info sheet (the first informant to have referred to it thus far!). They commented on my mentioning of modelling in my research title, I made it clear that this was provisional, and I am interested in all types of engineering advice.

Very interesting reflexion on science vs. engineering, seems like the informant had already thought about it. This might be due to their background in science vs. now working as an engineer.

I thought it would be valuable to share with the informant what I gathered so far with regards to science and engineering – it aligns nicely with the comments they made. I did caveat it as I feared it might have been a little too leading.

Interesting comments on standards as a policy tool, seems to function at the engineering/policy interface like models.

Very reflective informant, good quotes on engineering policy interactions in here too.

Multiple comments on being pressed for time and having too much work. Worth noting but let’s be mindful of the politics here.

Interesting reflexion on cost here too – with some slightly political statements. Interesting reflexion nonetheless, might be worth thinking how cost concerns influence advice giving and receiving. Will have to dig into this more.

Informant was very careful not to contradict colleague on modelling, does not view themselves as ‘an expert’ on the matter.

Again, very interesting reflexion on ‘independence’ towards the end of the interview.

I mentioned positivism towards the end of the interview, prompted a nice exchange with regards to the role of the researcher and parallels with the role of the engineers in policy.

Very careful not to say anything remotely controversial towards colleagues in the science team.

Appendix E: Codebook Phase 1

Code Name	Code Description	References (out of 492)
Engineering teams' background, roles and lived experience		**234**
Engineers tension between technical advice and policy implications	Draws on the idea that engineers mention that they offer technical advice. However this idea of purely technical advice is debatable.	**68**
Engineers focus on the technical	Engineers see their role as providing technical advice	24
Engineers vs. cost	Upfront cost is often opposed to solutions proposed by engineers and this is a source of frustration for the engineers.	22
Engineers mindful of policy implications	In contradiction with what has been coded before however, it is clear from some engineer and policy analyst comments that engineers cannot always provide purely technical advice.	21
Engineers reviewing a policy area, translating policy questions	Engineers describe themselves as translating policy questions into engineering ones and helping policy teams be the intelligent customer when the engineering work is outsourced.	**56**
For an internal project	When project are intenal (stay in-house), engineers describe themselves as translating policy questions into engineering ones	31
For an outsourced project	Engineers help policy teams be the intelligent customer when the engineering work is outsourced. This includes framing the questions and monitoring the outputs of the project.	24
Engineer background	This code covers the engineers' backgrounds	**54**
How engineers gained policy skills	Covers how the engineers interviewed gained the skills necessary to navigate the policy landscape	10
What counts as proper engineeirng	What do the engineers interview consider 'proper' engineering?	9
Engineers and purpose	Why are the engineers working in policy?	7
Engineering and private sector skills	How skills gained in the private sector can be useful for engineers in policy	5

Code Name	Code Description	References (out of 492)
Flexibility within engineering disciplines	Engineers opinions about being ‘generalist’ engineers.	5
Engineers confidence in advice	How could engineers be more confident in their advice	2
Engineers and expertise	Considers the relationship between engineers and expertise: do engineers consider themselves experts? Are engineers seen as experts?	**18**
Engineers informality and individual relationships	This code covers the informal ways engineering advice is asked for/given. A lot if the informal process depends on who the policy team knows.	**12**
Example of what engineers work on	Example of what engineers work on day to day	**11**
Engineers and trust	Do policy makers trust the advice given by engineers? Do engineers trust their policy colleagues’ expertise?	**9**
Engineers are trusted	Policy makers trust the advice given by engineers.	4
Engineers trust in policy colleagues	Engineers respect their policy colleagues’ expertise.	4
Engineers use own discretion	Engineers use their own discretion and judgement in their work	**6**
Policy teams' background, roles and lived experience		**108**
Policy analysts engaging and balancing stakeholders	Policy analysts primarily describe their role as engaging and balancing different stakeholders’ views and interests. This is an important component of the policy making process.	**43**
Example of what policy teams work on	Example of what policy teams work on day to day.	**17**
Policy analysts need engineers	Why policy analysts feel they need to collaborate with engineers in the energy policy field.	**16**
Policy analyst background	This code explore the policy analysts’ backgrounds.	**13**

Code Name	Code Description	References (out of 492)
How policy analysts gained exposure to engineering	How policy analysts gained exposure to engineering	4
Lack of technical background	Policy analysts reflect on their lack (or not) of technical background.	4
Policy analysts's private sector experience	Policy analysts reflect on the skills they learned working in the private sector.	3
Policy analysts and expertise	Who do policy analysts consider experts? Are analysts considered experts themselves? How do they engage with expertise?	**11**
Policy analyst turnover and advice	This code explores the high turnover in policy teams and what that means for advice and institutional knowledge.	**8**
Engineers vs. policy analysts		**58**
Similarities between policy analysts and engineers	What are the similarities between policy analysts and engineers' role in this policy field?	**38**
Summarising advice	Both policy makers and engineers summarise information and feeding it back.	28
Similarities between policy analyst and engineer roles	Other similarities between the policy analysts and engineers' roles.	9
Differences between policy analyst and engineer roles	What are the similarities between policy analysts and engineers' role in this policy field?	**19**
Models and standards		**42**
Models	How do policy analysts and engineers engage with modelling and models?	**35**
Model sources, creation and QA	How are models created, using what sources of data and how are they QAd?	17

Code Name	Code Description	References (out of 492)
Communicating model results	How are the results of the models communicated by engineers to policy analysts and analysts to deputy directors?	12
Model example	Examples of models used	4
Modelling tools	What tools do engineers use to model?	2
Standards	How do policy analysts and engineers engage with standards?	**5**
Using standards	How are standards used by engineers and policy analysts?	3
Standards example	Examples of standards	2
BEIS structure		**32**
The necessity of outsourcing engineering work	Why engineering work gets outsourced	**11**
Innovation team not a policy team	My informants have all been clear that the innovation team is not a policy team.	**10**
Navigating BEIS	Informant struggle to know who does what within the department and the turnover does not make it easier.	**11**
Science vs. engineering		**18**
Science and engineering differences	Why and how are science and engineering different?	**12**
Science and engineering collaborate	On some projects the science and engineering teams collaborate.	**5**

Appendix F: Focused Code Summary Example

Engineers tension between technical advice and policy implications

There seems to be a tension between engineering advice and cost, it seems that upfront cost is often opposed to solutions proposed by engineers and this is a source of frustration for the engineers.

Engineers have noted that a lot of the focus of "making policy decisions" is around "cost and not value" and this would warrant a discussion. The examples brought up were around the "cost of inaction", not paying for a solution now has cost repercussion in the future which are not given enough importance, especially when it comes to climate change.

This comment has been echoed by policy makers, especially when it comes to gas vs. electricity where gas is much cheaper than electricity despite being high carbon. This means that, in the eyes of policy maker, unless you think about long term impact too and not just upfront cost, "low carbon don't really have good economics".

That said, if you think about this from an industry and consumer point of view which is an exercise policy makers are involved in, "low carbon projects are a very hard sell" as "no consumers want to pay three times more for electricity". So even if the engineering solution is "technically excellent and would make things technically more effective", policy makers are weary of "about implementing a solution that would be overly burdensome to industry and has impacts on consumers".

A second point brought up was around the tension between doing thorough engineering work and getting the money spent within the budget timeframe. Policy makers have brought up the fact that they need to spend the money they have for projects to "get things out of the door by a certain deadline" and "to get the budget renew for the following year". Getting things done quickly because of "artificial" budget deadlines is a source of frustration for engineers that could use more time to research the best "technical solution".

Appendix G: Theoretical Code Summary Example

The stakeholder balancing exercise

Policy analysts primarily describe their role as engaging and balancing different stakeholders' views and interests. I would argue this is one of, if not the most, important component of the policy making process.

Interestingly, the engineers I have interviewed are involved in a similar balancing act as the policy makers. They engage different stakeholders, like academia and industry, to gather evidence and inform the advice they give.

It must be noted however that policy analysts have to balance a wider set of actors and interests, taking into account political, economic, social, technical, legal and environmental points of view. Engineers' balancing act mainly revolves around more technical concerns although I would argue there is no such thing as 'just technical advice'.

Perhaps this point is best conceptualised as a scale where the evidence and points of view gathered by engineers and policy analysts are always a mix of technical and political/economic concerns. The engineers will focus on evidence with a heavier technical component (tipping the scale towards the technical) and policy analysts will gather views that are more socio-economic/political in nature (tipping the scale the other way). I think this is a direct result of policy analysts and engineers working in a field – energy policy – at the intersection of the social and technical.

The balancing act that policy analysts have to perform can generate of tension between them and engineers. Policy makers have to frame the policy to maximise its chances of going through which might mean favouring other concerns/points of view against the advice given by engineers. One of the most salient manifestation of this is around cost and as policy analyst explain, sometimes the best solution from an engineering point of view is irreconcilable with the burden of cost to the industry and consumers and this burden takes precedence in the policy decision. This is source of frustration from engineers who have argued that the way cost-benefit analysis works in the civil service does not take into account long-term value and cost of inaction, especially relevant for the net zero transition.

Some policy analysts find it hard to push back against engineers who they consider technical experts, even though the push back is usually on non-technical grounds. This links to the fact that most policy analysts do not have an engineering background and they think it doesn't help their credibility, more to this point below.

With all this said, there is a high level of trust both ways. Policy makers trust the advice given by in-house engineers and engineers have a lot of respect for the policy analysts' knowledge of their respective policy areas. One of the engineers interviewed said they used to think policy should be made by engineers but since working at BEIS changed their mind seeing how complex regulation making can be. This shows that engineers are conscious of the value of and balancing efforts policy analysts are engaged in despite some of the pushback from policy analysts.

More detail on this can be found in the following focused codes: 'engineers tension between technical advice and policy implications', 'engineers and trust', 'policy analysts balancing stakeholders'

Appendix H: B-SEN Event Schedule

No.	Sub-Item & Description	Room	Presenter	Start Time	Discuss Minutes
Introductory items & Lunch					
1	Registration/reception	Palmer		13.00	60
2	Networking Lunch				
Speaker					
3	**Introduction**	Council		14.00	5
4	**Key Note Speech:** The shifting paradigms of production			14.05	45
	Break			14.50	10
Breakout Session					
5	Break Out 1 GSE Workshop	Council		15.00	30
	OR Break Out 2 Networking Workshop	Palmer			
	Move Room			15.30	5
6	Break Out 3 GSE Workshop	Council		15.35	30
	OR Break Out 4 Networking Workshop	Palmer			
Panel & Wrap Up					
	Break, tea, coffee & Biscuit	Council		16.05	10
7	Panel Discussion (Question Time format?)			16.15	40

Appendix I: Observation Notes Example

Random quotes from the day

- "Science is more focused on data, engineering on solutions" (32)
- "Engineers do engineering models, analysts (in central modelling team) for economic models" (32)
- "Scientists have their heads in the clouds and engineers have their boots on the ground!" (said as a joke by the Deputy Director Engineering and Research)

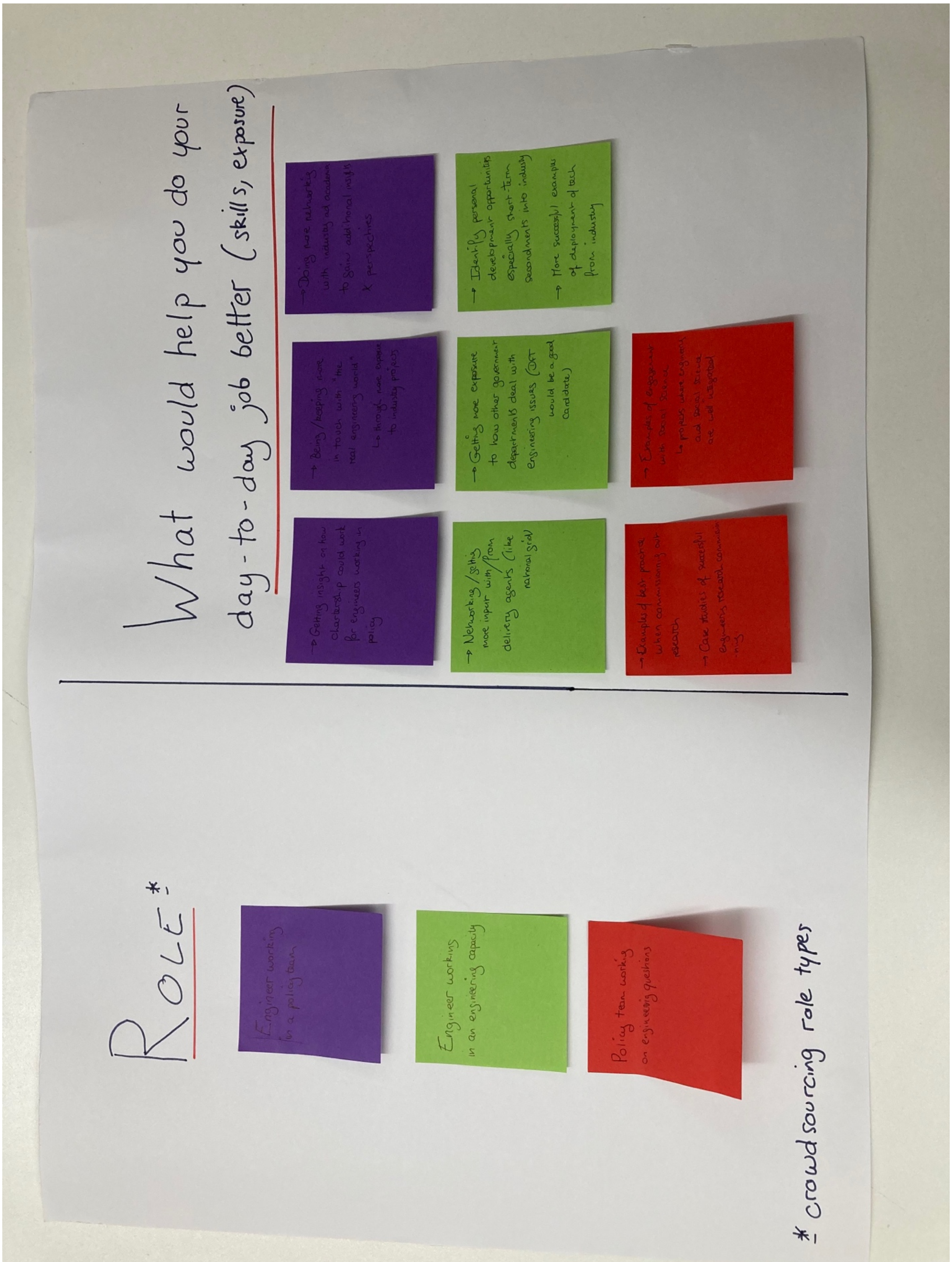
Board Q&A (CSA BEIS/ DD Eng and Research/ DD Science, Engineering & Analysis at Office for Product Safety and Standards)

- Gov needs to be more agile in regulating locally/personally produced items (PPE)
- The Civil Service as a whole can find the answers, it's about asking the right question and leveraging the CS's "distributed expertise" (my words)
- How can scientists at BEIS retain credibility in the eyes of the scientists outside?
    - To maintain engagement
    - "Science vs. science for policy" (my words)
    - Science for policy is "interdisciplinary", scientists at BEIS to act as "mobilisers of expertise", key skill of scientist at BEIS is to translate science into something non-technical people can understand
- How can we encourage cross-CS collaboration?
    - Needs to be both top-down and bottom-up
    - Issues of time frames ("I need this bit of information now")

Lists of relevant questions for the board on Slido (and number of upvotes):

- How do we, as public servants, tackle public mistrust in science and the rhetoric of "we've had enough of experts" (+7)
- Most memorable experiences of where research/evidence delivered by a team has really steered a decision? (+5)
- What would be your one piece of advice to us to ensure scientific evidence is embedded into decisions (+3)
- Where can you see good examples of effective collaboration between traditional STEM areas and social sciences and humanities? (+2)
- Will BEIS look to develop accredited training schemes with the engineering institutions, to help individuals gain chartered status?

Appendix J: B-SEN Workshop Board



Appendix K: List of Documents Seen & Collected

Document Type	Document Name	Document Description	Publicly Available? (link if 'yes')	Downloaded?
Model documentation	Utility-scale solar model	Documentation of a model to estimate land footprint resulting from a change in utility-scale solar regulation.	No	No
Internal policy document	Utility-scale solar policy draft	Draft policy brief to internally communicate policy recommendation regarding the change in utility-scale solar regulation.	No	No
Published policy document	National Policy Statement for Renewable Energy Infrastructure (EN-3)	National policy statement outlining the UK's strategy for developing renewable energy infrastructure.	Yes Link	Yes
Internal policy document	EV smart charging standards draft	Draft policy brief to internally communicate policy recommendation regarding the development of EV smart charging standards.	No	No
Published policy document	EV Smart Charging Government Response	National policy statement outlining the UK's strategy for EV smart charging.	Yes Link	Yes
Internal policy document	Energy demand and energy system diagram	Diagram illustrating household energy demand and energy management platforms. Developed by an engineering adviser and policy officer collaborating on DSR policy.	No	Yes

Published Policy Document	Smart Systems and Flexibility Plan 2021	Document setting out the steps the UK government will take to transition to a smarter and more flexible energy system	Yes Link	Yes
Published policy document	Invitation to Tender for the Provision of Hydrogen Standards for Heat Supporting Research and Evidence	Document inviting potential suppliers to set out their proposal to deliver primary research to support hydrogen standards for heat.	Yes Link	Yes
Published policy document	Mackay Carbon Calculator	Provides a model of the UK energy system that allows the exploration of pathways to decarbonisation.	Yes Link	No – available online
Model documentation	Biomass Strategy Multi-Criteria Decision Model	Documentation of a model to determine which uses of biomass should be prioritised to deliver optimally against government objectives.	No	Yes
Published policy document	BEIS Biomass Policy Statement	Government view on the role of biomass across the UK economy in the medium- to long-term.	Yes Link	Yes
Published policy document	Biomass Strategy	Biomass Strategy sets out the government's view on the role biomass can play in reaching net zero, what government is doing to enable that objective and where further action is needed.	Yes Link	Yes
Internal policy document	Policy brief on energy	Draft policy brief on the energy systems	No	Yes

	systems transition (1)	challenges of meeting long-term temperature goals to tackle climate change.		
Internal policy document	Policy brief on energy systems transition (2)	Draft policy brief on scale and challenge of the energy system transition to meet long-term climate goals.	No	Yes
Internal policy document	Policy brief on likelihood of extreme UK winter temperatures	Policy brief on the likelihood of extreme UK winter temperatures. Based on a review of academic articles on the topic.	No	Yes
Published policy document	DECC Annual Report and Resource Accounts 2008-09	Report on the annual activities of The Department of Energy and Climate Change for the year 2008-2009	Yes Link	Yes
Published policy document	DECC Annual Report and Resource Accounts 2009-10	Report on the annual activities of The Department of Energy and Climate Change for the year 2009-2010	Yes Link	Yes
Published policy document	DECC Annual Report and Resource Accounts 2010-11	Report on the annual activities of The Department of Energy and Climate Change for the year 2010-2011	Yes Link	Yes
Published policy document	DECC Annual Report and Resource Accounts 2011-12	Report on the annual activities of The Department of Energy and Climate Change for the year 2011-2012	Yes Link	Yes
Published policy document	DECC Annual Report and Resource Accounts 2014-15	Report on the annual activities of The Department of Energy and Climate Change for the year 2014-2015	Yes Link	Yes

Published policy document	BIS Annual Report and Resource Accounts 2015-16	Report on the annual activities of The Department for Business, Innovation and Skills for the year 2015-2016	Yes Link	Yes
Published policy document	DECC Organograms 2008-2015	Organisational structure of DECC 2008-2015.	Yes/No – some years are available others have been shared by participants Link	Yes
Internal policy document	Presentation on DECC to BEIS transition	Internal presentation slides on the machinery of government changes leading up to the creation of BEIS	No	Yes
Published policy document	BEIS Annual Report and Resource Accounts 2016-17	Report on the annual activities of The Department for Business, Energy and the Industrial Strategy for the year 2016-2017	Yes Link	Yes
Published policy document	BEIS Annual Report and Resource Accounts 2021-22	Report on the annual activities of The Department for Business, Energy and the Industrial Strategy for the year 2021-2022	Yes Link	Yes
Published policy document	The future of the Civil Service: Making the most of scientists and engineers in government	Review of the Civil Service's science and engineering profession in 2012	Yes Link	Yes

Published policy document	BSE and CJD: Science, Uncertainty and Risk	Parliament Office for Science and Technology technical briefing on the BSE outbreak in the UK in the late 80s / early 90s	Yes Link	Yes
Published policy document	Origin of the UK Foot and Mouth Disease epidemic in 2001	Report from the Department for Environment, Food and Rural Affairs on the 2001 Foot and Mouth disease epidemic in the UK in 2001	Yes Link	Yes

Appendix L: UCL Research Paper Declaration Forms

UCL Research Paper Declaration Forms
referencing the doctoral candidate's own published work(s)

Please use this form to declare if parts of your thesis are already available in another format, e.g. if data, text, or figures:

- *have been uploaded to a preprint server*
- *are in submission to a peer-reviewed publication*
- *have been published in a peer-reviewed publication, e.g. journal, textbook.*

This form should be completed as many times as necessary.

For Chapters 2, 6 and 7

Research manuscript already published

a) **What is the title of the manuscript?**

Towards a framework for understanding transdisciplinary engineering in policy practice: Insights from the UK's energy ministry

b) **Please include a doi for the work**

doi:10.3233/ATDE230671

c) **Where was the work published?**

In P. Koomsap, A.C.G. Cooper, J. Stjepandić (Eds.), *Leveraging Transdisciplinary Engineering in a Changing and Connected World*.

d) **Who published the work?**

IOS Press: Amsterdam, NL

e) **When was the work published?**

November 2023

f) **List the manuscript's authors in the order they appear on the publication**

Lioté, L. (sole author)

g) **Was the work peer reviewed?**

Yes

h) **Have you retained the copyright?**

Yes

Candidate
Laurent-Olivier Lioté

<signature>

Date:
February 2024

Supervisor
Dr. Adam Cooper

<signature>

Date
February 2024

For Chapters 4 and 7

Research manuscript already published

a) **What is the title of the manuscript?**

Designing transdisciplinary engineering programmes: A new wave in engineering education

b) **Please include a doi for the work**

doi:10.3233/ATDE230666

c) **Where was the work published?**

In P. Koomsap, A.C.G. Cooper, J. Stjepandić (Eds.), *Leveraging Transdisciplinary Engineering in a Changing and Connected World*. Amsterdam, Netherlands: IOS Press

d) **Who published the work?**

IOS Press: Amsterdam, NL

e) **When was the work published?**

November 2023

f) **List the manuscript's authors in the order they appear on the publication**

Lazar, I., Lioté, L. & Cooper, A.C.G.

g) **Was the work peer reviewed?**

Yes

h) **Have you retained the copyright?**

Yes

Candidate
Laurent-Olivier Lioté

<signature>

Date:
February 2024

Senior Author
Dr. Irina Lazar

<signature>

Date
February 2024

For Chapters 1, 2 and 7

Research manuscript already published

a) **What is the title of the manuscript?**

We Need to Talk About Engineering Policy

b) **Please include a doi for the work**

doi:10.1016/j.techsoc.2023.102196

c) **Where was the work published?**

Technology in Society

d) **Who published the work?**

ScienceDirect (Elsevier)

e) **When was the work published?**

January 2023

f) **List the manuscript's authors in the order they appear on the publication**

Cooper, A.C.G., Lioté, L. & Colomer, C.

g) **Was the work peer reviewed?**

Yes

h) **Have you retained the copyright?**

Yes

Candidate
Laurent-Olivier Lioté

<signature>

Date:
February 2024

Supervisor and Senior Author
Dr. Adam Cooper

<signature>

Date
February 2024

For Chapters 2, 4 and 7

Research manuscript already published

a) **What is the title of the manuscript?**

Modelling for the UK's utility-scale solar regulation change: Lessons for transdisciplinary engineering in policy practice

b) **Please include a doi for the work**

doi:10.3233/ATDE220646

c) **Where was the work published?**

In B. R. Moser, P. Koomsap, J. Stjepandić (Eds.), *Transdisciplinarity and the Future of Engineering*

d) **Who published the work?**

IOS Press: Amsterdam, NL

e) **When was the work published?**

November 2022

f) **List the manuscript's authors in the order they appear on the publication**

Lioté, L. (sole author)

g) **Was the work peer reviewed?**

Yes

h) **Have you retained the copyright?**

Yes

Candidate
Laurent-Olivier Lioté

<signature>

Date:
February 2024

Supervisor
Dr. Adam Cooper

<signature>

Date
February 2024