Accelerating Low Carbon Innovation: National Institutions and Effective Organisation Design

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I hereby declare that this thesis has not been and will not be, submitted in whole or in part to another University for the award of any other degree.

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Abstract

Accelerated clean electricity innovation is essential if global climate change targets are to be met by 2050. National innovation policy strategies are identified as key in delivering this, requiring policy makers to develop new approaches to technology funding and market development. At present, the role of politics in the emergence and implementation of innovation policy is not well understood by the innovation systems literature. There is therefore a gap in knowledge in relation to how national institutions shape the development of clean electricity innovation systems and how publicly funded organisations can be designed to accelerate innovation within them. This thesis addresses this gap by analysing how national institutions have affected the design of two publicly funded organisations for accelerated clean electricity innovation- the Energy Technologies Institute (ETI) in the UK and Advanced Research Projects Agency- Energy (ARPA-E) in the US.

The thesis opens with a paper that refines a layered institutional framework, demonstrating the effect of multiple institutions on the development of the UK's clean electricity innovation system 2000- 2018. The second paper builds on this system overview to introduce the case study of the ETI. The ETI's operation is analysed through a refined framework of ten principles for accelerated innovation organisation design, which explore how the formation and operation of an organisation is affected by the broader institutional conditions introduced in paper one. Paper three further develops the ten principles via a comparative case study of the ETI and ARPA-E. The impact of different national institutional contexts on organisation design is discussed and generalisable approaches for accelerated innovation explored.

This thesis offers two main theoretical contributions. Firstly, the refinement of a layered institutional framework for application to a sectoral innovation system, which brings new insights to understanding the role of institutions in shaping innovation system development. Secondly, the refinement and further development of ten principles for accelerated innovation organisation design, which contributes a theoretical link between national institutional conditions and how publicly funded organisations can be designed within this to implement innovation policy.

This research also makes three key theoretical contributions. It consists of the first in-depth analysis of the role of institutions in the development of the UK clean electricity innovation

system from 2000- 2018. It also provides the first academic analysis of the operation of the ETI, UK since the organisation ceased operation in 2017, adding a detailed study of a public-private partnership in a European setting to the growing literature on innovation organisation design. Finally, the thesis provides the first comparison of the operation of the ETI and ARPA-E, US, providing an international case study of two long-lived accelerated innovation organisations while taking into account the broader national innovation systems in which they have been developed.

The policy contributions of the thesis include new insights into the need for policy makers to pay greater attention to institutional context when designing and implementing innovation policy and public organisations for accelerating low carbon innovation. More prescriptive recommendations are also made in relation to the way in which UK policy makers can learn from US clean energy innovation system development.

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I dedicate this thesis to my Granddad, Donald Holliday Cowley, a great man and engineer.

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Preface

This PhD thesis is the product of four years of research undertaken at the Science Policy Research Unit (SPRU) at the University of Sussex. This research was funded by the UK's Economic and Social Research Council through a grant administered by the UK Energy Research Centre (UKERC). UKERC has sat at the forefront of uniting the energy community for over 15 years, conducting world class interdisciplinary research into sustainable energy systems.

This thesis is presented as three journal articles in the style of 'thesis by paper', all of which are solo authored. Paper 2 has been published in the journal of Environmental Innovation and Societal Transitions and paper 3 is under review at Energy Policy. Paper 1 is in working paper format, with plans for refinement into a co-authored paper with supervisor Professor Jim Watson for submission to Energy Research and Social Science. Alongside the work presented here, the author has contributed to workshops and academic and industry events as a representative of both SPRU and UKERC.

There is inevitably some repetition and disconnection between the three papers and the literature reviewed. The connecting chapters therefore aim to synthesise and add coherence to the content of the papers, so this thesis reads as a stand-alone contribution.

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Acronyms and abbreviations

ARPA-E- Advanced Research Programme Agency- Energy

BEIS- Department of Business, Energy and Industrial Strategy

BES- Basic Energy Sciences

BIS- Department for Business, Innovation and Skills

BP- British Petroleum

CCC- Committee on Climate Change

CCS- Carbon capture and storage

CEO- Chief Executive Officer

CfDs- Contracts for Difference

CME- Coordinated market economy

COP21- 21st annual Conference of Parties of the United Nations Framework Convention on Climate Change

DARPA- Defence Advanced Research Programme Agency

DECC- Department of Energy and Climate Change

DOD- Department of Defense

DOE- Department of Energy

EDF- Électricité de France

EFRCs- Energy Frontier Research Centers

EPSRC- Engineering and Physical Sciences Research Council

ERP- Energy Research Partnership

ESME- Energy Systems Modelling Environment

ETI- Energy Technologies Institute

ETIS- Energy technology innovation system

FiTs- Feed in Tariffs

GDP- Gross domestic product

HI- Historical institutionalism

ICT- Information and communications technology

IEA- International Energy Agency

IP- Intellectual Property

LCICG- Low Carbon Innovation Coordination Group

LME- Liberal market economy

m- Million

MLP- Multi-level perspective

Narec- National Renewable Energy Centre

OEMs- Original equipment manufacturers

Ofgem- Office of Gas and Electricity Markets

OREC- Offshore Renewable Energy Catapult

PPP- Public-private partnership

PV- Solar photovoltaics

R&D- Research and development

RD&D- Research, development and demonstration

RO- Renewables Obligation

RQs- Research questions

SIS- Sectoral innovation system

SMEs- Small to medium-sized enterprise

SoS- Secretary of State

TINAs- Technology Innovation Needs Assessments

TRL- Technology readiness level

UK- United Kingdom

UKERC- United Kingdom Energy Research Centre

US- United States of America

VoC- Varieties of capitalism

Glossary

Actor

An individual entity within a system able to respond to or form narratives in relation to developing certain habits and routines.

Habits and routines

The ability of actors to develop the means with which to embody existing narratives and maintain inertia within a system, as well as the ability to act creatively to create new narratives and drive change within a system.

Institution

The formal and informal rules that produce durable social structures, made up of symbolic elements, social activities and material resources that impose rules by defining the legal, moral or cultural boundaries of various activities.

Organisation

A type of institution that differs by containing internal mechanisms and functioning that binds people together around a common purpose to achieve certain objectives.

Political Economy

The interaction between the government and private, economic actors, which shapes the role of the state in the economy and innovation policy making over time.

Polity

The way in which a country is politically organised, for example in relation to its electoral system.

Values and norms

National attitudes that permeate culture and the functioning of institutions, often evolving with great inertia over decades, shaped by macroeconomic factors (Kere, 2016) such as domestic fossil fuel availability, and other factors like social preferences (Sovacool, 2014).

1. Introduction

This introductory chapter provides an overview of the research comprising the proceeding chapters of this thesis. Section 1.1 provides background information on the motivation behind and the relevance of this research. Section 1.2 summarises the relevant literature, identifying the gap in knowledge that this thesis addresses. Section 1.3 identifies the research questions and aims of the thesis, whilst section 1.4 goes on to detail the methodological approach taken to addressing these. Section 1.5 provides a summary of the three papers that comprise this thesis, and section 1.6 concludes with an overview of the thesis structure.

1.1. Background

1.1.1. Personal motivation

I was in Paris during COP21 as organiser of the Sustainable Innovation Forum. Ernest Moniz, then Secretary of Energy for the United States, gave a keynote speech in which he stated: "*We have the technology, now we need the policy"* (Climate Action, 2015). Indeed, 75% of emissions reductions required by 2070 can be delivered by technologies that already exist but require development (IEA, 2020a). Several other speakers echoed this sentiment throughout the event. This led me to the question- if the technology and political will exist, as evidenced by the high-level decision makers present at COP21, then *why* don't we have the policy? How do top-level political agreements move beyond setting aspirational goals to become implementable technology policy realities? (Victor & Jones, 2018). This question sparked the research in this thesis, which seeks to understand how clean electricity innovation policy can be accelerated by publicly funded organisations.

1.1.2. Significance of topic

Climate change has emerged as the defining challenge of our time, leading to global efforts to combat its severity (UN, 2015a; UN, 2015b). Accelerated clean electricity innovation has been identified as essential to meeting the aims of the Paris Agreement (IEA, 2020a), with the 'net zero' provision increasing the speed at which countries are required to reduce emissions by 2050 (Kazaglis et al., 2019). The International Energy Agency (IEA) highlight that national policy strategies are the single most important step to enabling this, with national governments able to provide funding, determine market expectations and develop effective regulatory environments (IEA, 2020a).

Despite the urgent need for accelerated clean electricity innovation however, there remains a disconnect between high-level climate change agreements and clean energy technology deployment (IEA, 2020a). Whilst a range of new technologies are required across multiple sectors if net zero is to be met, many of these remain at demonstration stage, with public funding insufficient to stimulate their ongoing development. This raises questions over the effectiveness of current energy innovation policy (IEA, 2020a; Watson et al., 2015; Ćetković et al., 2017; Mazzucato & Semieniuk, 2017).

Whilst innovation systems literature has emerged to explore 'best practice' policy guidelines for stimulating clean electricity research, development and deployment (RD&D) (Foxon & Pearson, 2007; Chiavari & Tam, 2011; Grubler et al., 2012; Winskel et al., 2014b), this work primarily focuses on immediate technological and economic drivers, such as research funding levels and the role of taxes and subsidies (Markard et al., 2020). If clean electricity innovation is to be accelerated at the pace required however, policy makers need to support whole systems innovation that challenges complex, historical institutional arrangements to create markets and drive consumer demand (Geels & Roberts, 2019; Weiss & Bonvillian, 2011). Within the innovation systems literature there has been less emphasis on understanding how existing institutions will affect this process (Ćetković et al., 2017; Sandén & Azar, 2005; McMeekin et al., 2019) and even less research on the effect of this on the design of the publicly funded organisations seeking to implement accelerated innovation policy (Breznitz et al., 2018; Haley, 2017).

The topic of this thesis is therefore timely and significant, as the UK and other signatories of the Paris Agreement rapidly need to develop effective national policy strategies to accelerate clean electricity innovation. Findings contribute to knowledge on how innovation policy and publicly funded organisations can be designed most effectively to support this process.

1.2. Literature review

This section provides a review of the literature relevant to the research in this thesis, placing it in context of the extant literature and identifying the gap in knowledge it seeks to address.

Whilst ‘institutions’ are frequently referred to in the literatures explored below, they are often not well defined (Edquist & Johnson, 1997). This thesis defines an institution as the formal and informal rules that produce durable social structures (Andrews-Speed, 2016). These are made up of symbolic elements, social activities and material resources that impose rules by defining the legal, moral or cultural boundaries of various activities (Scott, 2008). Institutions are therefore relatively resistant to change and transmitted over long periods, reinforced by the actors functioning within them (Jepperson, 1991; Giddens, 1984). As they are ongoingly brought to life by human interaction however, institutions also have the potential to “*enable change through their inherent ambiguity that can empower actors to experiment and learn”* (Andrews-Speed, 2016, p.216).

As organisations contain both formal and informal rules and are inhabited by the interactions of people, they can be regarded as a kind of institution (Hodgson, 2006). Organisations differ from the definition above however as they contain internal mechanisms and functioning that bind people together around a common purpose to achieve certain objectives (Hodgson, 2006). Multiple different organisations can emerge from an institutional environment as products of the practices that it formalises over time (Giddens, 1984). Interaction between the institutional environment and the organisations it produces can be used to maintain power or qualify change over time, as practices change to dismantle old and produce new organisational approaches (Hodgson, 2006).

1.2.1. Accelerating innovation

Policy discourses around tackling climate change have become framed within the need to ‘drive innovation’ (King, 2016; Stern, 2016). This marks a break in traditional conceptualisations of innovation as firm-centric and guided by economic growth, to recognising its role in solving increasingly urgent environmental and societal issues (Diercks et al., 2019; Schot & Steinmeuller, 2018; Wanzenböck et al., 2019). Climate change is additionally recognised as a *“super wicked”* problem (Levin et al., 2012, p.123), requiring innovation at a pace and scale neither achieved or necessary in the past (Kuzemko et al., 2016).
Energy innovation poses a ‘wicked problem’ of its own, requiring high capital intensiveness over long development periods to catalyse and sustain (Grubler et al., 2012). Studies indicate that energy technologies take between 20 and 68 years to move from first prototype to

capturing 1% of a national market (Gross et al., 2018; Bento et al., 2018; Kazaglis et al., 2019). This is in part due to the iterative, cyclical process of innovation that incorporates feedback from different development stages, depicted in Figure 1. Accelerating this process requires the requisite emergence of supporting policies, regulatory frameworks, firm engagement and societal support, to drive market creation and consumer demand (Roberts & Geels, 2019).

As energy represents a complex, established legacy sector (Weiss & Bonvillian, 2011), accelerated innovation is likely to be shaped by inertia contained within existing institutions, as new technologies increasingly drive disruption (Markard et al.,2020; Maguire & Hardy, 2009; Smink et al., 2015; Bergek et al., 2013; Berggren et al., 2015). Accelerating innovation at the speed and scale required therefore depends on funding and policies put in place today (IEA, 2020a).

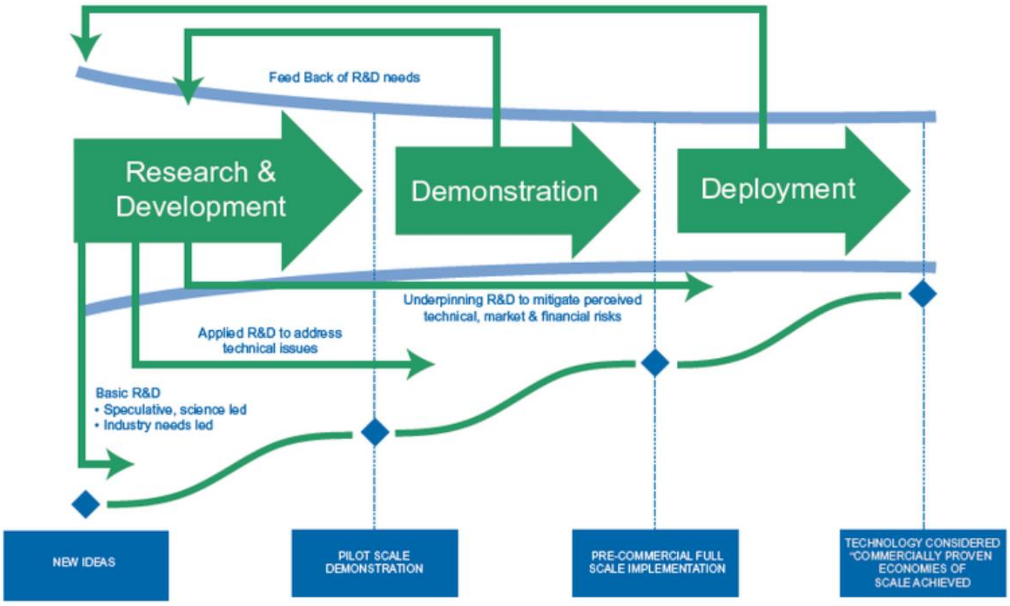


Figure 1- Cyclical innovation process (ERP, 2007, p.4)

1.2.2. Innovation systems theory

Innovation systems theories are widely used to understand the cyclical process of innovation and the design of innovation policy (Weber & Rohracher, 2012). This approach emerged in the latter half of the 20th century to understand the essential economic process of *"putting ideas into practice through an (iterative) process of design, testing, and improvement"* to establish industrial capabilities (Grubler et al., 2012, p.1673). Several approaches have since been developed, including national (Nelson, 1993), regional (Asheim & Gertler, 2005), sectoral (Malerba, 2004) and technology (Carlsson & Stankiewicz, 1991) perspectives of innovation systems.

The energy innovation system can be described as a sectoral innovation system, which is generally defined by the network of technologies, actors and institutions that accumulate via evolutionary growth over time (Breschi & Malerba, 1997; Dosi 1982; Freeman & Perez, 1988; Markard & Truffer, 2008; Wieczorcek & Hekkert, 2012). Clean electricity innovation is also discussed as part of the energy technology innovation system (ETIS), which similarly acknowledges the accumulation of structural dimensions, including institutional strength (Wilson & Grubler, 2014; Skea et al., 2019). Institutions are acknowledged as crucial in developing, diffusing, and using innovations, embedding actors within certain system rules and dynamics (Markard & Truffer, 2008). Indeed, ETIS recognises this dynamic between institutions and actors as one of the three key innovation system features (Gallagher et al., 2012).

Whilst the importance of institutions is acknowledged however, the literature's primary focus is on firm-led innovation (Fagerberg, 2004), meaning that an understanding of the accumulation and implications of institutional dimensions on the innovation processes remains limited (Edquist, 2011; Weber & Rohracher 2012; Kern, 2015; Bergek at al., 2015). Unruh (2000) for example, observes that the expansion of long-lived, centralised fossil fuel systems can lead to 'carbon lock-in', where a system is maintained in a cycle of technological, social and institutional self-reinforcement. Similarly, the ETIS is identified to suffer with issues of institutional interdependence, complexity and inertia (Gallagher et al. 2012). These factors can lead to innovation system failure (Foxon et al., 2005), as new forms of technology or knowledge are not valued within the system they seek to innovate (OECD, 2018; Owen, 2006). Indeed, Jacobsson & Bergek (2011) identify that there is an absence in an understanding of the "*politics of policy*" in the innovation systems literature (p.55).

The innovation systems literature is therefore ill-equipped to navigate the institutional complexity of existing systems developing policy strategies for accelerated clean electricity innovation. Indeed, Malerba (2002) identified that given the complexity of different institutional structures involved that *"the analysis of the role of institutions in sectoral systems is only at the beginning"* (p:257). Other literatures that more closely explore the role of public institutions in shaping innovation may therefore be beneficial to explore.

1.2.3. Political economy

Political economy approaches have been utilised to better understand the impact of the politics on innovation policy. The political economy literature explicitly acknowledges the role of public institutions in coordinating firms, placing institutional relationships at the centre of understanding why firms produce certain innovative outputs.

One prominent approach taken to investigating the impact of institutional arrangements on energy innovation is varieties of capitalism (VoC) (Hall & Soskice, 2001), which asserts that the institutional framework of a country *"controls its pattern of economic and technological specialization"* (Boschma & Capone, 2015, p.1902). VoC delineates two types of developed economies; liberal market economies (LMEs), in which firms have greater freedom to respond to market needs and drive more radical innovation; and coordinated market economies (CMEs) that foster greater state involvement and take a more incremental innovation trajectory (Hall & Soskice, 2001).

Despite receiving criticism for assigning innovation characteristics not evidenced empirically (Mikler & Harrisson, 2012; Taylor 2004) and being overly simplistic in market classification (Ćetković & Buzogany, 2016; Lachapelle & Patterson, 2013), the VoC approach has yielded useful insights into understanding how different national political contexts have impacted clean energy innovation policy. For example, Mikler & Harrisson (2012) found that the US's lack of climate leadership is due not only to a lack of political will, but also the priorities and functioning of its innovation institutions, which remain focused on military spending and more economically competitive fields. In the UK context, Ćetković & Buzogancy (2016) demonstrate that the Liberal Democrats' influence on the government from 2013-2015 facilitated more rapid renewables development in a policy environment that remains highly influenced by incumbent industry actors.

VoC approaches however, are not able to adequately analyse the non-market forces that influence public institutions and their decisions relating to clean electricity innovation. For example, VoC has been criticised for emphasising institutional stability and determinism as opposed to the possibility for change (Hancké 2009; Ćetković et al., 2017). This view of institutions as an enabling environment is similar to that of the innovation systems literature, in failing to explore the political dynamics of institutions on influencing accelerated innovation policy. Work by Amable (2003) and Deeg & Jackson (2007) on VoC theory has begun to conceptualise institutions beyond a static enabling environment. They consider linkages between different institutional layers in both maintaining equilibrium and generating points of disruption for incremental or radical change. Indeed, Boschma & Capone (2015) suggest that a closer investigation of the impact of sector-specific institutions as drivers for the emergence of new industries would constitute a useful contribution to the VoC literature.

Beyond VoC, several other political economy studies have sought to understand how politics shape the clean energy innovation landscape. Mitchell (2008) for example conducted a longitudinal case study of the UK, arguing that the Regulatory State Paradigm (coined by Moran, 2003) forms an *"iron band",* maintaining the UK's existing, neoliberal, market led energy system (p.1). This can only be removed by an entirely new paradigm that, *"like the stretching of an elastic band",* propels forward to knock the existing one out of the way (p.12). Similarly, Moe (2016) argues that we need a *"Schumpeterian moment in world history"* to enable renewable energy providers to transform centralised energy systems *(*p.210-11). In these understandings, institutions form a robust self-reinforcing whole that maintains a rigid equilibrium (Thelen, 2004), which needs to be removed and replaced to facilitate accelerated clean electricity innovation. These approaches therefore also do not adequately acknowledge the dynamics of system change, which have already facilitated high levels of renewables penetration and increased clean electricity innovation funding in liberalised markets like the UK (Bergek et al., 2013; Tayal, 2017).

Whilst political economy approaches have therefore provided valuable insights into clean energy innovation system development, their limited conceptualisation of institutions as rigid, national structures that facilitate the activity of firms fails to consider how these can change or shape this process.

1.2.4. Sustainability Transitions

The socio-technical transitions literature is interested in the transformation of system configurations, such as that for energy or transport. Systems are recognised to contain multiple technologies, markets and infrastructures, which are maintained and transformed by the engagement of the actors contained within them, including policy makers and institutions (Elzen et al., 2011).

The sustainability transitions literature has a deeper conceptualisation of stability and the possibility of change, acknowledging that a system may be both deeply entrenched in existing practices and contain many sustainable innovations (Köhler et al., 2019). The literature therefore seeks to better understand how broader economic, technological and political systems influence innovation, and how this can be scaled to transform the status quo (Skea et al., 2019).

The multi-level perspective (MLP) is a popular framework utilised by sustainability transitions practitioners. Pioneered by Geels (2002), the MLP incorporates three key components: the socio-technical landscape- concerned with overarching values and culture; regimes- which constitute dominant incumbent systems; and niches- in which innovations develop away from existing regimes and have the potential to emerge to eventually disrupt the status quo. The MLP demonstrates how these different dimensions interact and align to facilitate technological transition over time. It is therefore an effective framing to assist in shaping the development of innovation policy, moving beyond individual firms and technologies to recognise its positioning within the broader regime (Smith et al., 2010; Weber & Rohracher, 2012). Indeed, it offers a complementary 'transitions' focused view to innovation systems approaches focused on specific technologies (Markard & Truffer, 2008). Given these overlapping interests, some authors have started to incorporate innovation system and MLP approaches to understanding technology development within this broader context (see Meelen & Farla, 2013).

The MLP however, has been criticised for placing too much emphasis on bottom-up, niche led innovation, as opposed to that developed by existing regime actors (Schot & Geels, 2007; Berggren et al., 2015; Hölsgens et al., 2018). Winskel & Radcliffe (2014a) for example, identify that the emergence of accelerated energy innovation policy in the UK was led mostly by regime actors in a continuity-based approach. Geels (2014; 2019) has since highlighted the importance of integrating an understanding of regime level power dynamics into analyses.

More broadly, the sustainability transitions literature has faced criticism for failing to understand the politics of policy (Baker et al., 2014). In 2012, Goldthau & Sovacool noted that *"political economy of energy transitions is a vastly understudied area"* (2012, p.238), with Meadowcroft calling for political scientists *"to develop a politically oriented literature on sustainable transitions"* (2011, p.70). In the years since, the literature has sought to build a greater understanding of the impact of politics and power (Avelino & Wittmayer, 2016; Grin, 2012), the resistance and reorientation of incumbents (Bergek et al., 2013; Maguire & Hardy, 2009; Smink et al., 2015) and the role of actors and their interests on the development of innovative energy technologies (Ahlborg, 2017; Markard et al., 2016). Recent work has increasingly sought to incorporate insights from political science to better understand the non-neutral role of State (Johnstone & Newell, 2018) and political economy (Baker et al., 2014).

A key political science approach increasingly utilised to understand the complexities of socio-technical change is that of historical institutionalism (Andrews-Speed, 2016; Lockwood et al., 2017; Roberts et al., 2018; Köhler, 2019). This approach seeks to understand the role of institutions in enabling regimes to change and evolve over time, as opposed to viewing them as stable, monolithic structures that need to be disrupted or overturned (McMeekin et al., 2019). Recent work for example, integrates a greater institutional focus into the MLP to better understand accelerated, whole systems change (Roberts & Geels, 2019; McMeekin et al., 2019).

Another area emerging within the sustainability transitions literature is that of the role of intermediaries, which seeks to better understand the role of disparate innovation system actors, such as broker, boundary and third-party organisations, within this process (Kilelu et al. 2011). This also places a focus on institutions like government-supported innovation organisations, recognising their role in the evolution on effective innovation systems (see Kivimaa, 2014).

1.2.5. Historical institutionalism

Historical institutionalism evolved from new institutionalism, which is dedicated to understanding the impact of institutional structures on policy making.

New institutionalism was developed in the 1980s in response to the rational choice approach of traditional institutionalism, seeking to reincorporate the State into explanations of political action (Hall & Taylor, 1996). In the 1990s, economists introduced to new institutionalism the concept of the broader economic agent, which proposed that institutional structures evolve over time and have an important impact on market forces (North, 1990; Williamson, 2000). North’s seminal work on institutional ‘rules of the game’ drew attention to the informal, background conditions that impact the choices of institutional frameworks and organisations (North, 1990). Figure 2 demonstrates the multiple institutional layers at which these different forces were theorised to act (Williamson, 2000; 1998). Level one represents broader, culturally embedded, slow moving, informal institutions, which cascade to inform the way that formal institutions are shaped and operationalised in the levels below. The upward arrows represent system feedback, which can reinforce or challenge these conditions. The work of Williamson and North combines to demonstrate that norms and routines at an informal level shape economic growth, creating path dependencies that impact system dynamics beyond market operation (van der Steen, 2008).

Historical institutionalism is concerned with understanding the interactions that build between different institutional levels in a system over time (Thelen, 1999; Hall & Taylor, 1996; Andrews-Speed, 2016). This approach recognises that institutions are both self-reinforcing and constantly undergoing or providing opportunities for change (Andrews-Speed, 2016), marking a point of departure from the political economy and sustainable transitions literatures discussed above. Work by Streeck (2001) for example, views political economy relationships as being constantly established, reorganised, restored and defended against forces of disorganisation. Viewing institutions as such demonstrates the importance of understanding their past development, how they have interacted and their potential to evolve into the future.

Research by Thelen (2004) goes on to identify four pattens in which policy institutions change: layering of institutions over a core logic that remains the same; drift of policies in use despite no official decision for them to change; conversion of the goals of an existing policy without a change in instrument; and displacement of old institutions with new ones. The extent to which these changes take place is additionally influenced by the veto power of certain actors, whose agreement is required for the status quo to change (Tsebelis, 2000). Institutional change at one level can in turn affect those operating in the levels above and below, as their self-reinforcing nature is weakened. This creates opportunities for more disruptive change to occur (Andrews-Speed, 2016).

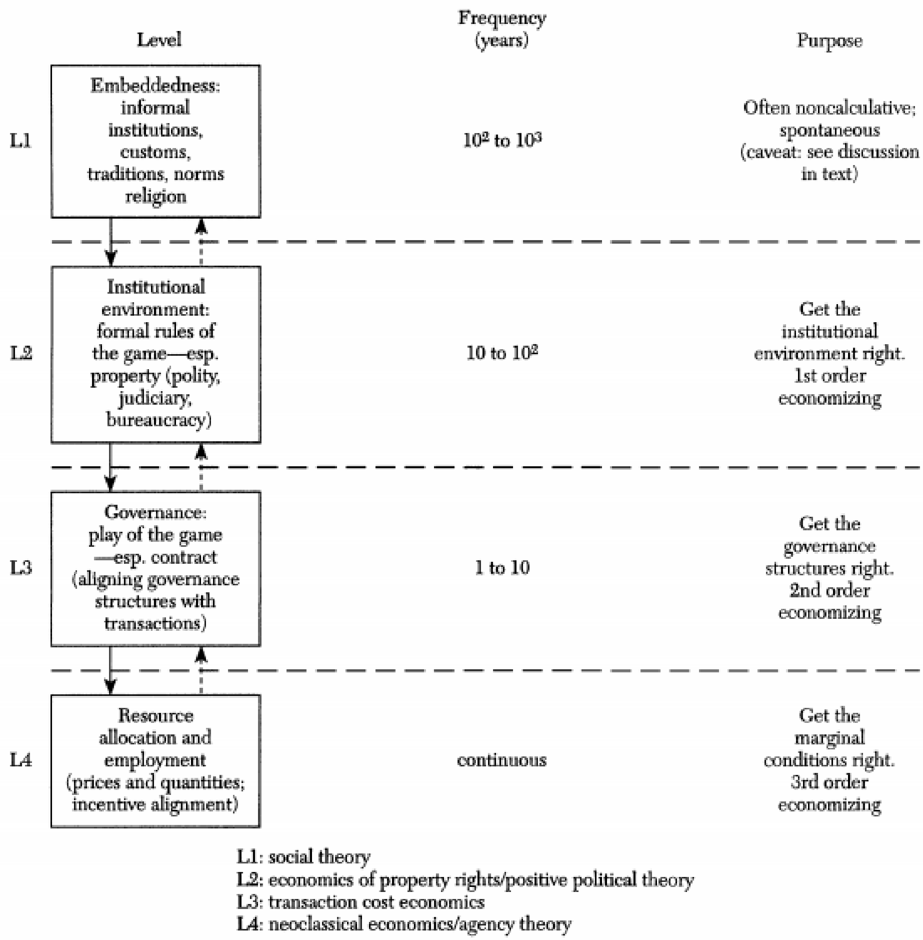


Figure 2- Layered institutional framework (Williamson, 2000, p.597)

Applying historical institutionalism to understanding clean electricity innovation system development therefore enables an analysis of how inertia and change within its institutional environment has shaped its emergence over time. This approach is highly relevant to this thesis, which aims to understand how policy approaches can accelerate innovation within these existing structures. It additionally demonstrates how publicly funded innovation organisations form part of a broader institutional landscape, which is shaped by multiple different interactions (Pierson, 2011; Thelen, 1999).

1.2.6. National institutions and innovation organisation design

This thesis is particularly interested in how national institutions affect the design of the publicly funded organisations that implement accelerated clean electricity innovation policy.

Initial research has demonstrated the effect of broader institutions on innovation organisation design. Anadon (2012) for example, demonstrates that the political economies of the UK, US and China affected the approaches taken by accelerated clean energy innovation organisations. This had implications on technology focus, allocation of funding to different innovation stages and the stability of the support available (Anadon, 2012; Glennie & Bound, 2016). Additionally, Karo & Kattel (2016) discuss how specific organisational path dependencies can form, in which organisation design is shaped by past national approaches to policy implementation.

Research however also demonstrates the ability of organisations to respond strategically and creatively to counter, circumvent or change the broader institutional environment in which they sit (Scott, 2008; DiMaggio, 1988; Christensen et al., 1997; Fligstein, 2001). Organisations therefore have the potential to reshape and redefine institutional environments by actively changing the rules of the game (Scott, 2008; North, 1990). This ability to drive change is especially important within the inertia of the energy innovation system, where organisations will need to challenge the prevailing system to deliver accelerated innovation policy (Dasgupta et al., 2016).

If innovation is to be accelerated therefore, it is essential that policy makers pay attention to designing innovation organisations that are able to continuously experiment and rapidly scale successful initiatives within their national institutional context (Glennie & Bound, 2016). Despite their key role in innovation policy delivery however, there is little research exploring how organisations could be designed to achieve this most effectively. Indeed in 2011, Jacobsson & Bergek called for the organisation of public bodies to become a research priority of the sustainability transitions literature, with Köhler (2019) highlighting deeper theoretical grounding of transitions in organisational theory as a priority.

At present, beyond some basic design preconditions of possessing "*high levels of human capital, experienced management and low levels of corruption or rent seeking"* there are few concrete principles agreed upon for designing effective innovation organisations (Breznitz et al., 2018, p.884). There are divergent views for example, on whether the state is optimally placed to support innovation (Mazzucato, 2015; Weiss, 2014) or whether this will lead to technological failure (Lerner, 2012; Lipsey & Carlaw, 1998). Empirical studies however, are beginning to shed light on certain design aspects for specifically accelerating innovation. These include the role of a strong mission (Glennie & Bound, 2016; Karo & Katell, 2016), positioning in the relation to the government (Breznitz et al., 2018; Breznitz & Ornston, 2013), approach to private sector engagement (Mazzucato & Robinson, 2018; Roumboutsos & Saussier, 2014; Breznitz et al., 2018; Winskel et al., 2014c) and operational aspects in relation to capabilities and flexibility (Bonvillian, 2018; Azoulay et al., 2019; Anadon et al., 2011; Chan et al., 2017; Taanman, 2012).

Work by Haley (2016; 2017) represents the development of an initial framework that explores the intersection of the effect of broader institutions like political economy with the design approaches taken by an organisation to drive accelerated innovation. Haley asserts that effective design can assist in addressing system shortfalls such as information capture, political capture and risk aversion (2017). Indeed, this directly complements work on intermediaries discussed in section 1.2.4, which is interested in the way in how organisations can be positioned to effectively drive certain functions within an innovation system (Kivimaa, 2014). The utility of Haley's approach in acknowledging and incorporating the effect of broader institutions on organisation design is explored further in Section 1.4.4.2.

This thesis seeks to builds on ideas drawn from historical institutionalism and innovation organisation design to contribute to a gap in the innovation literature by exploring how national institutions have shaped historic clean electricity innovation system development. It goes on to address a wider gap in knowledge in relation to how these national institutional environments have impacted the organisations implementing accelerated innovation policy, and how these might be designed to achieve their aims most effectively.

1.3. Research questions and aims

The preceding literature review demonstrates the gap in knowledge in relation to how national institutions shape clean electricity innovation system development, and how publicly funded organisations can be designed to implement accelerated innovation policy within these.

This thesis addresses this gap by considering the following research question:

How can publicly funded innovation organisations be designed to deliver accelerated clean electricity innovation within their national institutional context?

This overarching question is addressed via three different research questions (RQs):

- **RQ1:** How have national institutions influenced the evolution of clean electricity innovation systems?

- **RQ2:** How does the design of publicly funded innovation organisations affect their role in accelerating clean electricity innovation?

- **RQ3:** How has national context affected the design and approach of publicly funded innovation organisations?

These questions are explored in respect to specific case studies from the UK and US within the 3 papers comprising this thesis.

The research has the following aims and objectives:

Theoretical aims: to gain insights into the influence of national institutions on clean electricity innovation system development through the application of a refined theoretical framework drawn from historical institutionalism; to identify generalisable insights for effective accelerated innovation organisation design via the refinement of a framework of ten design principles.

Empirical aims: to analyse in detail how the institutional landscape for clean electricity innovation has evolved in the UK; understand why it developed in this way and the impact of this on the design of the ETI, a publicly funded organisation for accelerated innovation; refine these findings via a comparison to ARPA-E in the US.

Policy aims: to increase awareness of how institutions shape innovation systems and the design of publicly funded organisations; refining and developing a framework of principles that can be used to inform the design of effective publicly- funded organisations for accelerated low carbon innovation, which better enables policy makers to navigate the complexity of designing effective accelerated innovation organisations.

1.4. Methodology

This section introduces the methodological approaches adopted to answer the research questions identified above. It begins with an overview of the case study approach in section 1.4.1, with country and organisation selection explored in sections 1.4.2 and 1.4.3 respectively. Section 1.4.4 introduces the two analytical frameworks that are applied to these case studies: a layered institutional framework and ten principles for accelerated innovation organisation design. Finally, sections 1.4.5 and 1.4.6 go on to outline the approaches taken to data collection and analysis.

1.4.1. Case study approach

This thesis utilises a qualitative case study approach, which facilitates learning about context specific situations by providing a framework though which to analyse qualitative data in detail (Flyvbjerg, 2001; Yin, 2014). This is particularly relevant to analysing the socially driven interactions of institutional relationships, which are necessarily context specific, and is therefore the most appropriate approach to gaining situated understandings that can be used to inform broader theory building (Yin, 2014).

The clean electricity innovation system in the UK constitutes the core case study unit in paper 1, with paper 2 providing an embedded sub-unit (Yin, 2014) by concentrating primarily on one organisation within this system- the ETI. This approach permits a detailed, comprehensive analysis of the wider system in which the organisation is set, placing its design and operation within this broader context. Paper 3 utilises a comparative case study design, which more robustly tests the capabilities of the theoretical framework refined in paper 2, by contrasting the ETI with the ARPA-E in the United States. Paper 3 therefore offers an additional explanatory lens as to why different clean energy innovation pathways have been undertaken by revealing points of convergence and divergence between results (King, 2000).

1.4.2. Country selection: UK and US

The UK was selected as the primary case study country for this thesis, explored in papers 1 and 2. The UK represents an interesting case, as it has experienced a rapid expansion of its clean electricity innovation system, with new and evolving policy approaches increasing innovation funding from $89m in 2000 to an estimated $932m in 2018 (IEA, 2019d). Indeed, Winskel et al. remarked in 2014 that the UK represents a dramatic energy innovation system remaking, with *"much of its organisational and institutional make-up was entirely absent a decade earlier"* (2014a; p.599). This move to a global leader in clean energy generation and RD&D (IEA, 2019a) had appeared unlikely to political economy and sustainable transitions practitioners, with this transformation taking place without requiring the radical energy system disruption predicted (Geels, 2014; Mitchell, 2008; Moe, 2015). The UK's experience is therefore highly relevant to the aims of this thesis, which seeks to understand how national institutions have evolved and shaped the development of a successful clean electricity innovation system.

The US was selected as the comparative case study country in paper 3, as it presents both similarities and differences to the UK in historic energy innovation system development, explored in detail below. By selecting cases that share similar political and economic trajectories, differences in design of clean energy innovation organisation are less likely to be related to intrinsic differences in development level or political landscape, which would reduce the validity of theoretical observations (Miles & Huberman, 1994). By holding these elements constant, patterns or relationships detected via replication are more readily comparable between case studies and potentially other similar countries (Yin, 2014).

The following sections go on to explore the way in which political and economic context, electricity system governance, generation portfolio and innovation funding compare within each country, demonstrating key similarities and differences where present.

1.4.2.1. Political and economic context

The electricity systems of the UK and US have been shaped by the political economies and government structures in which they were established. Both countries have developed economies within an environment of plentiful domestic fossil fuel availability. Since the 1950s, this has facilitated the development of markets based on the use and export of fossil fuels, and the expansion of centralised electricity systems for powering domestic industry and increasingly affluent populations (Pearson & Watson, 2012; Carley, 2011). Whilst this narrative has started to diverge between the UK and US in recent years, a cultural identity as a fossil fuel exporter has historically influenced approaches to energy development (Kuzemko et al., 2016).

Both the UK and US can be identified as liberal market economies (LMEs), in which firms have greater control over determining innovation trajectory (Hall & Soskice, 2001). Vasudeva (2009) identifies that this causes the UK an US to pursue similar technology innovation policy approaches, which favour driving entrepreneurial activity and competition to produce a diversity of technology solutions. Historically therefore, both have placed emphasis on providing public funding for the early, science driven stages of R&D, after which market-led policy incentives are utilised to reduce private sector risk in commercial scale roll out, whilst not being seen to 'pick winners' (Anadon et al., 2011; PIU, 2002). This is especially true in the US after the high-profile failure of the publicly funded Synfuels Programme, which continues to influence government attitudes toward engagement in energy innovation projects (Grossman, 2009; Anadon & Nemet, 2013).

1.4.2.2. Electricity system governance

These broader political economy environments have had a direct impact on how the UK and US electricity systems have been governed and evolved, leading both to liberalise and privatise their energy systems. This has facilitated the involvement of large firms in managing electricity system development and maintaining energy security, thus enabling these firms a degree of influence over the direction of energy policy (Kuzemko, 2016; Stokes & Breetz, 2018; Ćetković & Buzogány, 2016).

The differing government structures of the UK and US however, has affected the extent to which privatisation and liberalisation have been implemented in each national context. Schmidt (2006) identifies the UK as a 'simple' LME, where the government acts as a single, central authority, and the US as a 'compound' LME, in which government authority is dispersed across multiple states. The UK government was therefore able to implement liberalisation and privatisation across all sectors and regions, whereas in the US the ownership of infrastructure and extent of liberalisation and competition varies from state to state (EIA, 2019).

The greater extent of system privatisation in the UK contributed to the loss of nationalised RD&D infrastructure throughout the 1980s and 90s, which was privatised and largely closed as a result (Winskel & Radcliffe, 2014). This stands in contrast to the US, which has maintained a series of 17 national laboratories that conduct the basic science supporting the development of many nascent energy technologies (Anadon et al., 2011). As a result, the US has maintained greater public energy R&D capabilities.

Whilst the UK and US differ in the organisation of political authority, they share similar forms of democratic governance. Both countries operate a first-past-the-post election system that produces a stable two party political system, lowering the prevalence of smaller parties (Geels et al., 2016). In the UK, consensus on the need for accelerated innovation to tackle climate change has built between parties in recent years (HMG, 2017a). In the US however, partisan polarisation has increased in recent decades, especially in relation to environmental issues (Dunlap et al., 2016; Mayer, 2019). The first-past-the-post system therefore proves more disruptive to US energy policy, which experiences deeper ideological differences between parties.

1.4.2.3. Electricity generation portfolio

The electricity generation portfolios of the UK and US from 1990- 2018 are depicted in Figures 3 and 4 below. Whilst both countries have experienced a reduction in coal use and growth in wind and solar power generation over the last ten years, the UK has demonstrated a more rapid shift towards clean electricity generation since 2010. This has been driven by differences in domestic fossil fuel availability and climate change policy approach.

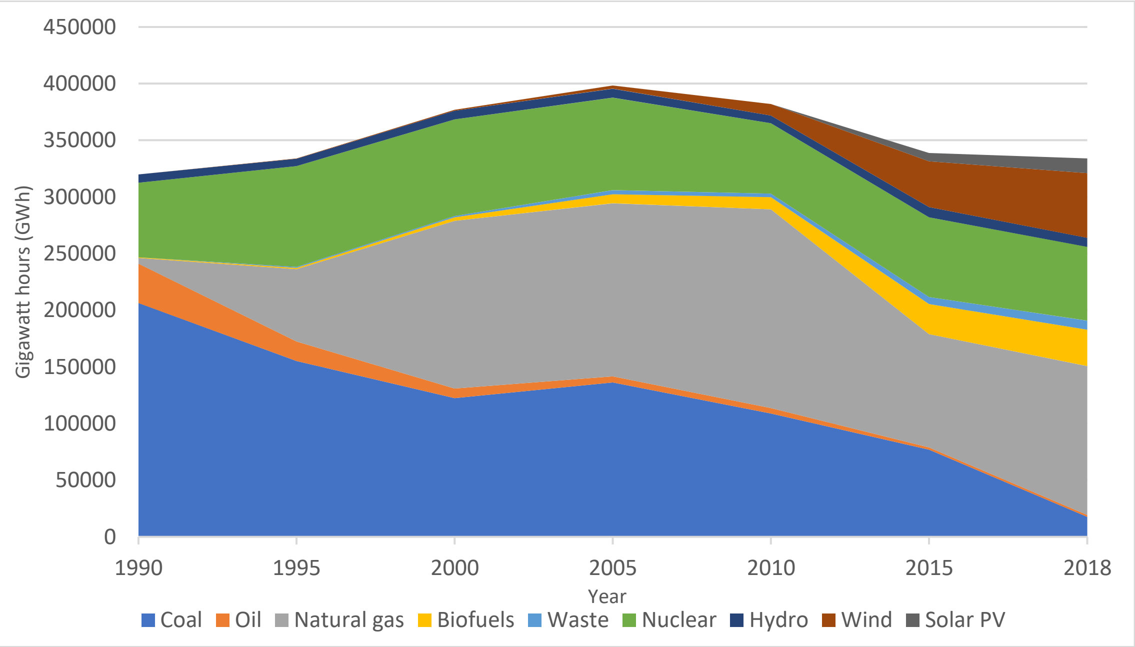


Figure 3- UK electricity generation by source, 1990- 2018 (IEA, 2019c)

In the UK, coal use was displaced from the system throughout the 1990s by the 'dash for gas', as privatised utilities quickly built power stations that took advantage of new domestic gas resources (Winskel, 2002). Over the course of the early 2000s, gas production peaked and a cross party narrative began to form around the need to address climate change. This led to new policies that encouraged renewables integration (PIU, 2002). Onshore wind, biomass combustion and more recently offshore wind have experienced accelerated growth since 2010, whilst coal generation plummeted as plants reached the end of their operational lives and faced increasing environmental regulation (see Isoaho & Markard, 2020). Total power production in 2018 was at its lowest since 1994 (BP, 2019) due to industrial restructuring and improvements in domestic and industrial energy efficiency policy (BEIS, 2019).

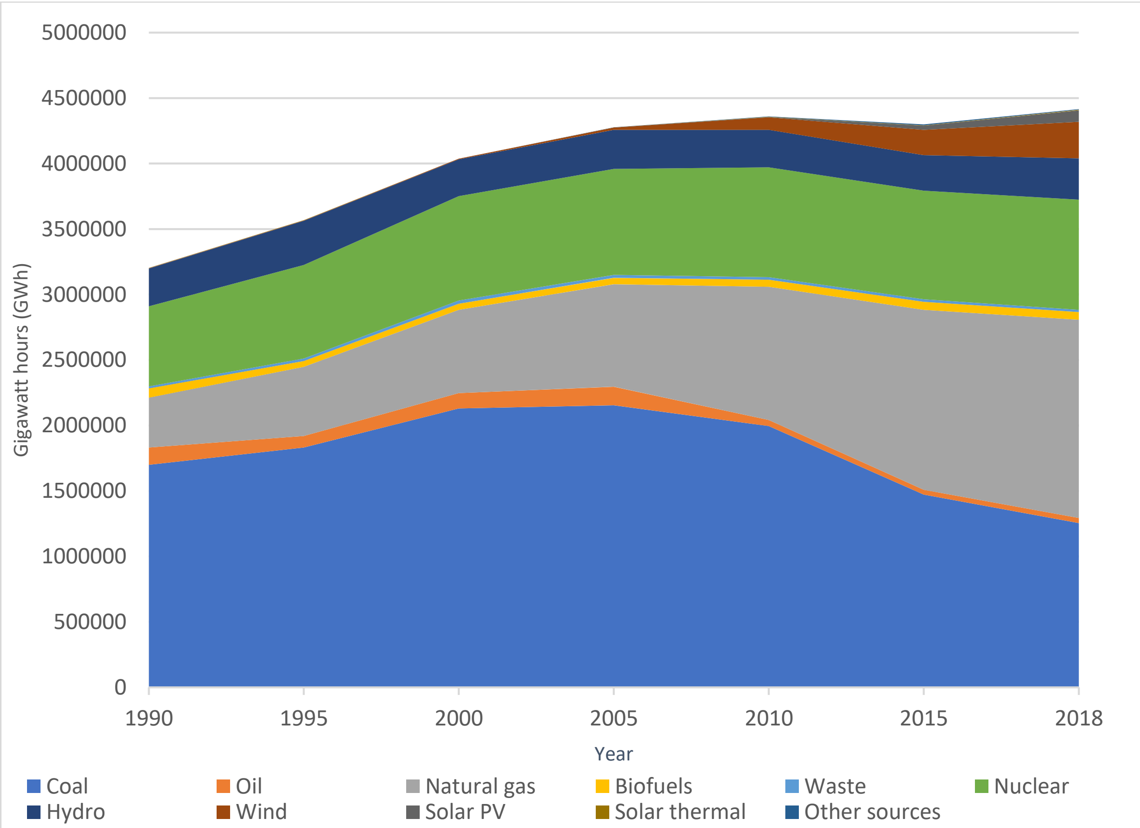


Figure 4- US electricity generation by source, 1990- 2018 (IEA, 2019c)

In contrast, the US has continued to expand natural gas generation and has experienced lower coal reduction and renewables penetration (IEA, 2019b). Coal use began to steadily decline in 2007, due to factors including increased availability of natural gas and renewable energy resources, stringent Environmental Protection Agency regulations on air quality and growing concerns over climate change (EIA, 2017a). A shift to natural gas at this time however, was facilitated by an increase of cheap domestic supply, as hydraulic fracturing and horizontal drilling technologies improved (Logan et al., 2013). This enabled unconventional methods of extraction such as shale and tight gas to offset declines from traditional gas resources (Healey & Jaccard, 2016).Large amounts of natural gas were added to the system between 2000- 2005, with the US recognised as the largest producer of natural gas in the world since 2009 (EIA, 2017b; Paltsev et al., 2011).

The US started to exploit onshore wind and solar resources from 2005 and 2011 respectively (Lopez et al., 2012; Wiser et al., 2015). This has been driven by falling technology prices and ambitious renewables portfolio standards, which differ from state to state (Perea et al., 2020; Yin & Powers, 2010). Unlike the UK, energy demand has continued to grow.

1.4.2.4. Innovation funding

UK and US energy innovation spend 1990- 2018 is depicted in Figures 5 and 6 below. After privatisation and market liberalisation, both countries experienced a reduction in innovation spend throughout the 1980s and 90s (Winskel & Radcliffe, 2014; Dooley, 2008). This trend began to reverse in the early 2000s, experiencing a peak after the financial crisis, leading to rising investment in a greater diversity of technologies.

Prior to 1990, both the UK and US's primary energy innovation investment was in nuclear power (Watson, 2008; Anadon, 2014). By the mid-1990s, UK investment had dipped particularly low across all technologies due to the loss of national research and testing infrastructure (Winskel & Radcliffe, 2014). In contrast, the US maintained its national laboratory infrastructure which enabled ongoing, cross cutting research on basic energy science (Dooley, 2008).

In response to a combination of energy security, economic and climate change concerns, funding levels in both countries have increased since the early 2000s, returning to the highest levels since the early 1980s (PIU, 2002; Holdren & Baldwin, 2001; Nemet & Kammen, 2007; Anadon et al., 2011).

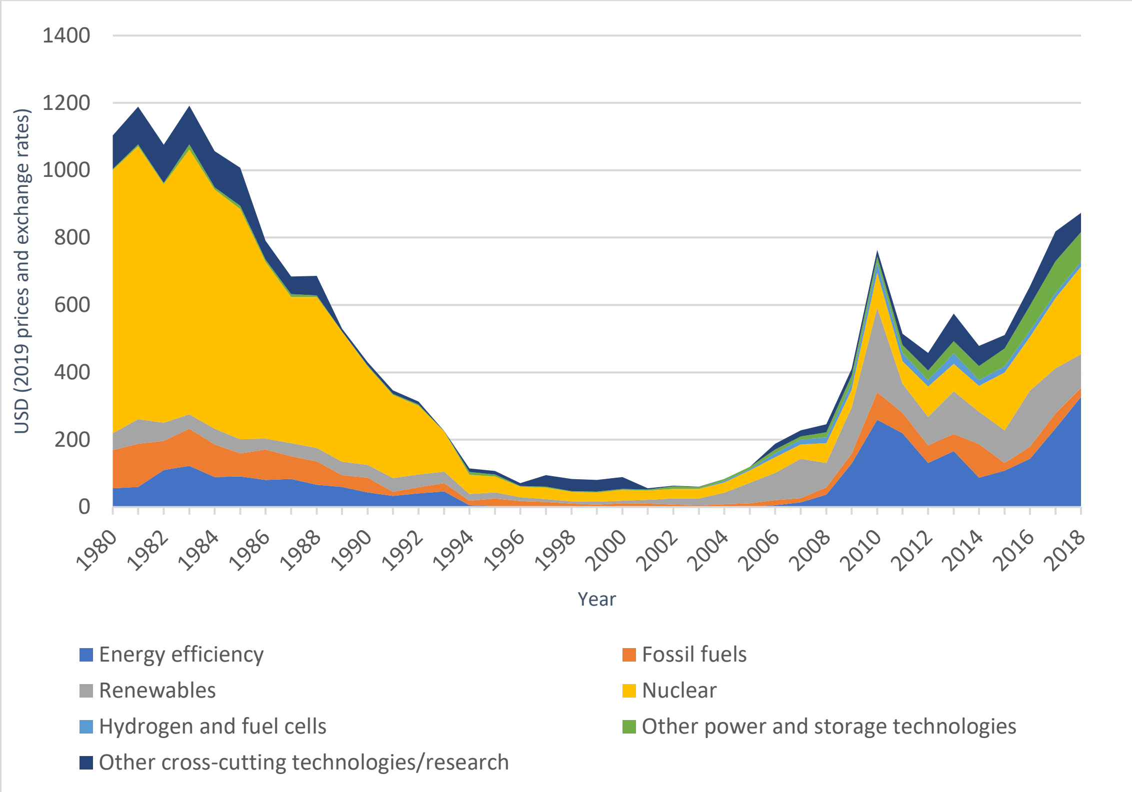


Figure 5- UK energy RD&D spend, 1980-2018 (IEA, 2019d)

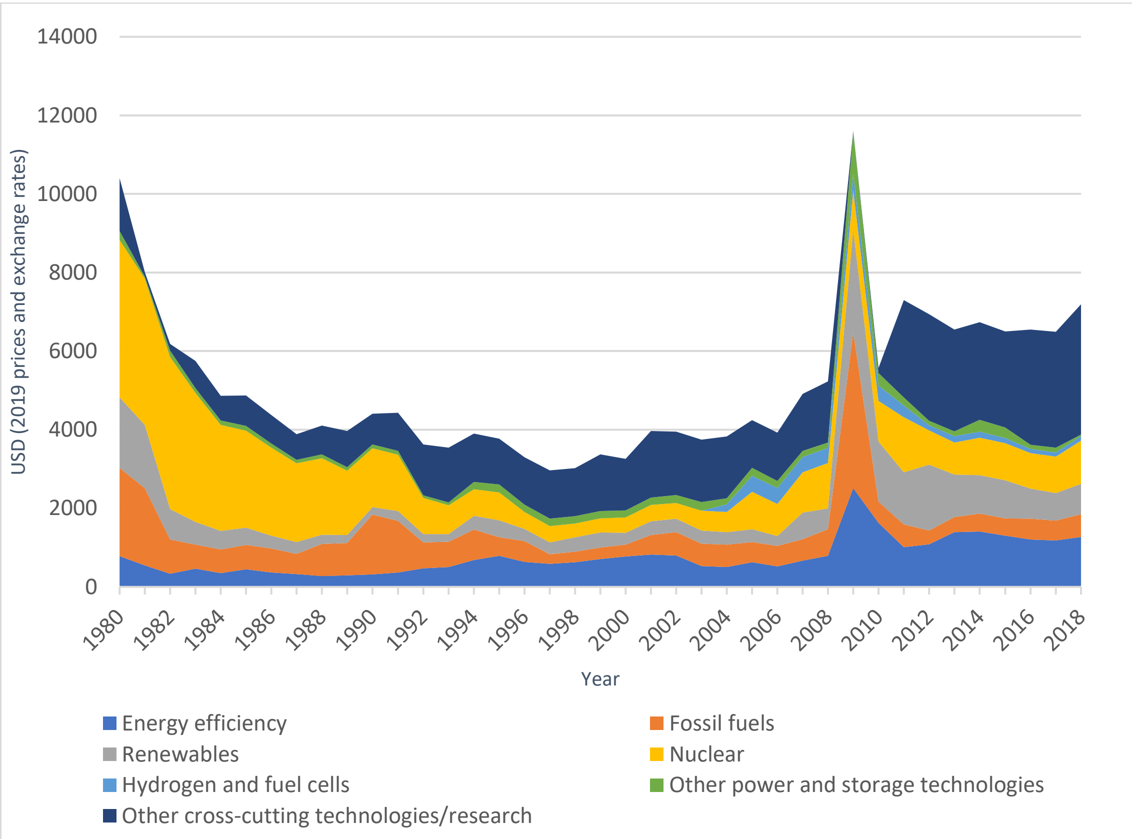


Figure 6- US energy RD&D spend, 1980- 2018 (IEA, 2019d)

The US has consistently been the largest funder of energy RD&D in the world, contributing over six times the amount of the UK in 2019 (IEA, 2020b). Viewed as a percentage of gross domestic product (GDP) however, the US and UK spent a similar amount of GDP in 2019, equating to 0.35%. They place 10th and 12th respectively in global energy innovation investment rankings, as illustrated in Figure 7 below (IEA, 2020d; p.5).

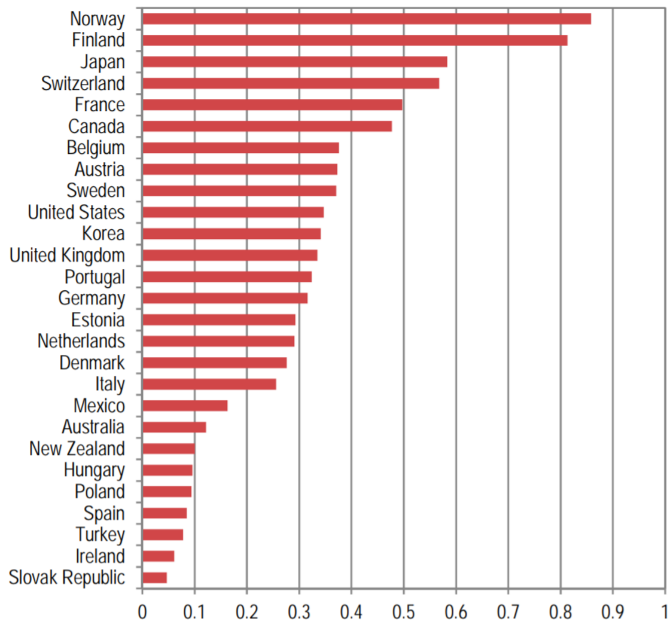


Figure 7- Total public energy RD&D budgets per thousand units of GDP by country for 2018

Much like the UK, over the last fifteen years the US has developed new policies and institutions to accelerate clean energy innovation (Anadon et al., 2011), building on its existing publicly funded infrastructure to develop a competitive, well-connected system (Policy Exchange, 2020). Since 2015 however, the UK has noticeably increased spending above even that after the financial crisis, with the US experiencing a less dramatic recent increase.

1.4.3. Organisation selection: ETI, UK and ARPA-E, US

Papers 2 and 3 of this thesis primarily focus on publicly funded organisations for accelerated low carbon innovation. Whilst the UK and US have developed multiple new organisations and institutions to accelerate innovation since 2000, the Energy Technologies Institute (ETI) in the UK and the Advanced Research Project Agency- Energy (ARPA-E) in the US were selected as case studies for several reasons.

Both organisations represent arms-length, mission-oriented organisations, which aimed to accelerate transformative energy innovation. Both were launched in the late 2000s, meaning that they can be analysed over ten years of operation. They also possess key differences, which include the TRL targeted and funding model utilised. As discussed above in relation to country selection, these similarities contribute to the validity and comparability of the results observed whilst these differences provide interesting opportunities for contrasting outcomes. A brief overview of each organisation is provided below.

ETI

Launched in 2007, the ETI ran for twelve years until 2019, with a mission to *"To accelerate the development, demonstration and eventual commercial deployment of a focused portfolio of energy technologies, which will increase energy efficiency, reduce greenhouse gas emissions and help achieve energy and climate change goals"* (ETI, 2018b, p.3). Focused on technology readiness levels (TRLs) 3-6, it was hoped that the ETI would galvanise strategic focus and provide a pull for research from university to demonstration level (DTI, 2007). The ETI started to wind down its operation in 2017, presenting an opportunity for this thesis to provide the first in-depth analysis of the organisation's operation, as explored in paper 2.

ARPA-E

ARPA-E was selected as the comparative case study in paper 3. ARPA-E was also developed in 2007 and funded as part of the American Recovery and Reinvestment Act of 2009 (NASEM, 2017). ARPA-E's mission aims to *"overcome the long term and high-risk technology barriers in the development of energy technologies"* (p.25) and *'to ensure U.S. technological leadership'* (ARPA-E, 2010, p.ii). Based on the design of the Defence Advanced Research Projects Agency (DARPA), ARPA-E seeks to accelerate the development of transformative technologies at TRLs 1-3 (Azoulay et al., 2019; Alexander, 2009). ARPA-E continues to operate after ten years, with this recommended to continue into the future by an independent review (NASEM, 2017).

1.4.4. Analytical frameworks

As explored above, this thesis seeks to understand both the broader institutional environment in which an innovation organisation is developed and how this interacts to affect the design and operation of a specific organisation. Understanding this intersection is explored via the development of two interrelated frameworks, as demonstrated in Figure 8 below.

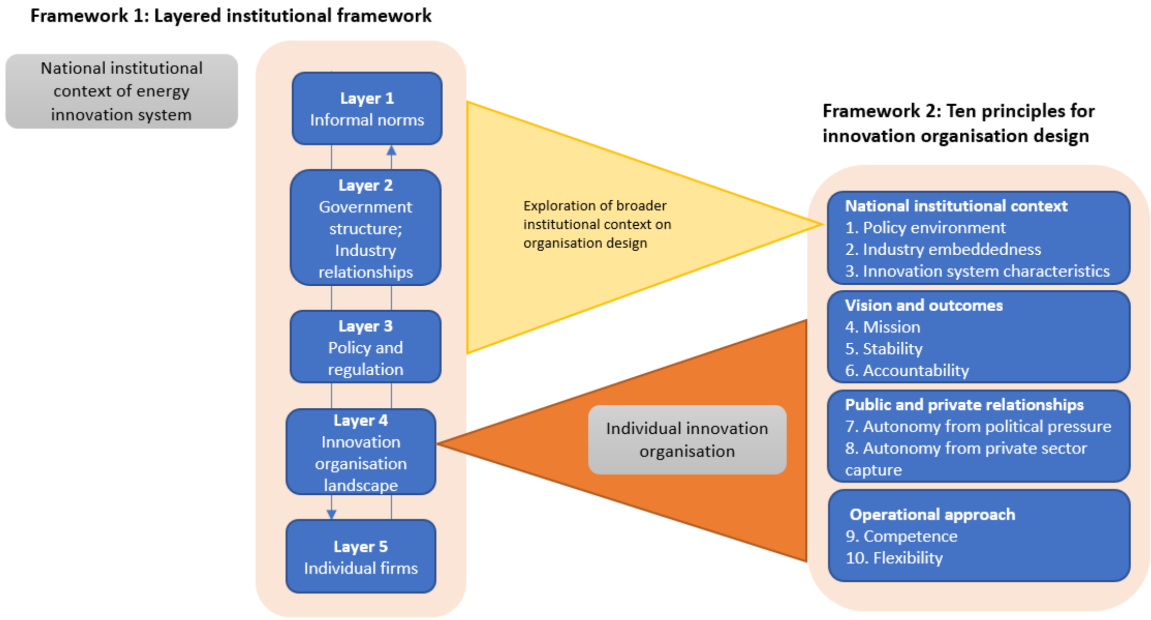


Figure 8- Intersection of Framework 1 and Framework 2

Framework 1 represents a layered institutional framework, which demonstrates the interaction of multiple institutions over time and how this directly links to the evolution of the organisational environment in Layer 4. By viewing multiple institutions within a system together, the framework better facilitates an understanding of how institutional approach and focus has shifted over time to shape the evolution of the energy innovation system.

Framework 2 introduces ten principles for innovation organisation design, which are applicable to a single organisation within layer 4 of framework 1. The first three of the ten principles directly reference the role of the institutional structures addressed in layers 2 and 3 of Framework 1, demonstrating the influence of these institutions on the external and internal operation of organisations seeking to accelerate low carbon innovation.

Together therefore, the frameworks form a nested, complementary understanding of how the broader institutional environment affects individual organisation design and how organisations can navigate this environment to accelerate innovation. They are discussed in greater detail below.

1.4.4.1. Framework 1: Layered institutional framework

RQ1 is addressed in paper 1 by utilising a refined layered institutional framework of the energy innovation system. This approach develops theoretical insights from Groenewegen & van der Steen's (2006) study, which sought to demonstrate the critical importance for policy makers to get *"the institutional environment right"* for national innovation systems to function optimally (p.283). Influenced by Williamson's (2000) visualisation of institutional levels, the framework explores five institutional layers that affect innovation system development.

Work by van der Steen et al. (2008) went on to apply the framework to a comparative case study of the emergence of two renewable energy technology innovation systems in Denmark and Holland, 1970- 2006. Conclusions of this work demonstrated that innovation system development was informed by an interaction of multiple institutions and actors in the five layers identified. For example, in Holland restructuring of the policy environment in layer 3 to support combined-heat-and-power solutions was possible due to open political economy relationships in layer 2 and a tradition of a strong central government making decisions on technology in layer 1. In Denmark a different innovation story emerged, with the long-term presence of cooperatives in layer 4 reflecting national attitudes relating to scepticism of centralised political power at layer 1, enabling actors to innovate boldly in wind energy solutions in layer 5.

Figure 9 details the refined version of this theoretical framework applied in this thesis. A description of each layer is outlined briefly below, with full detail available in Section 2.3. Layer 1 comprises informal norms and values that permeate all other institutions. Technology is positioned alongside the informal institutions in layer 1, as this also affects the operation of all institutional layers beneath. Layer 2 addresses polity, the structure of government departments and the nature of its interaction with the energy industry. Layer 3 is concerned with the policy and regulatory landscape that affects energy innovation. Layer 4 examines the publicly funded organisations and networks that support the delivery of clean electricity innovation policy. Finally, layer 5 considers the impact of the habits and routines of individual actors and their role in driving change.

This represents a modified version of the framework developed by van der Steen et al. (2008), available in Annex A. The reason for these refinements is twofold: firstly, to make the

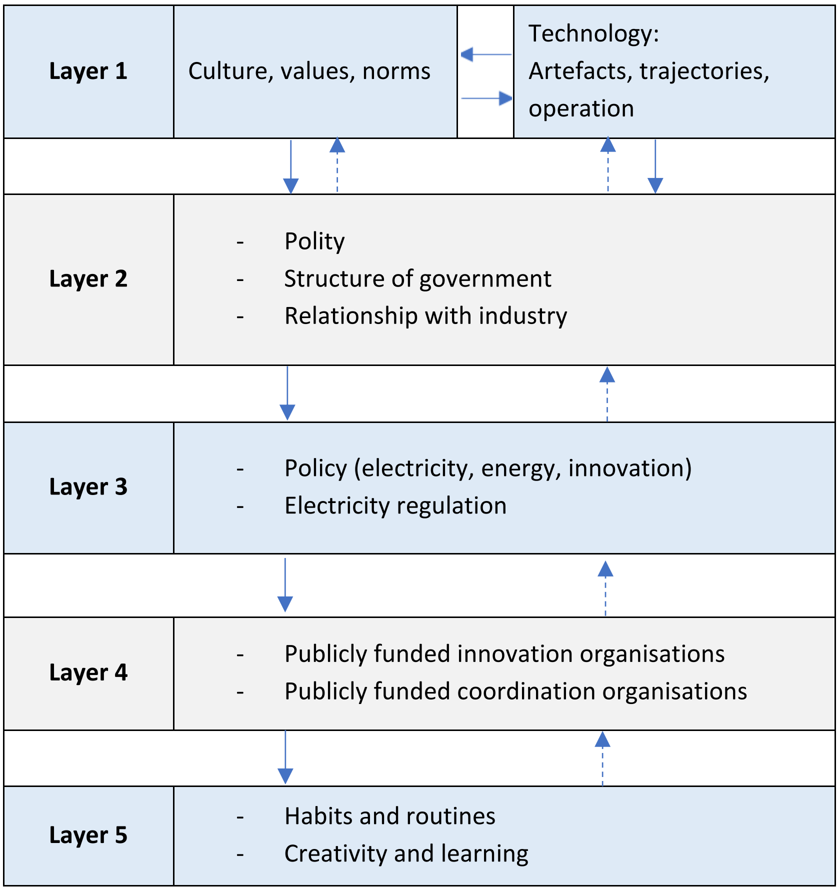


Figure 9- Layered institutional framework, refined from van der Steen (2008)

framework more suitable for application to a sectoral as opposed to technological innovation system. This for example, included removing details relating to more specific institutions such as price regulations, as their technology specific nature became too granular a frame through which to understand the sectoral system. Secondly, the layers now more explicitly focus on the role of multiple national public institutions, the key focus of this thesis, in the evolution of the sectoral system in three ways. Firstly, Layer 2 has been refined to include polity and structure of government, both aspects of the political system, to explore in greater detail the way in which different departments and approaches to governance have affected energy system development. Secondly, the focus of layer 3 has shifted from economic and financial policy to focus more specifically on electricity and climate change policy and electricity system regulation. This narrowing of focus was required to enable detailed analysis of these institutions within a sectoral innovation system context. Finally, this focus is replicated in layer 4, which is interested in publicly funded organisations as opposed to technology specific contracts and organisations.

The framework places institutions into a hierarchy, each layer embedded in that above, with the downward arrows indicating the constraints placed on the layer immediately below (Groenewegen & van der Steen, 2006). This is relevant to Malerba's (2005) understanding of how a sectoral innovation system is maintained by interaction and co-evolution, with alignment facilitating access to resources, markets and broader coalitions that exert influence over institutions and create path dependencies (van de Ven et al., 1989; Unruh, 2000).

The upward arrows between layers however illustrate the possibility of disruption and realignment, as changes at different layers can conflict as well as reinforce one another (van der Steen et al., 2008). In this regard, the framework demonstrates the presence of top-down inertia and the opportunity for institutions to drive change and evolve (van der Steen et al., 2008). This is specifically relevant to the focus of this thesis on organisations, as North (1990) regards these simultaneously as part of a broader institutional framework and vehicles to drive its change by both following and influencing the rules (Edquist & Johnson, 1997).

In terms of theorising how change at the different layers occurs however, Williamson (2000) states *"I mainly neglect these feedbacks"* (p:596), with Groenewegen and van der Steen (2006) also not elaborating on how this process could occur. van der Steen (2008) begins to explore the role of incremental changes and external shocks in destabilising existing structures, but again provides no great detail on how change actually occurs. Despite remaining elusive, these upward arrows are of interest to this thesis, as they demonstrate the presence of a dynamic environment in which the actions of organisations can drive change. Indeed, results in Section 2.5 demonstrate feedback cycles of information during the evolution of the UK innovation system over 15 years, for example, with the experience of organisations in layer 4 culminating to shape policy decisions at layer 3.

The exact activities that drive upward institutional change is difficult to capture, as it is representative of the continuous interaction of actors as they are ongoingly brought to life by human interaction (Jepperson, 1991; Giddens, 1984; Andrews-Speed, 2016). It is these interactions that are key in changing surrounding institutional structures and enabling innovation to move in new directions (Hekkert et al., 2007). This is recognised by Edquist and Johnson (1997) as an ability to *"deliberately change or adapt existing institutions or create new ones, which means that there is a dual subject–object relationship between actors and institutions"* (p.598). Capturing the effect of this on innovation system development has indeed been identified as problematic (Hekkert et al., 2007), exacerbated by the institutional complexity of multiple institutional layers, each containing multiple organisations and actors. The theories of institutional change explored by Streeck (2001), Thelen (2004) and Tsebelis (2000), could provide insight here and a greater understanding to the way in which actors in different institutional layers interact and shift over time. Given the lack of current research into this therefore, it beyond the scope of this thesis to map these concepts to the process of change at different layers. Indeed, more work in relation to applying insights from institutionalism into understanding these upward drivers of change are suggested as an area for future research in Section 5.

The framework presented above is therefore appropriate for addressing RQ1, as it facilitates an understanding of how multiple institutions interacted in the evolution of public sector support for the UK's clean electricity innovation system. The importance of each layer and the role that it has played in shaping the development of surrounding institutions and organisations can be compared against one another, allowing for new insights to be made into the influence of existing institutions and the way that change has occurred over 18 years in the making of the UK's clean electricity innovation system.

1.4.4.2. Framework 2: Ten principles for innovation organisation design

RQ2 and RQ3 are addressed in papers 2 and 3 via the application of a framework of ten principles for innovation organisation design, introduced in Section 1.2.6. Originally identified by Haley (2016; 2017) the principles draw on a range of disciplines including *"public administration; political economy; industrial policy; developmental economics; sustainability transitions and innovation studies"* (2017, p.109). This interdisciplinary approach frames the design of an innovation organisation within the broader system of which it is part, making it appropriate for this thesis's interest in the effect of national institutions on the development organisations that accelerate clean electricity innovation. Haley's (2017) original principles were identified as:

1. Comprehensiveness
2. Flexibility
3. Autonomy from Short-term Political Pressure
4. Mission Orientation
5. Embeddedness within Policy Networks
6. Autonomy from Private Interests
7. Competence
8. Credibility

9. Stability
10. Accountability

Haley tested the utility of these principles via an initial application to ARPA-E, which demonstrated their usefulness in understanding how innovation organisations can be designed to effectively accelerate innovation. It also highlighted that there are potential trade-offs between certain design principles, demonstrating that there needs to be a careful balance considered between embedding the private sector and maintaining autonomy for example (Haley, 2017). These insights sought to act as a jumping-off point for more detailed empirical application to organisations operating within different national contexts.

After initial refinement and application of the principles in paper 2, paper 3 incorporated these insights to further improve the utility of the principles for analysing accelerated innovation organisation design. The culmination of these changes is presented in Figure 10 and discussed in greater detail below.

Removal of 'Credibility' as a separate principle

Haley (2017) defines the principle of credibility as building private sector trust and demonstrating a sustained financial commitment. Through detailed application in paper 2, it was clear that this principle was addressed as a key aspect of three other principles. Private sector trust is a key aspect that needed to be considered in relation to 'Industry embeddedness' (principle 2), and 'Autonomy from private sector capture' (principle 8), as credibility shapes the way in which an organisation builds relationships with firms. Additionally, financial credibility is key to creating organisational 'Stability', explored in principle 5. Credibility was therefore removed as a separate principle.

Category	No.	Organisational principle	Description
National institutional context	1	**Policy environment**	• Takes an innovation approach supported by multiple policy instruments • Aims to build cross party narrative around its activities
	2	**Industry embeddedness**	• Engages relevant private sector actors in an equitable way • Builds cross-sector trust and understanding on direction of technology development
	3	**Innovation system characteristics**	• Forms part of a coherent innovation system that contains complementary institutions and organisations • Interacts to facilitate resource and knowledge flow between stages of technology development

Vision and outcomes	4	**Mission**	• Defines a clear organisational aim • Attracts talented employees through the autonomy of a strong mission • Focuses on performance as opposed to bureaucracy and procedure
	5	**Stability**	• Takes a long-term innovation focus • Retains sufficient and predictable funding for long term project development
	6	**Accountability**	• Transparency of achievements • Adopts non-ambiguous success metrics • Dedicates capacity to communicating outputs to the appropriate audiences
Public and private relationships	7	**Autonomy from political pressure**	• Decouples organisation from the agenda of individual policy makers • Protects policy makers from failure • Retains access to broader public resources
	8	**Autonomy from private sector capture**	• Engages with firms on public sector terms • Ensures that policy makers retain the ability to decide technology trajectory • Protects intellectual property from private capture
Operational approach	9	**Competence**	• Engages high-quality leadership with the skills to develop an appropriate vision • Empowers staff to act autonomously • Develops strong and appropriate knowledge and skill sets • Understands how technologies will sit within the wider innovation system
	10	**Flexibility**	• Creates a nimble, entrepreneurial organisational culture • Encourages evaluation and change of internal processes • Ability to pivot away from failure, or to fail quickly • Responds to changes in innovation system dynamics and technological windows of opportunity

Figure 10- Ten principles for accelerated innovation organisation design, refined and developed based on work by Haley (2017)

'Comprehensiveness' split to become 'Policy environment' and 'Innovation system characteristics'

Haley's original principle of 'Comprehensiveness' has been separated in to two distinct principles of 'Policy environment' (principle 1) and 'Innovation system characteristics' (principle 3). Haley's original principle conflated these two aspects, making it more difficult to explore their role in organisation design.

'Policy environment' addresses how an organisation sits within the broader policy mix, which may be impacted by the structure of the political system and the extent to which departments are joined up or decision makers change. 'Innovation system characteristics' differs by more specifically exploring how innovation system actors are able to respond to policy, and how organisations can work within system structure to successfully accelerate innovation. This may involve other aspects beyond policy, such as coordination and knowledge sharing networks, or the availability of test infrastructure. Despite some overlap, examining these two aspects separately enables more detailed analysis of these aspects on organisation design.

Definition of 'Industry embeddedness' is updated

'Industry embeddedness' (principle 2) has been updated to reflect the challenge of accelerating innovation in legacy sectors. Haley's initial (2017) conceptualisation of embeddedness was based on literature focused on the emergence of the IT sector (Evans, 1995; 2008), where industry development benefitted from building sustained, consistent linkages with private sector actors to develop effective policy. The dynamics of industry engagement in a legacy sector like energy therefore is not considered, which may negatively affect the development of innovation policy. Private sector relationships in these sectors need to be carefully navigated to ensure that relationships are built with firms able to drive the desired innovation policy aims forward and ground these in public interest. The focus of this principle has therefore shifted to consider which private sector actors are *currently* embedded in innovation policy and which *need* to be if an organisation is to achieve its aims.

Principles of 'Competence' and 'Flexibility' redeveloped to integrate internal aspects of organisation operation

The focus of 'Competence' (principle 9) and 'Flexibility' (principle 10) have been refined to more closely focus on the internal design and operation of an organisation. Haley (2016) initially developed the design principles in relation to *institutional* design, which he defined as *"the rules that govern society"* (2017, p.110). Despite being based on this broader definition of an institution, the principles were not adjusted when applied to the specific unit of an organisation (Haley, 2017). Detailed empirical application of the principles in paper 2 demonstrated that the existing principles did not adequately address dimensions of internal organisational functions, with the focus remaining on the way in which the organisation interacted with external institutions. The refined principles in Figure 10 therefore integrate insights drawn from the innovation organisation literature, discussed in section 3.2.4. This renders the principles able to analyse these important aspects of organisation design.

Reordering of the principles into four categories

Finally, informed by the refinements discussed above, the principles have been reordered into four broader categories that identify their role in relation to organisation design. The first three principles are concerned with the broader institutional context in which an organisation is positioned. These effect both the type of innovation needed given past policy direction and the ability of an organisation to address or challenge this. Principles four, five and six relate to developing a clear vision and outcome for the organisation, whilst principles seven and eight address the public and private relationships an organisation seeks to cultivate. Finally, principles nine and ten relate to the operational approach adopted by the organisation. These categories and descriptions of each principle are explored in greater detail in section 4.3.

Use of this framework therefore enables RQ2 and RQ3 to be answered by analysing an organisation in relation to the broader institutional context in which it develops, in direct relation to its internal operation. This enables the different influences, tensions and synergies between design principles to be better understood, enabling generalisable aspects of effective accelerated innovation organisation design to be explored.

1.4.5. Data collection

Primary data collection took the form of 35 semi-structured interviews, lasting between 45 minutes and one hour. Semi-structured interviews were utilised as they facilitate the use of both planned questions and a more conversational, flexible approach to data collection (Rubin & Rubin, 2011; Kvale, 2008). This maximised the amount of time spent with high-level interviewees, with the use of tailored questions framed within conversation enabling the most relevant information to be explored (Yin, 2014). This was particularly important in addressing RQ1, where interviewees possessed a broad range of experience that sometimes required corralling, or the ability to pursue unexpected lines of enquiry (Grix, 2010).

The interviews were conducted in two phases; the first focused on UK interviewees to address RQ1 and RQ2 and the second primarily on US interviewees in order to address RQ3. Interviewees were sent an overview of the project and asked for verbal consent for the interview to be recorded for use within this thesis. Interview recordings were primarily made using a smartphone application, after which they were then downloaded and stored securely, with files renamed as numbers to ensure interviewee anonymity. Some interviews were transcribed by the author and others using ‘Go Transcript’ online transcription service.

Other primary sources utilised to answer RQ2 and RQ3 consisted of attendance of the ETI ten-year anniversary event, the ARPA-E Ten Years of Energy Innovation Summit and a high-level workshop on clean energy innovation in the US. These provided access to presentation and discussion panel data, as well as engagement and discussion with stakeholders that assisted in developing a greater contextual understanding of the space. Table 1 summarises the data collection process, with more detail available on interviewees in the corresponding papers.

Paper	Research question	Primary data collection	Date of collection
1	1- How have national institutions affected the evolution of the UK clean electricity innovation system 2000- 2018?	22 semi-structured interviews with key stakeholders	February- April 2017
2	2- How did the design of the ETI affect its role in accelerating clean electricity innovation in the UK?	10 semi-structured interviews with ETI affiliated stakeholders Data from 12 interviews for paper 1 that discussed the ETI Attendance of the ETI10 event, London, UK 1 additional semi-structured interview	March- April 2017 February- April 2017 3-4 October 2017 March 2020
3	3- To what extent have different national contexts affected the design of the ETI and ARPA-E?	13 semi-structured interviews with key stakeholders Workshop on 'Accelerating Climate-mitigating technology development and deployment' Attendance of the ARPA-E Ten Years of Energy Innovation Summit, Denver, US	April- July 2018 6-7 June 2018 8- 10 July 2019

Table 1- Summary of primary data collection

Secondary data collection formed the basis of detailed theoretical analysis and case study development, utilising a broad wide range of academic and grey literatures, described in each paper. This facilitated triangulation of primary data, accurately locating it within a broader evidence base to produce more accurate and contextualised results (Baxter & Jack, 2008; Yin, 2014).

As data was collected and analysed it was used to iterate and adapt the methodological frameworks utilised, in an approach akin to Straussian Grounded Theory (see Reiger, 2019).

This is especially true of Framework two, which evolved significantly between RQ2 and RQ3 as a results of detailed, empirical application highlighting opportunities to improve its utility.

Utilising this approach has enabled detailed primary and secondary qualitative data to be analysed in a systematic way to produce new insights into the complexities of institutional continuity and change. The collection of primary data from a range of different sources viewed alongside secondary resources produced a detailed data set less susceptible to the bias of particular interviewees and authors. The limitation of this approach is a lack of direct quantitative analysis of innovation investment and performance, also restricted by the lack of availability of comparable data sets. This would have provided a complementary dataset in relation to funding flow and performance over time.

1.4.6. Data analysis

Interview transcripts were analysed using NVivo 11 & 12™ software, which enabled common themes and patterns in the data to be identified. To analyse RQ1, the coding structure mirrored the layered institutional framework adopted, with nodes pertaining to the five institutional layers. These then contained further nodes that were developed via analysis of the interview data. These included case nodes that referred to specific organisations, institutions and people; and thematic nodes that identified more subjective, descriptive aspects emerging from the data as it was analysed, such as the perceived role of different organisations. For RQ2 and RQ3, this pattern was repeated but with the coding structure mirroring the ten organisational design principles.

The use of NVivo software enabled an effective coding structure to be adopted across all the data, which could be easily searched by theme, actor or key word. Additionally, the weighting of data coded to each node demonstrated the relative importance of that topic, indicating areas of particular interest or further analysis.

Secondary data was similarly organised in relation to the different analytical frameworks and utilised where possible to triangulate themes appearing in the primary data. An overview of the research design for each paper is indicated in Figure 11 below.

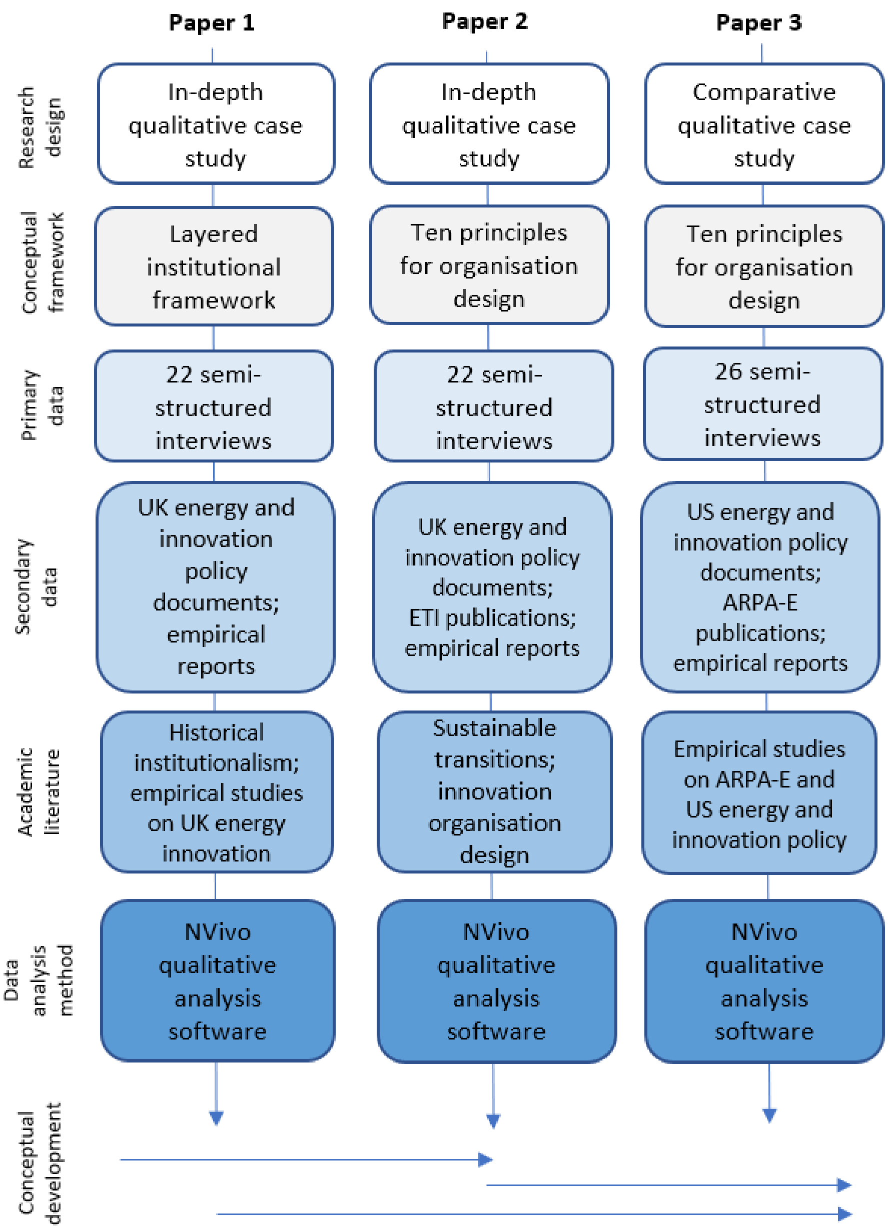


Figure 11- Overview of research design

1.5 Summary of papers

This section provides an overview of the content of the three papers that comprise this thesis:

Paper 1: Understanding national clean electricity innovation system development: A case study of the UK

Paper 2: Designing publicly funded organisations for accelerated innovation: A case study of the Energy Technologies Institute, UK

Paper 3: Publicly funded organisations for accelerated low carbon innovation: A comparative case study of the ETI, UK and ARPA-E, US

Paper 1 is currently in working paper format, with plans to be refined with co-author Professor Jim Watson for submission to Energy Research and Social Science in April 2022. Paper 2 was published in Environmental Innovation and Societal Transitions in June 2022. Paper 3 is under review at Energy Policy as of September 2021. Figure 12 provides an overview of how the three papers sit together to form this thesis, with each discussed in greater detail below.

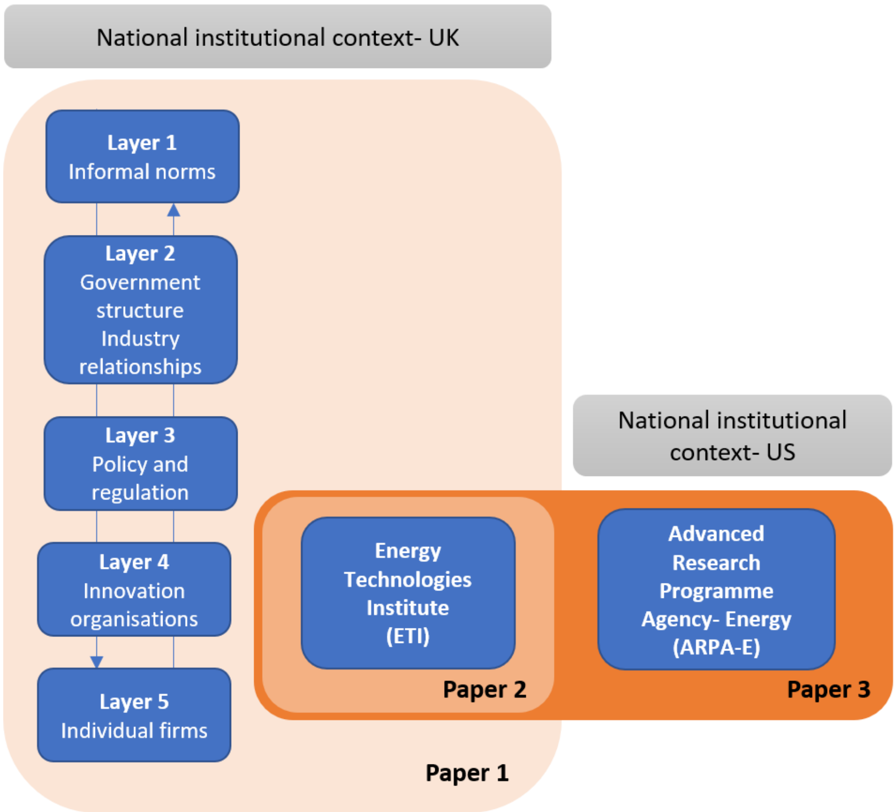


Figure 12- Overview of papers

Paper 1: Understanding national clean electricity innovation system development: A case study of the UK

The first paper explores the influence of five layers of national institutions on the development of the clean electricity innovation system in the UK, 2000- 2018. The paper reviews the literature on the role of politics in innovation system development and change. It goes on to refine and apply a layered institutional framework originally developed by van der Steen et al. (2008).

The application of this framework reveals the influence of enduring, top-down informal institutions on those developed beneath, which has caused clean electricity innovation to occur within the existing, centralised electricity system. Institutions supporting clean electricity innovation have evolved over time at different speeds, creating a landscape of gradual, uneven change. As the centralised system faces increasing pressure to deliver whole system innovation, this will require increased institutional disruption, as more radical changes to system infrastructure, markets and regulation will be required. The paper argues that policy makers should pay closer attention to the broader institutional environment in order to make effective accelerated clean electricity innovation policy, creating greater stability and links with a diverse range of stakeholders.

Paper 2: Designing publicly funded organisations for accelerated innovation: A case study of the Energy Technologies Institute, UK

The second paper investigates how the design of the ETI affected its operation and ability to accelerate clean electricity innovation. A framework of ten principles for innovation organisation design, initially developed by Haley (2017), are refined and discussed in relation to their relevance to the sustainable transition and innovation organisation literatures.

Results indicate that the design of the ETI impaired its ability to pursue its mission of accelerating transformative innovation. Key to this was the embedding incumbent firms in a Public-Private Partnership (PPP) model, creating issues related to risk appetite and accountability. Additionally, the ETI lacked a diverse range of competencies and organisational flexibility, further contributing to a more incremental approach to innovation.

Detailed empirical application of the design principles in this paper demonstrated that they would benefit from a greater focus on internal organisation operation alongside external system interactions. These insights were integrated into the framework and applied in paper 3.

Paper 3: Publicly funded organisations for accelerated low carbon innovation: A comparative case study of the ETI, UK and ARPA-E, US

The third paper develops a comparative case study of the ETI, UK, and ARPA-E, US, exploring how their design affected their operation and ability to accelerate transformative innovation. The national institutional context of each organisation is explored, after which they are analysed against ten principles for innovation organisation design.

The paper demonstrates that the design of ARPA-E was much better suited than the ETI to the mission of accelerating transformative innovation. The comparison reveals generalisable insights for accelerated innovation organisation design and the potential tensions that exist in pursuing these. Results also indicate that the success of an organisation is dependent on the support of broader national institutions, such as policy environment, innovation system composition and industry engagement in market development.

1.6. Thesis structure

This thesis is structured into the following chapters:

1. **Introduction**
   Provides a review of the relevant literature; the research context and questions; a summary of the analytical frameworks utilised; an overview of methodological approach; and a summary of the three research papers that comprise this thesis.

2. **Paper 1: Understanding national clean electricity innovation system development: A case study of the UK**
   Develops a layered institutional framework to analyse how national isntitutions have affected the development of the UK clean electricity innovaiton system 2000- 2018. Through a qualatative case study it demonstartes the importance of considering the broader institutional landscape in which accelerated innovation policy is made, identifying policy implications to navigate this.

3. **Paper 2: Designing publicly funded organisations for accelerated innovation: A case study of the Energy Technologies Institute, UK**
   Refines ten principles for accelerated innovation organisation design, framing their usefulness within the sustainability transitions literature and applying them to an in-depth case study of the ETI. This demonstrates the importance of matching

organisation design with mission if the desired innovation is to be accelerated effectively.

4. **Paper 3: Organisations for accelerated low carbon innovation: A comparative case study of the ETI and ARPA-E**
   Further develops ten principles for accelerated innovation organisation design, applying them a comparative case study of the ETI and ARPA-E. Results explore generalisable aspects of accelerated innovation organisation design and the importance of considering national institutional context in their adoption.

5. **Conclusion**
   Provides answers to the research questions; outlines the key theoretical, empirical and policy contributions of the thesis; discusses potential avenues for further research; and provides concluding remarks.

2. Paper 1: Understanding national clean electricity innovation system development: A case study of the UK

2.1. Introduction

Accelerated clean energy innovation is required if we are to meet the aims of the Paris Agreement (IPCC, 2018; IEA, 2020a). In 2018 however, national clean energy innovation research, development and demonstration (RD&D) funding for non-commercial technologies continued to fall beneath the required levels (IEA, 2019e). This raises questions over the effectiveness of current innovation policy in supporting the range of technologies required (IEA, 2020a; Watson et al., 2015; Ćetković et al., 2017; Mazzucato & Semieniuk, 2017).

Whilst literature has emerged to explore 'best practice' policy guidelines for stimulating clean energy RD&D (Foxon & Pearson, 2008; Chiavari & Tam, 2011; Grubler et al., 2012; Winskel et al., 2014a), there has been less emphasis on understanding the way in which the politics embodied in existing innovation systems impacts the implementation of these policies (Ćetković et al., 2017; Sandén & Azar, 2005). Clean electricity innovation systems pose a particular challenge in this regard, as technological and institutional inertia combine to deeply impact relationships between actors (Hughes, 1983; Unruh, 2000; Moe, 2016). Understanding the politics of innovation systems is therefore essential if accelerated change is to be achieved.

The United Kingdom (UK) provides an interesting case study of the emergence of a clean electricity innovation system. New and evolving policy approaches have increased innovation funding from £34.1m in 2003 to an estimated £717.4m in 2018 (IEA, 2019d), with Winskel et al. (2014a, p.599) stating that the UK represents a dramatic energy technology innovation system remaking: *"In 2013 much of its organisational and institutional make-up was entirely absent a decade earlier."* Indeed, the UK has overcome strong existing energy technology regimes (Geels, 2014; Mitchell, 2008) to become a global leader in clean energy generation and RD&D (IEA, 2019a; CCC, 2020).

This paper seeks to understand how the politics of the UK's existing energy innovation system has shaped the emergence of its clean electricity innovation system, by developing an approach drawn from historical institutionalism. This foregrounds the role of government, politics and policy to address the question: how have national institutions affected the evolution of the UK clean electricity innovation system, 2000-2018?

Conclusions demonstrate the influence of enduring informal, top-down institutions of centralisation and liberalised market structures on the institutions that have developed beneath it, which has enabled the clean electricity innovation system to develop solutions within the existing, centralised electricity system. Institutions have evolved over time at different speeds to facilitate this, creating a landscape of gradual, uneven change. As the centralised electricity system faces increasing institutional and technological pressure to deliver whole system innovation, more radical institutional change to system infrastructure, markets and regulation may be more likely to emerge.

The paper is organised as follows. Section 2 reviews the literature on the politics of energy innovation systems, whilst section 3 introduces the theoretical framework. Section 4 outlines the case study methodology and section 5 provides an overview of the UK energy innovation system. Section 6 explores the results and section seven concludes with the policy implications of this paper.

2.2. Literature review

2.2.1. Innovation systems

Innovation systems literature emerged in the latter half of the 20th century with the aim of understanding the essential economic process of *"putting ideas into practice through an (iterative) process of design, testing, and improvement"* to establish industrial capabilities (Grubler et al., 2012, p.1673). These theories are used widely to design innovation policy (Weber & Rohracher, 2012). Several approaches have emerged, including national (Nelson, 1993), regional (Asheim & Gertler, 2005), sectoral (Malerba, 2004) and technology (Carlsson & Stankiewicz, 1991) perspectives of innovation systems.

Clean electricity innovation takes place within a sectoral innovation system (SIS), which focuses on the production and consumption of new and established products within a particular industry (Bergek & Jacobsson, 2003; Edquist, 2010). The boundaries of a SIS are generally defined by the technologies that the sector has produced over time, with Breschi & Malerba (1997, p.130) utilising the concept of a *"technological regime"* to describe the network of actors and institutions that accumulate technologies and knowledge through evolutionary growth (Dosi 1982; Freeman & Perez, 1988; Markard & Truffer, 2008). Clean electricity innovation has also been discussed as part of the energy technology innovation system (ETIS), which similarly acknowledges the accumulation of structural dimensions over time, including institutional strength (Wilson & Grubler, 2014; Skea et al., 2019).

As the innovation systems literature is primarily focused on firm-led innovation however (Fagerberg, 2004), its understanding of the accumulation and implications of institutional dimensions on the innovation processes is limited (Edquist, 2011; Weber & Rohracher 2012; Kern, 2015; Bergek at al., 2015). Unruh (2000) for example, observes that the expansion of long-lived, centralised fossil fuel systems can lead to 'carbon lock-in', where a system is maintained in a cycle of technological, social and institutional self-reinforcement. Similarly, the ETIS is identified to suffer with issues of institutional interdependence, complexity and inertia (Gallagher et al. 2012). These factors can lead to innovation system failure (Foxon et al., 2005), as new forms of technology or knowledge are not valued within the system they seek to innovate (OECD, 2018; Owen, 2006). Indeed, Jacobsson & Bergek (2011, p.55) identify an absence in an understanding of the "*politics of policy"* in the innovation systems literature.

The energy innovation system approach therefore proves ill-equipped in navigating the complexity of existing systems in developing policy strategies for accelerated clean electricity innovation. To better address this, literatures that more closely centre the influence of political interactions on clean electricity innovation need to be explored.

2.2.2. Politics of innovation systems

Emerging research has increasingly drawn on political science approaches to better understand the politics of clean electricity innovation systems.

The role of a county's political structures has been demonstrated to impact innovation policy. Schmidt & Sewerin (2017) for example, identify the effect of budget allocation processes 'stickiness' of clean energy innovation policy interventions, with the US's volatile Congressional system proving less stable than that of Germany. Electoral processes also have an impact, with Lockwood et al. (2013) identifying that a first-past-the-post election system reduces the stability required to develop new institutions in comparison to proportional representation. Work by Baccini & Urpelanien (2012) goes on to demonstrate that frequently changing political parties can fracture energy innovation policy approaches, reducing the effectiveness of R&D programmes.

The role of political economy has been explored in the varieties of capitalism (VoC) literature, which asserts that the institutional framework of a country *"controls its pattern of economic and technological specialization"* (Boschma & Capone, 2015, p.1902; Hall & Soskice, 2001). Whilst VoC has received criticism for incorrectly assigning the type of clean energy innovation that a country will pursue (Mikler & Harrisson, 2012; Taylor, 2004) and being overly simplistic in market classification (Ćetković & Buzogany, 2016; Lachapelle & Paterson, 2013), it has yielded useful insights into understanding the effect of national political contexts on energy innovation policy. For example, Ćetković et al. (2017) discuss that the UK's support for onshore wind innovation was impacted by a majoritarian political system that failed to provide policy certainty, contributing to a low number of patents and projects being developed by companies from outside the UK.

In recent years, the sustainability transitions literature has sought to develop a greater understanding of the politics of clean electricity innovation. Application of the multi-level perspective (MLP) has proven effective in moving beyond individual firms and technologies to recognise how the broader regime affects energy innovation policy making (Smith et al., 2010; Weber & Rohracher, 2012). Geels et al. (2016) for example, identify that incumbent firms have played a key role in deploying clean energy technologies in the UK, via the utilisation of market-based policies. This has implications on which clean electricity technologies have been funded to support this trajectory. McMeekin et al. (2019) go on to discuss that this has led to more incremental change to the UK's electricity infrastructure, which has recently triggered increased innovation policy attention on network and distribution systems.

The MLP however has received criticism for placing too much emphasis on bottom-up, niche led innovation for technology change, as opposed to those developed by existing regime actors (Schot & Geels, 2007; Berggren et al., 2015; Hölsgens et al., 2018). Geels (2014; 2019) has since highlighted the importance of integrating an understanding of regime level power dynamics into analyses, and the MLP remains a prominent approach (Köhler et al., 2019).

The sustainability transitions literature more broadly has sought to build a greater understanding of the impact of politics and power (Avelino & Wittmayer, 2016; Grin, 2012), the resistance and reorientation of incumbents (Bergek et al., 2013; Maguire & Hardy, 2009;

Smink et al., 2015) and the role of actors and their interests on the development of innovative energy technologies (Ahlborg, 2017; Markard et al., 2016). Recent work has increasingly incorporated insights from political science to better understand the non-neutral role of State (Johnstone & Newell, 2018) and institutional structures (Lockwood et al., 2017).

Whilst useful, the approaches explored above generally emphasise the stability of existing institutional structures (Hancké, 2009; McMeekin et al., 2019; Kuzemko et al., 2016). In this regard, institutions are understood as forming a robust self-reinforcing whole that maintains a rigid equilibrium (Thelen, 2004) that need to be destroyed and replaced to facilitate clean electricity innovation.

2.2.3. Historical institutionalism and institutional change

New institutionalism is a political science approach dedicated to understanding the impact of institutional structures on policy making. In response to the rational choice approach of traditional institutionalism, new institutionalism was developed in the 1980s to reincorporate the State into explanations of political action (Hall & Taylor, 1996). NI is therefore well equipped to explore the impact of politics on national institutional environments, recognising them as dynamic and constantly undergoing change (Andrews-Speed, 2016).

New institutionalism theories applied to energy innovation to date have primarily been sociological and organisational approaches, which are concerned with how certain technologies are developed and diffused. For example, discursive approaches have been utilised to analyse how ideas and narratives drive institutional change (Kern et al., 2014; Niemelä & Saarinen, 2012). Whilst these approaches have been effective in analysing the creation of new policy paradigms and innovation niches *within* a system, they are less useful in analysing the system itself, and its impact upon shaping these outputs.

In order to explore the impact of these broader institutions, historical institutionalism (HI) is gaining increasing interest in the sustainable transitions literature (see Lockwood et al., 2017), as a branch of new institutionalism concerned with how processes and inertia build within systems and relationships between actors (Thelen, 1999; Hall & Taylor, 1996). HI provides a large, mature literature that emphasises the impact of institutional design (Andrews- Speed, 2016), making it highly relevant in understanding how this has shaped changing innovation systems.

Work by Streeck (2001) for example, views political economy relationships as being constantly established, reorganised, restored and defended against forces of disorganisation. Viewing institutions as such demonstrates the importance of understanding their past development, how they have interacted and their potential to evolve into the future. Indeed, Thelen (2004) goes on to identify four pattens in which policy institutions change: i) layering of institutions over a core logic that remains the same, ii) drift of policies in use, despite no official decision for them to change, iii) conversion of the goals of an existing policy without a change in instrument, and iv) displacement of old institutions with new ones. The extent to which these changes take place is additionally influenced by the veto power of certain actors, whose agreement is required for the status quo to change (Tsebelis, 2000).

Empirical work by work by Bird (2015) and Keay et al. (2012) demonstrates how inconsistencies in the UK's approach to energy policy have built over time, as new instruments have been layered over time on traditional market-based approaches. Furthermore Lockwood et al. (2015) identify the veto power of Ofgem in shaping UK electricity markets. Insights from historical institutionalism therefore demonstrate how change and continuity can build within an energy innovation system, to shape its evolution over time (Kuzemko et al., 2016).

2.3. Analytical framework

This paper utilises and develops a layered institutional framework to explore how national institutions have affected the emergence of the UK's clean electricity innovation system.

Initially developed by Groenewegen & van der Steen (2006), the framework sought to demonstrate the critical importance for policy makers to get *"the institutional environment right"* for national innovation systems to function optimally (p.283). Based on Williamson's layered model of institutional economics (1998; 2000), Figure 13 identifies five layers of institutions that affect innovation system development. van der Steen et al. (2008) applied this framework to explore the institutional dynamics of clean electricity TIS development in the Netherlands and Denmark, 1970- 2008. Findings showed that institutions functioned as the selection environment for the innovation process, demonstrating the importance of considering the interaction between multiple institutions over time in the development of clean electricity innovation systems.

The framework has been refined by the author from the original to focus more specifically on the political institutions affecting sectoral innovation systems. The layers are discussed in turn below.

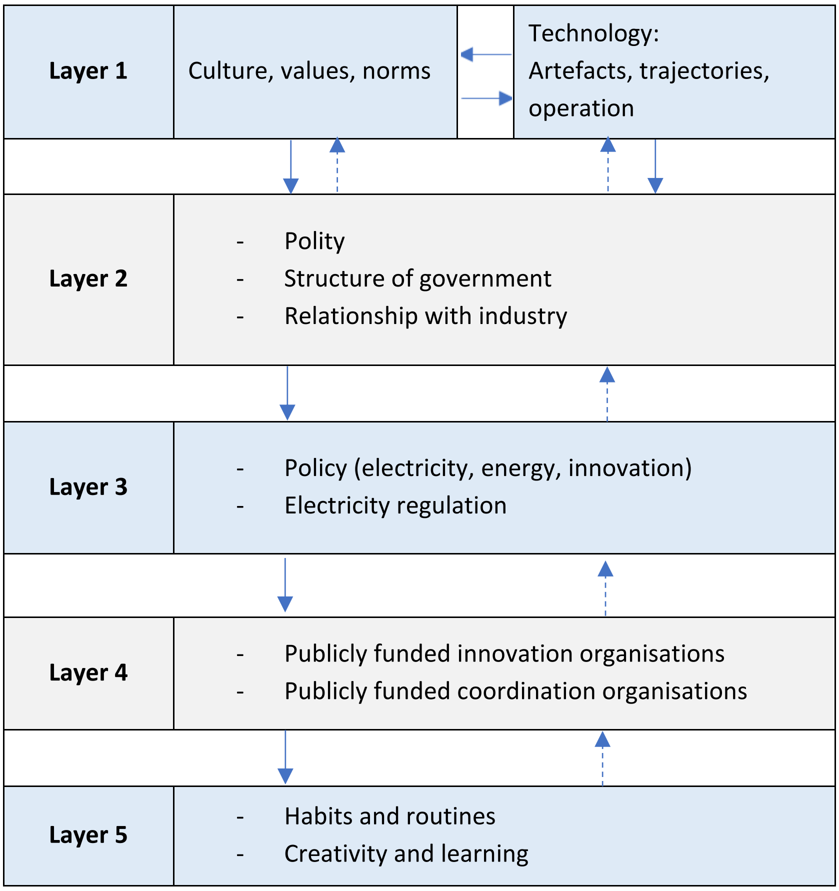


Figure 13- Layered institutional model of an innovation system, refined from van der Steen et al. (2008)

Layer 1 is often *"taken as a given"* by institutionalists (Williamson, 2000, p.596), comprising informal cultures, norms and values held nationally that permeate all other institutions. These norms evolve with great inertia over decades, shaped by macroeconomic factors (Kere, 2016) such as domestic fossil fuel availability, and other factors like social preferences (Sovacool, 2014). Change at this layer may go un-noticed, as trends gradually accumulate in a spontaneous process as opposed to in purposeful, creative actions (Andrews-Speed, 2016; van der Steen et al., 2008). Examining this layer enables a better understanding of how clean electricity innovation has been shaped by national norms around engagement in markets, energy resources and government approaches.

Technology infrastructure is positioned alongside the informal institutions in layer 1, as this also affects the operation of institutional layers beneath. Comprising physical infrastructure it exerts its own characteristics, for example causing a delay in response to changing national values or gaining a sudden impetus to change as international technology markets evolve (van der Steen, 1999).

Layer 2 addresses the structure of government and the nature of its interaction with the energy industry. Innovation is influenced by the government's role in the economic system (van der Steen, 2008) and cannot be considered a neutral, rational actor (Johnstone & Newell, 2018). Political institutions at this layer create indirect impacts on innovation policy (Weaver & Rockman, 1993), constraining and enabling outcomes without being the immediate and direct cause of public policy (March & Olsen, 2006). This includes the aspects of political economy discussed in section 2.2.2. and how firms are engaged in innovation policy making (van der Steen, 2008). Examination of this layer shows how government structures have shaped and been shaped by industry to set the broader conditions for energy innovation approaches.

Layer 3 is concerned with the energy and innovation policy and the supporting regulatory landscape. Policies may reflect inertia embodied in the institutional layers above as they evolve over time (Edmondson et al., 2019) or choose to act against previous approaches to meet a different aim in the country's interest. Whilst Oliver & Pemberton (2004) theorised that policy paradigms could be changed in quite a linear manner as more appropriate policies reveal themselves, in practice the process is much messier as policies are continually revised often in non-complementary ways (Schaffer & Bernauer, 2014; Edmondson et al., 2018). Considering this layer in the context of those around it facilitates a greater understanding of its evolution and how it has acted with or against other institutions and policies.

Layer 4 examines the publicly funded organisations and networks that support the delivery of clean electricity innovation policy. These institutions establish their own rules and membership structures (Hodgson, 2006) to engage actors in delivering innovation. Whilst innovation organisations are impacted by the institutional environment in which they are developed (Anadon, 2012), they can also be active agents in adopting different missions and operational approaches that enable them to challenge this (Scott, 2008; Glennie & Bound, 2016). The networks that coordinate organisations and engage with other innovation system actors are also important in the development of clean electricity innovation systems (Hannon et al., 2014). This layer additionally addresses networks of industry actors that act as vehicles for firms to influence the government to take particular policy and technology approaches. Observations at this layer shows the way in which the innovation system organises to deliver and respond to clean energy policy.

Finally, **layer 5** considers the impact of the habits, routines and the ability to act creatively of individual system actors. Depending on the question being analysed, the actors of interest can range from individual members of society to the regions or nations engaged in a low carbon energy agreement (van der Steen et al., 2008). In this analysis, the individual actors of interest are identified to be energy firms, as key actors working with government to shape energy innovation over time.

The hierarchal nature of the framework demonstrates evolutionary change over time. Work by North (1990) places emphasis on informal institutions at layer 1, viewing formal institutions as a manifestation of these underlying values and norms. The downward arrows indicate this top-down effect on the formal institutions beneath, whilst the upward arrows represent the reinforcement of these values at each layer (Groenewegen & van der Steen, 2008). These institutional relationships generally produce incremental innovation, reinforcing the innovation system in which they operate (Groenewegen & van der Steen, 2008).

Equally however, the arrows can represent the way in which institutional change can occur at and move between the different layers. For example, changes in layer one will impact institutional stability in the layers below, loosening accepted norms and values to enable them to develop differently as they adapt to changing circumstances. If multiple institutions start to change, the habits and routines of individual actors at layer five becomes less stable, creating opportunities for new habits and routines to be formed in response. This opportunism can affect change in institutions operating in any layer, breaking top down inertia, and shows how radical institutional change could take place (Groenewegen & van der Steen, 2008).

This paper utilises this understanding of institutional change and continuity over time to analyse the way in which these different layers have interacted 2000- 2018 to shape the emergence of the UK clean electricity innovation system.

2.4. Methodology

2.4.1. Case study context

As depicted in Figure 14, the UK's electricity generation portfolio has changed dramatically since 1990. Historically dominated by coal, in the mid-1990s coal began to be displaced by natural gas generation, with this trend peaking in 2008. Renewables generation started to increase from 2005 and more rapidly so from 2012, increasing to 33% of generation by 2018. Figure 15 provides a more detailed breakdown of renewables generation since 2000, revealing that onshore wind and bioenergy grew most rapidly between 2005 and 2009. Offshore wind generation started to expand from 2009, and solar from 2013 (DUKES, 2019b).

Coal generation declined even more rapidly from 2013, reaching just 5.1% of generation in 2018 (DUKES, 2019a). Despite several plants being decommissioned nuclear power has continues to supply around 19% of electricity. Total power production in 2018 was at its lowest since 1994 (BP, 2019), largely due to industrial restructuring and improvements in domestic and industrial energy efficiency policy (BEIS, 2019; CCC, 2020). These changes in electricity generation portfolio have contributed to the UK reducing its carbon emissions faster than any other G20 economy (CCC, 2020).

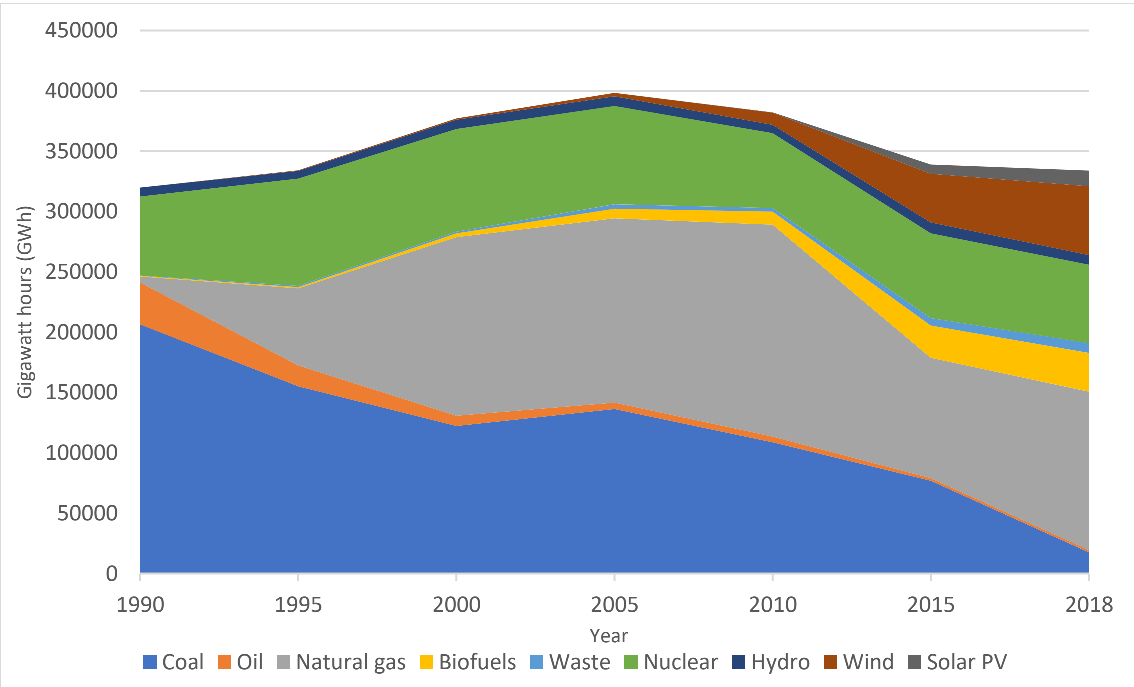


Figure 14- UK electricity generation by source, 1990- 2018 (IEA, 2019c)

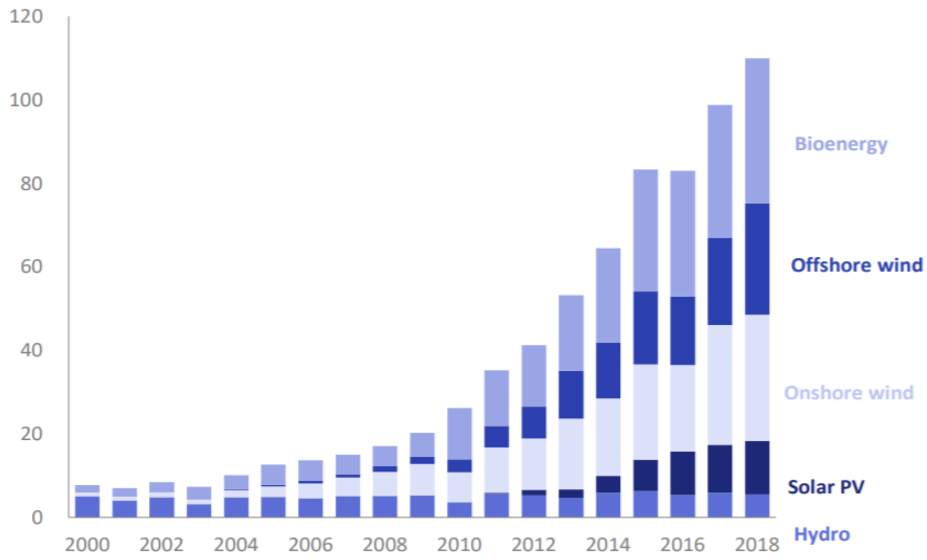


Figure 15- Contribution of renewables generation to electricity generated in the UK (TWh) (DUKES, 2019b)

Figure 16 illustrates that UK energy RD&D funding has also drastically increased since 2000. The process of privatisation that began in the 1980s, causing spending to reduce across all energy technologies, most notably nuclear power. An upturn in investment began in 2003, after low investment levels were flagged in 2000. The financial crisis of 2008 led to a surge in investment in 2010, boosting funding renewable energy and energy efficiency. Whilst this peak was not been maintained, investment has steadily increased and returned to the same level as the 1980s. This investment is now spread across a broader range of technologies such as energy storage, which enable the system to incorporate increasing amounts of intermittent generation.

These large increases in clean electricity generation and innovation investment indicate that the clean electricity innovation system has evolved rapidly 2000-2018, which has required rapid development and change across a legacy sector dominated by fossil fuels and low innovation investment. The approach taken below aims to explore the way this system has emerged and been shaped by these surrounding institutions.

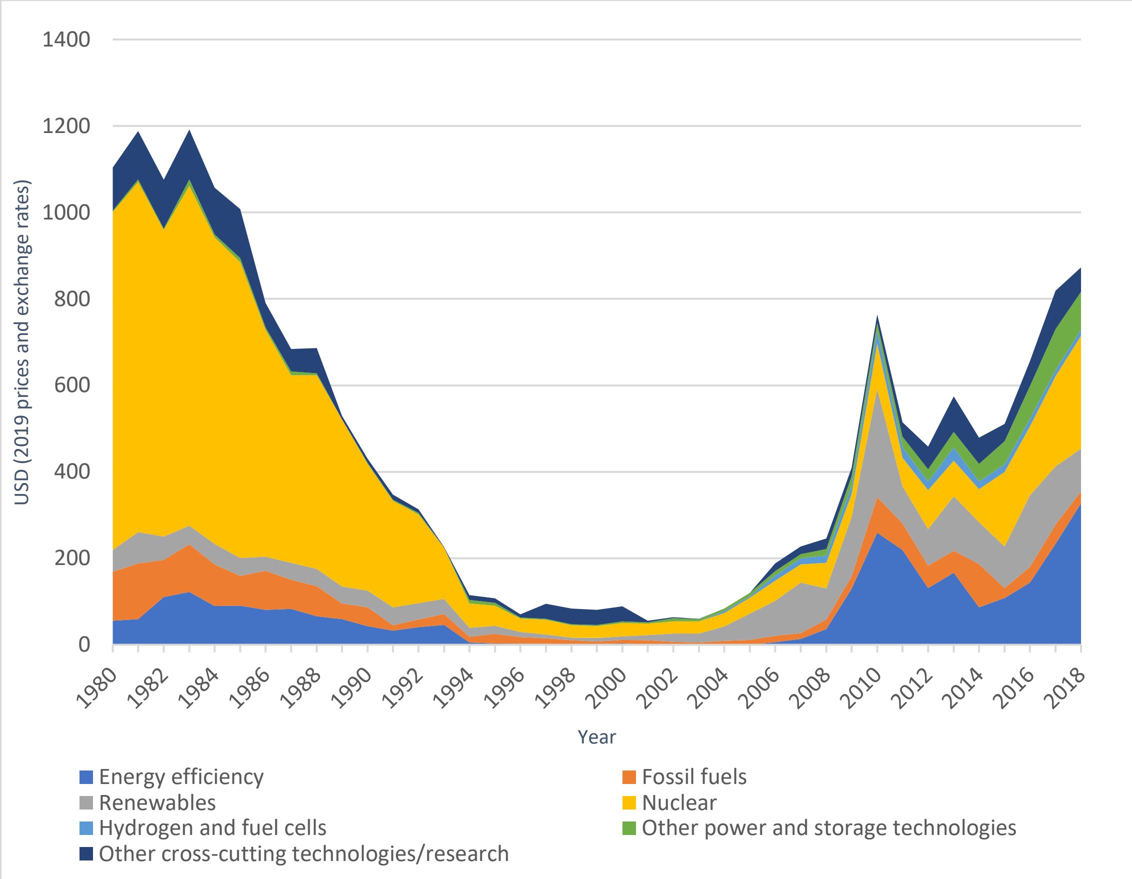


Figure 16- UK Energy RD&D spend 1980- 2018 (millions of USD) (IEA, 2019d)

2.4.2. Data collection and analysis

This paper takes a qualitative case study approach to the context specific evolution of the UK clean electricity innovation system (Flyvbjerg, 2001; Yin, 2014). The year 2000 was selected as the starting point for this study as the year UK published its first Climate Change Programme (DETR, 2000). The Programme detailed a plan to cut carbon dioxide emissions by 20% below 1990 levels by 2010, raising awareness over the need for increased levels of clean electricity innovation.

An extensive literature review was conducted, collating academic publications, white papers, policy documents and other grey literatures on the composition of and investment in the UK energy innovation system 2000- 2018. The scope of analysis was limited to UK institutions, enabling a focus on national evolution and change.

The literature review process identified an initial list of 15 high-level individuals for primary data collection, based on their involvement in key institutions over different time periods. Identification of an additional 7 interviewees was conducted utilising a snowball sampling approach, in which interviewees were asked to recommend contacts that they felt would add value to the research based on their years of experience (Biernacki & Waldorf, 1981; Bewley, 2002). The 22 interviewees are summarised in Table 2.

No.	Job function	Organisation
1	Managing Director	Firm
2	Director of Innovation	Firm
3	Director	Firm
4	Chief Economist	Firm
5	Head	Firm
6	Head	Government Department
7	Director	Government Department
8	Former Scientific Advisor	Government Department
9	Chief Scientific Advisor	Government Department
10	Head	Government Office
11	Deputy Chief Executive	Industry Association
12	Chief Executive Officer	Publicly funded innovation organisation
13	Chief Operating Officer	Publicly funded innovation organisation
14	Head	Publicly funded innovation organisation
15	Director	Publicly funded innovation organisation
16	Director	Publicly funded innovation organisation
17	Head	Publicly funded innovation organisation
18	Chair	Publicly funded innovation organisation
19	Head	Research Council
20	Director	Research Council
21	Head	Research Council
22	Professor	University

Table 2- UK Interviewees

Semi-structured interviews were conducted to allow for a fluid inquiry into highly situational knowledge (Rubin & Rubin, 2011). Interview questions were designed to gain insights into each layer, enabling an exploration of each interviewee’s experience of different institutions. A sample interview questions are available in Annex B. Interview data was transcribed and analysed using NVivo software, enabling detailed analysis of results within and between layers. This data was triangulated with findings from the literature to produce robust, comprehensive results (Baxter & Jack, 2008; Yin, 2014). Where interview data is referred to in the text the interviewee is identified by their number in correspondence with Table 2.

2.5. Results

2.5.1. Layer 1: Informal institutions and technology

Clean electricity innovation is framed within two enduring informal norms of a history of plentiful domestic fossil fuel availability and the pursuit of liberal market economy values.

Historically, coal mining has constituted a large part of the UK economic and cultural landscape (Supple, 1987). The plentiful availability of coal drove the nationalised development of an increasingly centralised energy system throughout the 1950s, as plants grew in size and efficiency. This was complemented by the addition of large, centralised nuclear power plants during the 1960s.

In the 1970s, the economy began to experience increasing levels stagnation and a steep decline in prosperity, leading to unionised public-sector workers participating in wide-spread strikes, particularly coal miners (Supple, 1987). By the 1979 election, the Labour government was perceived to be unable to control the unions or tackle unemployment, leading to a Conservative party victory (Supple, 1987). The incoming government created an ideological break from the post-war consensus on nationalised industry, economic regulation and a strong welfare state (Heppell, 2002). Within this new ideology, the government reduced spending and became an enabler of liberalised markets for more efficient delivery of societal solutions. This resulted in a programme of privatisation and liberalisation implemented throughout the 1980s, of which the electricity system and coal were of central importance (18; Pearson & Watson, 2012). National laboratories that served as technical centres of expertise in energy innovation were also privatised and largely closed (21).

These liberalised market conditions and the UK's ongoing fossil fuel availability facilitated the 'dash for gas' in the early 1990s. Twenty power stations were built in seven years, displacing coal generation and transforming the UK electricity generation portfolio (12; Winskel, 2002). Whilst there was some variety in the size of the new natural gas plants installed, these were also primarily large scale, supporting the existing centralised system of electricity production.

The UK's approach to electricity management was viewed as successful into the early 2000s, with the UK recognised to have achieved self-sufficiency (PIU, 2002). A system of centralised plants connected by high voltage transmission made electricity prices low in comparison to previous decades (PIU, 2002), meaning that at this stage of time there was no concern over drastically reduced clean electricity innovation spend (14).

By the late 1990s however, these informal institutions were beginning to be called into question. Rising political and societal concerns over climate change challenged both the dominance of fossil fuel and the ability of liberal market economy approaches to produce sustainable economic growth into the future. The UK ratified the Kyoto Protocol in 1998, committing to a 12.5% carbon emissions reduction 2008- 2012 in comparison to 1990 levels (DECC, 2015a). Domestic natural gas availability peaked in 2005, shifting the long-held norm of plentiful fossil fuel availability to the need to address energy security concerns, creating impetus around the development of national clean energy markets. Since the early 2000s interviewees expressed that a *"strong climate consensus"* (6) has built across political parties, as drivers and agendas around these climate change related narratives have coalesced (6; 17).

Throughout the 2000s, the UK's centralised electricity system has integrated increasing amounts of large-scale renewables with little change to its structure (Geels et al. 2016). This infrastructure however is coming under increasing pressure, as the integration of greater levels of intermittent and decentralised generation requires flexible, two-way energy flows to maintain security of supply (NAO, 2010). Interviewees discussed that the dominance of centralised, supply focused system was now reducing, as whole systems thinking has emerged over the last five years (12, 14). A continuing global shift toward ICT is now driving the proliferation of digital and demand side technologies to address this, facilitating market opportunities for digitalisation and decentralisation of energy generation and services.

Therefore, whilst informal and technology institutions in layer 1 have operated successfully over many decades to develop an efficient and secure energy system, they are being increasingly challenged by emerging values and technology trajectories in relation to climate change and whole systems change.

2.5.2. Layer 2: Political institutions

Figure 17 overleaf provides an overview of the changing political environment during this period. A collation of Figures 17, 18 and 19 into one diagram is available in Annex C.

2.5.2.1. Polity

Since 1979, a first-past-the-post electoral system produced a stable, two party political system, lowering the prevalence of smaller parties like the Greens (Geels et al., 2016). This stability has been challenged twice since 2000, with the 2010 election producing a Conservative- Liberal Democrat coalition and the 2017 election a Conservative- Democratic Unionist Party alliance. Interviewees noted that whilst the overarching aims and values toward clean energy had stayed the same through periods of parliamentary change, with things "*only changing around the edges"* (18), the "*different flavours of politics*" (10) between parties has impacted clean electricity innovation approach between governments (7; 2; 22). Under Labour for example, there was a willingness to invest in new technologies that were not commercially viable, whereas the Conservative government of 2015 placed economic viability of innovation as a priority and were less willing to subsidize technology deployment (9). Technology focus has also been impacted. Under the Conservative- Liberal Democrat coalition for example, the Liberal Democrat Secretaries of State was opposed to nuclear power whilst the Conservative Chancellor started to drive innovation investment into small modular reactors (6; 9).

Interviewees also highlighted the issue of disruptive changes to innovation policy occurring *within* existing governments, as incoming Secretaries of State and energy related Ministers brought their own ideas, prejudices and perceptions of innovation (5; 6; 14; 16; 19). One interviewee discussed that this is a particular issue for energy innovation as the sector is complicated and counter-intuitive, requiring individuals to move beyond initial assumptions and party tribalism to make effective decisions (5). Between 2007 and 2015 there was a high turnover of civil servants in comparison to previous years, seeing seven energy ministers and five Secretaries of State. These changes created a lack in the consistency and stability required for market creation and raised concerns over the development of institutional memory within the government (5; 9; 16). Since 2016, there has been greater stability as the Conservative government became the single ruling party.

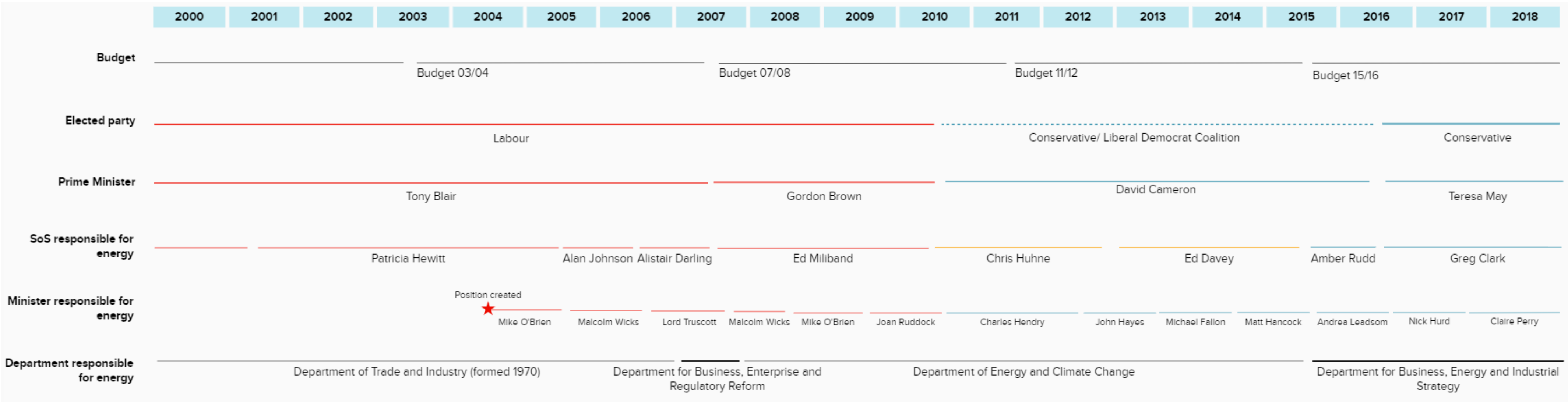


Figure 17- Overview of political change in layer 2

2.5.2.2. Structure of government

Centralisation

The UK government is run in a centralised manner, with low levels of decentralised power within the energy sector (Johnstone et al., 2017). The Labour Government had challenged this in 1997, devolving government institutions in Scotland, Wales and Northern Ireland, which have since diverged in electricity innovation policy approach (Anandarajah & McDowall, 2012). The extent to which this been able to occur however is contested, with Little (2016) for example, detailing that in the Scottish context Ministers are not able to make significant decisions regarding energy policy for which the power remains centred in West Minster.

In 1998, nine devolved regional development agencies were created in England, each possessing a Science and Industry Council that fed into the development of a national innovation approach (TSB, 2008). After the financial crisis of 2008, the incoming Conservative government announced that the regional development agencies would be abolished and replaced by Local Enterprise Partnerships. These have since developed competencies in promoting regional clean energy options but are not involved in promoting regional innovation (Cairney et al., 2019). While no financial support was initially forthcoming from the government, greater policy efforts in relation to returning more decision-making power to local regions were made. In 2011 for example, the Localism Act sought to give local authorities new freedoms and flexibility including the ability to impose new taxes, develop certain business discounts and collaborate to drive down costs. The role and authority of Mayors was also recognised and increased (HMG, 2011).

While there is ongoing momentum around the need for local and regional clean electricity project development however, there remains a lack of funding and support to facilitate project development at meaningful levels (Webb et al., 2016). Centralised electricity markets remain a large barrier to progress, limiting the extent to which decentralised markets for innovative technologies can be created (UK100, 2020).

Regulatory bodies

The electricity market is regulated by the Office of Gas and Electricity Markets (Ofgem), which sets the codes and standards for access, connection, planning and operation of the electricity system (Lockwood et al., 2015). Developed in 2000, Ofgem replaced forerunners Office of Gas

Supply and the Office of Electricity Regulation, which were formed after initial market privatisation. Ofgem's remit is to maintain an economically efficient system that minimises electricity prices for consumers. Informed by the liberal values discussed in layer 1, Ofgem was designed on the premise that system related RD&D would be conducted by equipment manufacturers, with the investment risk ill-suited to the organisations aims (3; Jamasb & Pollitt, 2007). A focus on system efficiency means that the transmission and distribution operators also downscaled RD&D investments (Pollitt & Bialek, 2008; McMeekin et al., 2019), however this has started to be challenged in recent years.

Departmental structures

After the closure of the Department of Energy in 1990, energy policy making was moved to the Department of Trade and Investment (Kuzemko, 2012). It remained here until 2007, at which point the Department of Energy and Climate Change (DECC) was created to make more coherent policy decisions on energy affordability, security and climate change (4; Pearson & Watson, 2012). Interviewees identified that DECC had a positive impact on making the clean electricity innovation policy landscape less disjointed and engaged a team around the mission of energy system change (4; 6). One interviewee commented *"DECC allowed the distinct issue of energy innovation- a policy end in its own right- to become more mission focused, like a defence or health programme"* (7). DECC produced a centralised strategy for clean electricity innovation funding and an evidence base for its deployment, allowing better technology choices to be made in a consolidated way (4; 6). Throughout the 2010s, this enabled the government to accumulate competencies in electricity innovation policy and become less reliant on firms or external bodies to set priorities (6; 9).

DECC however also faced criticism for focusing government efforts disproportionately on clean electricity innovation at the expense of the more complex areas of heat and transport (7; 11; 16) and siloing climate issues away from other departments (4; 11). An interviewee commented that DECC also made technology assumptions based on existing supply-side infrastructure at the expense of addressing the need for more decentralised approaches (14). In the broader political context, interviewees commented that DECC additionally suffered from being viewed as a weak, idealistic department positioned at the edge of government that did not pay enough attention to market creation (6; 7; 9; 18).

In 2016, the Department of Business, Energy and Industrial Strategy (BEIS) merged DECC with the larger Department for Business, Innovation and Skills. Interviewees viewed this development as positive, as clean electricity innovation has become more directly positioned alongside economic growth via inclusion in the Industrial Strategy. Whether this will lead to a more coherent vision setting for whole system innovation however remains unclear (14; 18).

2.5.2.3. Government relationship with industry

After energy system liberalisation and privatisation, electricity generation and delivery became dominated by a small number of large utilities, equipment manufacturers and oil and gas majors (18; Geels et al., 2016). These incumbent firms have worked with the government to construct and operate generation assets and maintain system security over many years (5; 7; 12; Johnstone et al., 2017) and therefore regularly interact with various levels of government and Whitehall (7; 12; 14). An interviewee commented that subsidies and tax breaks received by these firms have *"become a part of the furniture"* (5), given the role that they have played in maintaining national energy security.

The lobbying of incumbent energy firms in influencing clean energy innovation is recognised in the sustainable transitions literature (Kuzemko et al., 2016; Smink et al., 2015; Augenstein & Palzkill, 2016), with interviewees discussing how trade associations, industry bodies and professional institutes have played a key role in facilitating this (3; 11; 13; 14; 16). Kuzemko et al. (2016) discuss the influence of these industries has skewed innovation support away from technologies like ocean energy, which require greater levels of early-stage support. At present there remains a lack of opportunities for smaller, emergent companies to engage in a similar way, with representation of these firms remaining at a low resolution given the sheer number of solutions being developed (6; 16; 22).

Obtaining accurate figures of the RD&D spend of private companies is difficult, however work by Jamasb & Pollitt (2015) demonstrate that investment by major generation, transmission and distribution companies reduced in line with government spending throughout the 1990s. In the early 2000s, incumbent firms possessed little understanding of what future low carbon technologies would be required, creating a desire to engage with the government to understand how they could engage and not develop stranded assets (9; 15). This led to the development of the Energy Research Partnership (ERP) in 2005, a public-private forum for the development of coherent clean electricity innovation policy (18; 21; Anadon, 2012). Such a panel by its nature limits the number of voices represented despite acting like an industry council (6). The ERP was instrumental in developing the Energy Technologies Institute (ETI), discussed in layer four.

These relationships with industry led Kuzemko (2016) to identify that UK energy policy has become depoliticised, with the influence of firms reducing the extent to which the government can direct technology innovation. Indeed, the extent of privatisation and liberalisation has meant that the government has been required to develop new approaches to driving industry investment in innovation (18), as until recently energy firms have been developed and regulated with no incentive to invest in RD&D (13; Jamasb & Pollitt, 2007). Ofgem’s market codes and standards for example, remain geared toward and influenced by existing, centralised system actors representing a key layer of electricity governance hindering system change that often goes unnoticed (Lockwood et al., 2015).

Since the 2010s, there has been a more pronounced shift toward clean electricity technology development and changes in market regulation, increasing opportunities for smaller companies to engage. New utilities for example have been able to break the dominance of the Big 6 (Kattirtzi et al., 2021) and renewables and demand side industry lobbies are gradually becoming more well organised (16). The Industrial Strategy of 2016 marks a shift in the government’s willingness and ability to intervene in market development, which may mark a further move away from incumbent dominance in influencing clean electricity innovation.

2.5.3. Layer 3: Policy and regulation

Interviewees identified the key role of clear clean electricity innovation policy in setting a secure direction of travel for private investors (3; 16; 17; 18). It was commented that between 2000- 2018 the government had provided the *‘broad building blocks’* of a vision to achieve this- the only option available given the unpredictability of the innovation process (6). Figure 18 overleaf provides an overview of the changing policy environment during this period.

2.5.3.1. Labour: 2000- 2010

The 2002 Energy Review contained a foreword by Prime Minister Tony Blair, predicting that energy trends from the last 15 years were about to end (PIU, 2002). The UK was no longer self-sufficient in fossil fuel supply and more stringent climate change measures were required beyond the 2000 Climate Change Programme (DETR, 2000). The Energy Review also acknowledged the need for new energy innovation policies to mobilise the UK's strong scientific base into driving the emergence of new technology markets (PIU, 2002). Whilst market-led mechanisms were highlighted as the means to achieve this, it was also noted that failures in energy markets required policies that prioritised sustainability moving forward (PIU, 2002).

The Non-Fossil Fuel Obligation was replaced by the Renewables Obligation (RO) in 2002. The Non-Fossil Fuel Obligation had primarily been developed to support new nuclear generation, proving largely ineffective in driving renewables installations (Foxon et al., 2005). The ROs A more detailed Renewables Innovation Review came in 2004, identifying the key technologies needed to meet climate targets (DTI, 2004). This placed emphasis on developing on and offshore wind to meet the 10% renewables target by 2010, as the most scalable technology under RO support. The UK had several large firms involved in onshore wind manufacture and installation well positioned to apply this expertise to offshore wind innovation, creating a ready-made base of expertise (DTI, 2004). Due to high capital costs of these large-scale technologies only large utilities able to utilise the RO could afford to drive this development forward.

By 2006, empirical evidence suggested that policies to date were not delivering the renewable deployment required to meet climate targets (HoC, 2007). Additionally, the Stern Review (Stern, 2006) highlighted the urgent need to increase global public investment in energy innovation and move policy support beyond market driven mechanisms. The 2006 UK Energy Review concluded that the government should take a more active role in crowding in private sector funding to increase the number of technologies moving from early to later stages of innovation (DTI, 2006a; Watson, 2008).

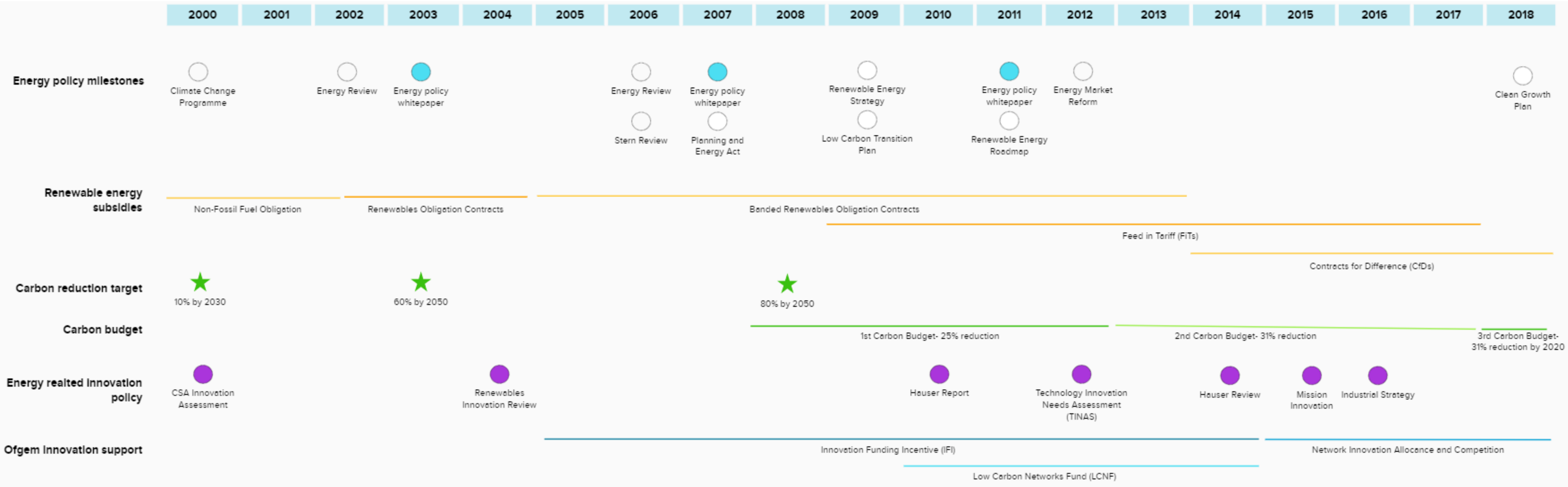


Figure 18- Overview of policy change in layer 3

A second Energy White Paper was released in 2007, which incorporated new concerns around energy security and calls to more explicitly include nuclear in the future technology mix (DTI, 2007). The paper also outlined a rise in innovation funding for pre-commercial demonstration, including the announcement of a £1bn competition for carbon capture and storage (CCS). Ofgem also sought to increase innovation and reduce system losses via the introduction of the Innovation Funding Incentive for transmission and distribution networks operators (SDC, 2007). Whilst the incentive encouraged the demonstration of new technologies, it was criticised for being too low and failing to scale demonstration stage technologies (15; SDC, 2007). Innovation efforts therefore remained largely constricted to enabling networks to accommodate greater levels of on and offshore wind (McMeekin et al., 2019).

In 2008, the Climate Change Act was passed, setting a legally binding target of 80% carbon emissions reduction below 1990 levels by 2050. The implementation of the Act would be supported by the Committee on Climate Change (CCC), an independent body advising the government on evolving climate change scenarios and recommended carbon reduction budgets (Averchenkova et al, 2018). The Prime Minister heralded the Act as revolutionary in tackling the biggest long-term challenge facing the world, responding the British public's desire to tackle the issue and cementing the UK as a global leader (Churcher, 2007). The Conservatives backed the Act, calling for even stricter annual budgets (Churcher, 2007). This cross-party support provided greater policy certainty around clean energy innovation (1; 6; 18) and planted a seed of stability for technology developers (14). Indeed, two interviewees commented that this regulatory approach had much more of an impact on innovation investment than the formation and actions of DECC (12; 18). The first CCC report (2009) echoed that market led policy instruments were not enough to drive the longer-term innovation needed, highlighting the need for innovation in heat pumps and CCS technologies in particular (CCC, 2009).

In 2009, multiple new policy interventions started to target moving earlier stage technologies toward commercial viability. The RO became banded by technology, increasing the amount of funding support for earlier stage technologies like wave energy. Offshore wind continued to benefit from the RO and the centralised nature of its planning, which unlike onshore wind did not involve local and regional authorities (Toke, 2011). Whilst deployment involved demonstration and learning, it enabled a networked coalition of actors to emerge that included incumbent utilities and public organisations, increasing the industry's credibility (Kern et al., 2014).

The 2009 UK Renewable Energy Strategy announced that Feed in Tariffs (FiTs) would be introduced in 2010 for small scale renewables generation and the RO phased out in 2013 (HMG, 2009b). This was viewed as a somewhat dramatic ideological step by then Secretary of State, with such a non-competitive tariff previously considered inconceivable for the UK to embrace (Mitchell & Connor, 2004). The 2009 UK Low Carbon Transition Plan however went on to identify offshore wind, nuclear power and CCS technologies as options for investment to meet the aims of the Climate Change Committee.

Despite CCS being discussed since 2007, its development continued to present a complex, high-risk innovation funding challenge (Kern et al., 2016; Nemet et al., 2018). Between 2007-2009 the demonstration prize had produced nine initial applications and the winning Longannet project in Scotland. Despite mobilisation by project developers however, in 2011 the project collapsed as expected costs looked to exceed the £1bn funding on offer from government. This money was ring-fenced by DECC for future investment and the competition remained active (Kern et al., 2016).

2.5.3.2. Conservatives and Liberal Democrats: 2010- 2015

The coalition government of the Liberal Democrats and Conservatives entered office in May 2010. A new energy White Paper on Affordable and Low-Carbon Electricity was released in 2011, highlighting the need for the energy system to support a smart, diverse and secure range of clean electricity technologies by 2030 (DECC, 2011a). The role of Ofgem and energy market structures were recognised as restricting progress in this regard (3; 11; Lockwood et al., 2015). The report introduced measures for electricity market reform (EMR), which would include the introduction of Contracts for Difference (CfDs) to provide a guaranteed subsidy for power generated and a carbon floor price to support the European emissions trading scheme. These measures aimed to accelerate investment in mature technologies, creating and improving markets for these technologies.

The White Paper once again identified that current policy efforts were not enough to drive the scale of the investment needed to meet 2020 system requirements, estimated to be some £110bn (DECC, 2011a). The Renewable Energy Roadmap released shortly after sought to provide comprehensive, targeted actions on renewables development (DECC, 2011b). The report identified six key clean electricity technologies including offshore wind and marine energy, which, unlike onshore wind and biomass, required increased levels of RD&D. An additional £50m was committed to the development of these technologies. An element of the actions identified was the development of supporting institutions and infrastructure for offshore wind, recognised as project development bottlenecks (DECC, 2011b).

Offshore wind accelerated in deployment despite remaining expensive, as a Cost Reduction Task Force (DECC, 2013) and Sector Strategy (HMG, 2013) were introduced, further galvanising a powerful coalition of actors (Kern et al., 2014). In contrast, wave energy development suffered due to a policy focus on array-scale technology deployment, which failed to adequately focus on earlier and mid stages of innovation (Hannon et al., 2017). Whilst the CfDs did begin to channel more investment into the earlier stages of wave development, the coalition of actors engaged in hopes of large-scale deployment lost confidence as a dominant technology did not emerge (Hannon et al., 2017).

As the FiT drove increasing domestic solar PV penetration, DECC (2014) sought to drive innovation in decentralised generation, demand response and the roll out of smart meters. Ofgem introduced the Low Carbon Networks Fund (LCNF) to further encourage distribution operators to integrate clean electricity focused solutions as part of their role in the low carbon economy (Ofgem, 2010). £500m was administered 2010- 2015 to enable the testing of demonstration scale technologies and novel operating and commercial arrangements (UKERC, 2016). Analysis of Low Carbon Networks Fund funding however found that it largely contributed to incremental innovation, with less attention given to the value of novel approaches (Frame et al., 2018).

2.5.3.3. Conservatives: 2015- 2018

In May 2015, the Conservatives won a majority election, publicly campaigning on the policies enacted by the coalition government since 2011, which made them *“the greenest government ever”* (Conservative Party, 2015).

The 2015 Autumn Spending Review committed £250m over 5 years into increasing RD&D of nuclear technologies, including a competition with the aim of deploying one of the world’s first small modular reactors in the 2020s (HMT, 2015). The £1bn CCS competition fund was dropped, causing project bids developed over four years by firms including Shell and Drax to collapse (Carrington, 2015). Two interviewees mentioned the cancelling of CCS funding appeared to be a quick way to try and save £1bn of taxpayer money and created deep distrust within industry (5, 18). Fears over costs overrunning and opportunities to import CCS technologies however have also been identified as reasons for the competition's termination (Kern et al., 2016). The cancelling of the scheme raised concerns over the sustainability of the Conservative government's energy policy 'reset', which relied on CCS accompanying all gas-powered plants by 2030, as coal was phased out by 2025 (DECC, 2015b). Overall, the policy reset signalled a partial retreat from previous policy that sought to develop technology specific market incentives. Whilst support remained for offshore wind and the commissioning of Hinkley Power C in 2016, innovation support returned to supporting earlier stages of R&D (McMeekin et al., 2019).

Shortly after the energy policy reset, the 21st Conference of Parties (COP21) of the United Nations Framework Convention on Climate Change took place, at which the UK ratified the Paris Agreement and committed to Mission Innovation, representing a doubling of spending on clean energy RD&D to £500m by 2020 (DECC, 2015c).

In July 2016, Teresa May replaced David Cameron as Prime Minister and introduced the Industrial Strategy (IS). The IS aims to align the UK economy's strong business environment with strong government aims to secure future markets (9; HMG, 2017a). Whilst representing a large break in liberal market economy values (13), some interviewees commented that it is not a new concept (8; 9), with the development of the offshore wind industry reflecting technology specific government support. One interviewee commented that it differs in aiming to hold *"people's feet to the fire"* in terms of creating value to the economy beyond themselves (12).

The UK's Clean Growth Strategy was published in 2017 in response to the 5th CCC carbon budget, which recommended an intermediate target of a 57% carbon reduction by 2028- 2032 (Busch et al., 2018). It complemented the aims of the IS, which aims to place clean growth at its heart (HMG, 2017a), committing £2.5bn to low carbon innovation between 2015 and 2021 (HMG, 2018). Clean growth was described by two interviewees as the new government buzzword (14, 12), with big challenge programmes like Faraday linking it to delivery of key parts of the IS.

The smart systems and flexibility plan was published in 2017, outlining actions that the government, Ofgem and industry can take to remove barriers to demand side technologies like energy storage (14; HMG, 2017b). Momentum in this area has continued to grow as distributed generation has grown, leading to several to-scale projects that demonstrate technologies that enable bi-directional power flow energy storage and network management (Gangale et al., 2017; Jenkins et al., 2015).

Interviewees reflected that clean electricity innovation policy now needs to evolve to take a whole systems approach, supporting the development of digital technologies to integrate the needs of electricity, heat, transport and grid innovation (2; 3; 11; 14; 17; 18). Therefore, whilst the IS provides greater policy coherence and stability, its ability to stimulate technology markets is yet to be seen (5; 9).

2.5.4. Layer 4: Organisations and networks

This section focuses in on publicly funded innovation organisations and coordination bodies that have supported clean electricity innovation. The organisational landscape became increasingly crowded and complex during the 2000s, as organisations were created that overlapped and were not sufficiently coordinated. As the governments competencies and vision has developed, the landscape has continued to evolve to become more strongly coordinated. Figure 19 overleaf provides an overview of the changing policy environment during this period.

2.5.4.1 Innovation organisations

In 2000, early-stage energy R&D was primarily presided over by Research Councils UK, a non-departmental public body that coordinated the UK's seven research councils. In 2004, the Research Council Energy Programme was created, aiming to better coordinate research and postgraduate training with energy and climate change policies (Meller, 2014). The energy programme develops an annual strategy, enabling it to remain responsive to policy changes (19).

Since this time, investment by the Research Councils in energy innovation has grown significantly across a diverse range of mechanisms. The 2001 Supergen Programme for example coordinated research funding across seven areas of clean energy research, representing the largest government investment ever in fundamental clean energy research (RCEP, 2016). An interviewee highlighted that the government is now entering a more responsive mode of innovation, moving away from a bottom-up technology approach toward those that directly benefit emerging markets (19). Indeed, a 2016 review revealed that the research produced by the Supergen's had been poorly linked to industry needs (RCEP, 2016). The UK Energy Research Centre (UKERC) represents another enduring Research Council investment. Formed in 2004 after the 2002 Energy Review, UKERC has been valuable in taking a whole systems approach to energy policy and represented a constant presence in the innovation system (18).

The Technology Strategy Board was established in 2004 as a government advisory panel on longer term technology strategy across all industry sectors (Hannon et al., 2014). Viewed as effective in transferring knowledge between universities and industries, it became a non-departmental public body in 2007 (TSB, 2009). The Board rebranded as Innovate UK in 2014 and has grown substantially, focusing on the development of UK based firms to drive economic growth (TSB, 2009). As well as funding the organisations discussed below, it delivers the Energy Catalyst Fund, targeting grants at early stage technology development; the Knowledge Transfer Network, with one focused on energy innovation; and offers Knowledge Transfer Partnerships between business and academia (Hannon et al., 2014).

In 2016, the Research Councils and Innovate UK came together to form UK Research and Innovation (UKRI). UKRI aims to coordinate early-stage research with desired future market development, creating a wider debate within Whitehall on what early stage R&D budgets are for (7; Policy Exchange, 2020). This increased coordination seeks to sharpen the focus of R&D programmes and address energy innovation system gaps that currently exist between organisations (7; 18).

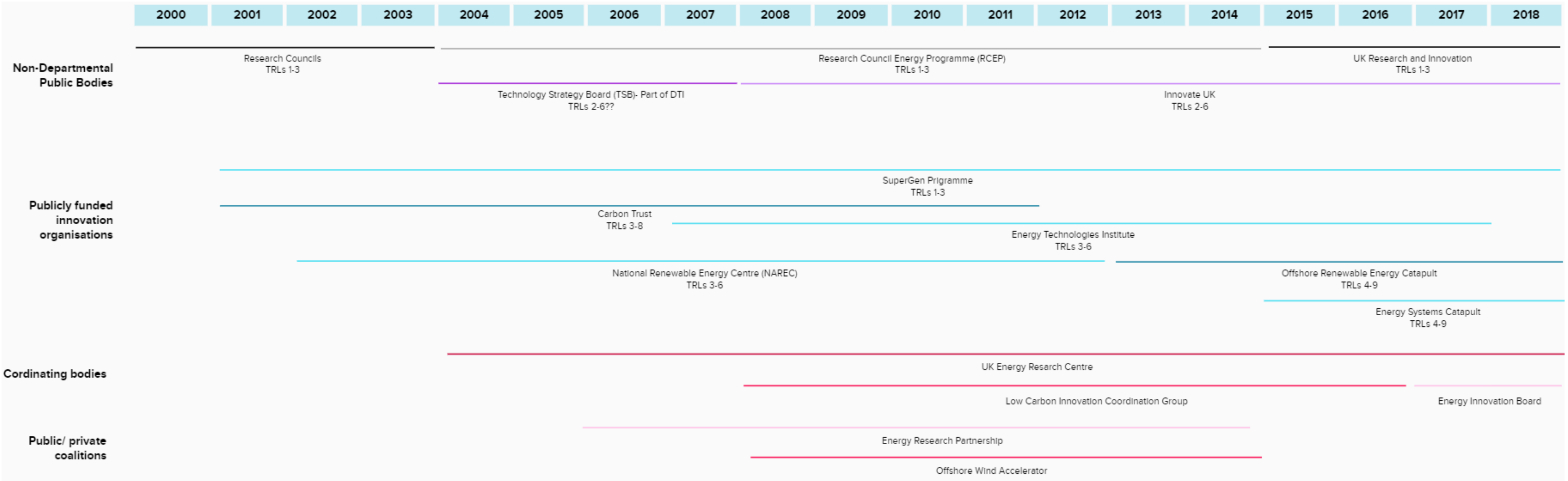


Figure 19- Overview of organisational change in layer 4

Whilst the organisations above broadly coordinate energy RD&D, several publicly funded organisations have been created to specifically stimulate clean electricity innovation. The Carbon Trust was established in 2001 on the recommendation of the 2000 Climate Change Programme (Wordsworth & Grubb, 2003). The Carbon Trust's purpose was to reinvest the £130m raised by the climate change levy back into businesses to accelerate uptake of low carbon solutions. It operated at arm's length of the government as a private entity to avoid political interference and engage firms in delivering policy aims (6; 19). Over its ten years of operation, the Carbon Trust moved from technology agnostic investment to strategically intervene for maximum impact, with great autonomy from government (1; 6). Public funding for the organisation ceased in 2011, with an interviewee discussing that by this time the government felt that they could bring operations back in house at a lower cost (22).

In 2008, the Carbon Trust created the Offshore Wind Energy Accelerator, uniting 9 offshore wind developers to reduce offshore wind costs via innovation[1]. The organisation primarily received industry funding and focused on close to market innovations with a clear market pull (Williams, 2016). The accelerator remains in operation and continues to receive support from Innovate UK. As this technology market has matured, its innovation roadmaps are now focused more on O&M and supporting component development (OWIH, 2018).

The Energy Technologies Institute (ETI) was created in 2007 with the aim of galvanising strategic focus and providing pull for research from university to demonstration level (DTI, 2006b). An interviewee described the ETI as an experiment characteristic of this time, during which a desire to engage energy firms in accelerating clean energy technology development made a private, arms-length organisation politically attractive (7). Taking the form of a public-private partnership (PPP) it convened the EPSRC, Innovate UK, DECC and six incumbent energy firms including Shell, British Petroleum (BP), E.ON and Electricitie de France (EDF) Energy (DTI, 2006b).

Ultimately, the design of the ETI impeded the organisation's ability to meet its aims (see chapter 3) and led to some cross over with the activities of the Carbon Trust in accelerating innovation closer to market. Operating for ten years, it invested £400m largely into supporting

[1] Carbon Trust, Offshore Wind Accelerator. Available at: https://www.carbontrust.com/our-projects/offshore-wind-accelerator-owa Accessed: 21.03.20

the development of modelling and evaluation technologies and offshore wind deployment (21; see section 3.4.3.).

In 2010, the role of science and innovation policy came under greater scrutiny as the government sought better to translate the UK's high scientific capacity into long term economic growth. The Hauser Report was produced for the Secretary of State for Business, Innovation and Skills and explored successful innovation organisations from other countries (Hauser, 2010). It recommended the creation of a series of technology and innovation centres to enable UK industry to develop absorptive capacity for innovative products and to provide *"translational infrastructure"* between universities and the private sector to facilitate commercialisation (p.1).

In 2011, funding for a network of Catapult centres was confirmed in the Government's Innovation and Research Strategy for Growth (2011), with the aim of providing long term support for industrialising research outputs and competing in international markets (7; TSB, 2011a). Unlike the ETI that conducted a variety of projects across multiple technology areas, the Catapults provided *"laser precision"* to specific sectors (12), with each adopting different characteristics as they became anchored in their industry's innovation system (Anderson & Le Blanc, 2013; TSB, 2011b). The Catapults adopted a funding model of one third from core public funding from Innovate UK, one third from collaborative public-private projects and one third from winning private R&D contracts (TSB, 2011b). A 2014 review of the performance of the Catapult network recommended that the approach continue and be expanded to other sectors (Hauser, 2014). Two Catapults have been created that support clean electricity innovation- the Offshore Renewable Energy Catapult (OREC) and the Energy Systems Catapult.

OREC was identified as one of the first three Centres to be developed (TSB, 2011b), with the Carbon Trust and National Renewable Energy Centre (Narec) winning a consortium bid to run it (TSB, 2012). Narec was a renewables test facility initially developed by the North East Regional Development Agency in Northumberland 2002, merging with OREC in 2014 (Gibson, 2014). The ETI had invested £25m in developing a wind turbine drive train test rig at Narec (DECC, 2011b), enhancing the world class test facilities that OREC has since developed[2]. An interviewee discussed that OREC has been instrumental in deploying larger, more cost-effective turbines that have rapidly increased turbine generation capacity by facilitating

[2] Offshore Renewable Energy Catapult, THE LEVENMOUTH DEMONSTRATION TURBINE: Available at: https://ore.catapult.org.uk/testing-validation/facilities/levenmouth/ Accessed: 13.08.20

learning through doing (12). Another mentioned that OREC had become *"a trusted intermediary through which industry has been able to collaborate"* (12) and created a pipeline of projects upon which the private sector can rely for investment (5).

The Energy Systems Catapult started operation in 2015, focusing on convening the right actors and overcoming barriers to data access in developing future energy systems (7). The organisation built on expertise and infrastructure developed by the ETI's Smart Systems and Heating Programme.

2.5.4.2. Coordination organisations

Prior to 2008, diffuse clean energy innovation activities were happening across departments, with energy tied up in broader science and innovation budgets (Skea et al., 2019). As the financial crisis restricted departmental funding pots, the Low Carbon Innovation Coordination Group (LCICG) was created to better coordinate these activities around a common evidence base (6; Hannon et al., 2014). A key achievement of the LCICG was the development of the Technology Innovation Needs Assessments (TINAs), commissioned by DECC for delivery 2011-2016. These aimed to analyse the future innovation needs of multiple technology sectors, identifying priority demonstration stage technologies based on required investment versus potential UK market growth (1; 14). Government interviewees commented that the TINAs were extremely useful in presenting a robust, coherent evidence base to Treasury during the 2015 Budget Review (6; 7; 14), playing a role in the £500m energy innovation funding received by BEIS in 2016 (14).

Whilst the LCICG aimed to unite cross-sector actors to make the clean energy innovation funding landscape less confusing to navigate (HoC, 2014), one interviewee commented that it included too many actors and voices to be effective (12). It was additionally staffed by mid-level civil servants, rendering it less effective in aligning policy across departments (6; 9). This limited its role in coordination and knowledge sharing across government (10; 14), failing to attract the attention on Ministers in energy innovation the level of other concerns such as energy security (9).

The Energy Innovation Board replaced the LCICG in 2016 and will take the TINAs forward once they have been reassessed, if still relevant (14). The Board aims to be more directive than the LCICG, engaging a smaller number of senior staff members across key departments to create greater coherence and stability across the clean electricity innovation funding landscape (7; GOS, 2018).

2.5.5. Layer 5: Habits and routines of individual actors

As identified in section 2.3., the actors focused on here are incumbent firms. In 2000, the incumbent 'Big six' utilities dominated electricity generation, comprising Centrica, EDF, E.ON, RWE, Scottish Power and Scottish and Southern Energy (Blyth et al., 2015). Investment in R&D reduced from 2000- 2015, with that remaining largely focused on operational improvements (8). During this period, clean electricity innovation was primarily driven by original equipment manufacturers (OEMs), whose equipment utilities were incentivised to install and run (8; Jamasb & Pollitt, 2015). It was commented by one interviewee that utilities expect innovation to come from the supply chain in this manner, with OEMs aiming to keep the utilities and other developers happy (12). OEMs have been observed to work with emergent technology firms, which were set up with the aim of outcompeting multiple other small technology firms to provide their product to a large OEM (18). In the wind sector for example, there now exist a handful of dominant OEMs that have absorbed specialised firms such as Siemens-Gamesa. A UK example is General Electric's purchase of Blade Dynamics, funded by the ETI to develop 1MW wind blade technology (Weston, 2015).

Oil and gas majors are increasingly engaging in clean energy innovation activities (12) and have played a role in keeping CCS innovation funding on the table, with Shell and BP for example advancing these interests through membership of the ETI. As technology costs and risks remain high, the Oil and Gas Climate Initiative represent a consortium through which innovative investments are made, such as the development of the first commercial scale CCUS project in Teeside (OGCI, 2018). There has also been an increased use of venture capital to enable work with more innovative, fleetfooted companies (4). This enables these firms to minimise risk whilst remaining responsible to shareholders (9), whilst facilitating new technologies to scale more quickly (Coyne, 2019).

Section 2.5.2.3. discusses how these firms have been able to interface with and influence the government in relation to energy innovation. The publicly funded organisations discussed in section 2.5.4. have additionally involved utilities and OEMs in different ways, with the ETI representing an example that engaged incumbent firms in understanding future clean electricity markets and how to avoid stranded assets (21). A firm that has exerted particular influence is Rolls-Royce (5), who were involved in the ETI and more recently led the consortia secured £44m in RD&D investment in small modular reactor technologies[3]. The dominance and ongoing influence of these firms alongside market led policy has facilitated the development of large scale, supply side clean electricity innovation.

As the amount of intermittent and distributed generation on the grid has continued to increase however, policy and markets for systems flexibility, decentralisation and digitalisation have increased. New firms are emerging as suppliers, utilities and technology providers, encouraged by the activities of organisations like Innovate UK (3). New utilities in particular are engaging in innovation in relation to tariffs and supply flexibility, challenging the prominence of the Big 6 (Kattirtzi et al., 2021).

Large utilities are also responding to these emerging conditions by adjusting business models and integrating innovative solutions (3). Livieratos & Lepeniotis (2017) for example, explore the way in which Enel, EDF, E.On and Iberdrola are now utilising corporate venture capital approaches to integrate the skills and knowledge required to develop innovative new products. Given that the structures in which these companies operate is difficult to change (4; 12; 18) and requires a coming to terms of dramatic change after such a long period of time (5), firms that have anticipated these changes have been able to respond to shifting institutional environments. This has been identified and described by Bergek et al. (2013) as creative accumulation. An interviewee commented however that the different parts of large utilities often have different priorities and they are just beginning to *"feel their way through this transition"* (11). Indeed, work by Kattirtzi et al. (2021) demonstrate disruption caused by increasing levels of digitalisation and further regulatory updates by Ofgem may lead to unanticipated challenges to their ability to successfully innovate.

2.6. Discussion

The results above explore how different institutional layers have evolved over time to affect the development of the UK's clean electricity innovation system. This discussion examines key

[3] Low-Cost Nuclear, Industrial Strategy Challenge Fund, UK Research and Innovation. Available at: https://www.ukri.org/innovation/industrial-strategy-challenge-fund/low-cost-nuclear/ Accessed 28.09.20

ways in which the institutional layers have interacted to shape this process and the utility of the framework in exploring this.

Results demonstrate the underlying influence of the UK's liberal market economy values and history as a fossil fuel producer at **layer 1** on the development of the institutional layers beneath. The privatisation and liberalisation of the electricity system led energy policy to become focused on facilitating low electricity costs, aligning the priorities of policy makers and utilities. The historic availability of plentiful fossil fuel resources facilitated the development of an energy system powered by centralised, large-scale power plants at increasing efficiency levels, starting in the nationalised post-war era. This centralised infrastructure has remained dominant despite a technological shift toward renewable energy generation. Therefore, as climate change has emerged as a new informal norm in layer 1, responses have been shaped through these enduring institutions.

Industry relationships with the government in **layer 2** have remained primarily dominated by powerful utility and fossil fuel actors, exerting influence over the creation and protection of certain technology markets. The role of these firms in shaping energy policy is supported by other layer 2 institutions, including the centralised structure of government and a liberalised approach to regulation. Indeed, until recently Ofgem's remit has been slow to support systems level innovation, impacting the effectiveness of their innovation investments in **layer 3**. Ofgem has therefore been recognised to have created an institutional bottleneck to clean electricity innovation (Lockwood et al., 2015; Kuzemko et al., 2016).

Additionally, aspects of government structure in **layer 2** have caused inertia in the rate and coherency with which policy makers have been able to create effective new institutions for the delivery of clean electricity innovation. For example, the high turnover of ministers and civil servants during the Coalition government caused issues in consistency at lower layers, reducing the ability for investors to take risks in driving innovation market development.

These institutional arrangements initially resulted in market led policies in **layer 3**, such as the Renewables Obligation which supported incumbents in driving the uptake of large-scale renewable technologies closer to market. It also influenced the development of publicly funded innovation organisations in **layer 4**, such as the Carbon Trust and Energy Technologies Institute, which sought to heavily engage firms in technology development. These institutional interactions led to a focus on the commercialisation of large, supply side technologies, integrated by existing utilities into centralised systems infrastructure.

This has shaped innovation focus toward the development of offshore wind, with the promotion of technology specific policy in **layer 3** and the Offshore Renewable Energy Catapult in **layer 4** to provide ongoing support for market development. At earlier stages of innovation investment, nuclear fission and CCS technologies have remained on the innovation agenda, shaped by industrial relationships and interests in **layer 2**. The difficulty of commercialising these technologies within a liberalised electricity market however demonstrate the ongoing influence of this **layer 1** value, with CCS support in particular failing to produce a demonstration scale project.

Until the mid-2010s, the UK's institutional makeup therefore largely facilitated clean electricity innovation system development within existing system, regulatory and market architectures. Since 2016 however, larger shifts have started to emerge which increasingly challenge this narrative. This has been driven by the increasing importance of climate change and ongoing technological advancements in clean electricity innovation in **layer 1**. Centralised infrastructure is now under increasing pressure to incorporate growing amounts of intermittent, decentralised generation and integrate the digital and energy demand focused technologies that will facilitate this. This requires innovation to fundamentally address underlying systems architecture if clean electricity innovation is to continue be accelerated (Markard, 2018; Markard et al., 2020; McMeekin et al., 2019).

There has also been a shift in **layer 2**, as the role of government in innovation policy and industry relationships has shifted. The Industrial Strategy signifies the government's willingness to intervene in the development of clean electricity innovation systems, identifying it as a key pillar of economic growth. Whilst momentum around a technology specific approach started in the Labour Government in the mid 2000s, this initially came under political scrutiny whilst receiving progressively greater attention by government. The Department of Energy and Climate Change has now become part of the Department for Business, Energy and Industrial Strategy, which carries greater institutional clout and resources in relation to funding and policy making. Additionally, the creation of the Energy Innovation Board and UK Research and Innovation in **layer 4** represent new, high level institutions seeking to coordinate and drive innovation aims.

These institutional changes have cascaded to affect the layers below. Policy and regulatory attention in **layer 3** has shifted toward increasing systems flexibility, with Ofgem and BEIS working together to develop a joint strategy to achieve this. Correspondingly, UK Research and Innovation have increased investment in energy storage and the Energy Systems Catapult has been launched in **layer 4**. These developments are presenting opportunities for both incumbent and emergent firms in **layer 5** to innovate new business and technology approaches to deliver digital and demand related solutions. Incumbent firms are increasingly engaging with emerging actors to fund and scale these solutions, although tangible progress remains slow (Kattirtzi et al., 2021).

Usefulness and limitations of the analytical framework

The interplay of the different institutional layers explored above combines to demonstrate how the UK's clean electricity innovation system has evolved over time. This has primarily been driven by change in layer 1, which has led to the evolution of institutions at layers 2, 3 and 4 that have changed and strengthened over time. For example, the Low Carbon Innovation Coordination Group produced the Technology Innovation Needs Assessments, which helped to identify priorities for the current £500m energy innovation fund. Another example is the Energy Technology Institutes' development of the smart systems and heat programme, which went on to form the basis of the Energy Systems Catapult. As change has accelerated in layer 1, this has led to more fundamental changes in layer 2 in relation to industrial strategy development. This demonstrates the top down nature of institutional change, which is now creating pressure on the layers beneath.

The layers also demonstrate that institutions have not necessarily changed and evolved in an even, harmonious manner. For example, the inertia contained within the regulatory approach of Ofgem in layer 2 has created resistance to pressure from layer 3 to accelerate the uptake of grid scale innovations. Another example is the 'policy reset' by the Conservatives in layer 3, which was contradictory in accelerating clean electricity innovation and reduced technology specific support despite the economic success of offshore wind. The incoherence of these institutional changes was discussed as confusing by interviewees, impeding the creation of stable markets and government capacity (7; 16).

Additionally, the framework demonstrates that centralisation has remained particularly dominant institution. It is embedded in informal values in layer one in relation to increasing efficiency and reducing cost of national fossil fuel generation, which was delivered by centralised infrastructure. It is also a key feature of government structure and electricity market regulation in layer 2. This has led to clean electricity technologies being delivered within centralised systems architecture and industry relationships. Whilst more transformative institutional change is now required, values in relation to centralisation will likely continue to shape their approach. For example, it is unlikely that there would be the political will in the UK to support radical decentralisation of generation capacity or local energy market development.

Whilst the framework has proven a useful heuristic lens through which to examine this complexity, there are several features that made its application difficult. Categorising some institutions into a particular layer proved challenging and occasionally arbitrary, with intermediaries like Innovate UK straddling layers 3 and 4 as both organisations and policy makers.

There was also subjectivity around which aspects of each layer should be included and foregrounded. For example, this paper has not focused on land ownership and permitting despite these being aspects of regulation that may have impacted the innovation system in layer 3. This also caused difficulty in applying layer 5, as there are multiple key actor groups involved in shaping clean electricity innovation. For example, the focus on incumbent firms here left no room to explore the influence of non-for profits or other actors, which have also shaped institutional approaches to clean electricity innovation (Kern et al., 2014).

Finally, layer 1 was also a challenge to empirically apply as it contains both informal values and technology trajectories, which represent two very different institutions. The framework would therefore benefit from future research that better defined its boundaries for inclusion.

2.7. Concluding remarks and policy implications

This paper applies a framework of five institutional layers to understanding how national institutions have affected the evolution of the UK clean electricity innovation system, 2000-2018. It demonstrates the influence of enduring informal institutions on those developed beneath, which has caused clean electricity innovation to occur within the existing, centralised electricity system. Institutions supporting clean electricity innovation have evolved over time at different speeds, creating a landscape of gradual, uneven change. As the centralised system faces increasing pressure to deliver whole system innovation, this will require increased institutional disruption, as more radical changes to system infrastructure, markets and regulation will be required.

Energy innovation policy making should be considered within this broader institutional landscape, which will need to navigate multiple changing institutions to be effective in accelerating innovation. This work therefore has several implications for policy makers.

Encourage a diversity of different narratives and interactions in layer 2 to enable government to build the competencies needed to effectively accelerate policy

The industry actors engaged in delivering clean electricity innovation by policy makers to date primarily remain large incumbent firms. These actors are more likely to reinforce incremental institutional change, which may affect the ability for policy to accelerate innovation moving forward. The government should therefore seek to engage a diversity of voices and views to inform policy as institutional pressure to drive whole system decarbonisation continues to grow. This would enable policy makers to take a more evidence-based approach to clean priority setting, moving away from the influence of incumbent lobbying in making decisions.

Have greater institutional patience in layers three and four to create stability for investors and deepen public capabilities

Whilst policy direction at a high level can often transcend administration, change in specific policies and innovation organisations are often more at the whim of individual ministers. This can lead to a lack of stability and longevity, eroding their ability to support innovation through to market deployment. Policy makers should therefore seek to problem solve within existing institutions as opposed to reaching for new solutions too quickly. This would prevent institutional breaks, creating greater market security and enable specialised capacity and resources to build.

Be more strategic in developing technology specific policy, replicating the success of offshore wind

As different technologies face different institutional barriers, tailored knowledge of individual technologies will enable these to be understood and overcome more quickly. The success of offshore wind demonstrated the importance of patience and consistency in this regard. A more strategic approach to defining which technologies the UK should focus RD&D efforts on and which could be imported from other countries or are not be desirable in the system, could enable more specific technology markets to be identified.

Identify and address broader institutional blockages at different layers that impact the effectiveness of innovation policy

Innovation policy efforts should consider the institutional environment beyond policy mix, in order to best work with or challenge these conditions to ensure that policy can be implemented effectively. For example, tweaking a policy instrument is likely to prove ineffective in driving a particular technological innovation if it strengthens relationships with the wrong kind of firm or continues to be restrained by a lack of regulatory engagement or is incompatible with existing system infrastructure. This is particularly relevant in the example of Ofgem regulation, which may need be addressed if the markets and incentives for systems innovation are to support innovation policy targeting to grid or decentralised technologies.

More carefully consider the design of institutions in relation to their aim and the way they will operate alongside other institutional layers

For policies and organisations to achieve their aim and have potential longevity, the way in which it is designed to interact with actors within and outside the institution should be considered more closely. For example, the level of seniority it engages in delivering its aims or the extent to which its funding approach appeals to both major political parties. This will require a more transparent, systemic approach to clean electricity innovation and an understanding of which actors need to be engaged to facilitate this deeper coordination. Actors from across layers may need to come together to understand the issues from multiple different angles to identify points at which institutional change might create the most benefit to the rest of the system.

3. Paper 2: Designing publicly funded organisations for accelerated innovation: A case study of the Energy Technologies Institute, UK

3.1. Introduction

A range of clean energy technologies need to be developed and deployed commercially if the aims of the Paris Agreement are to be met (IPCC, 2018). For this to occur at the pace and scale required, governments need to develop technology specific innovation policy (Kattel & Mazzucato, 2018; Sanden & Azar, 2005) to accelerate the research, demonstration and deployment (RD&D) of nascent clean energy technologies and create future markets for their use (IEA, 2011). Meeting this policy challenge will require new approaches to implementing and evaluating the public organisations that support and fund energy innovation, to ensure that policy interventions produce the desired outcomes (Kattel & Mazzucato, 2018; Hekkert et al., 2020).

Whilst publicly funded innovation organisations are shaped by the socio-technical environment in which they are developed (Anadon, 2012; Dasgupta et al., 2016; Bonvillian, 2015) they can also be designed in a way that maximises innovation policy effectiveness (Berznitz et al., 2018; Glennie & Bound, 2016). They are therefore an important actor in driving sustainable transition, as their ability to interact with the broader system to implement innovation policy is key to the emergence of technologies that have the potential to transform the existing system (see Raven et al., 2016).

Whilst the sustainable transition literature has begun to consider the role of different actors more closely (Martiskainen & Kivimaa, 2018; Bohnsack et al., 2016; Upham et al., 2020), there is as of yet no literature addressing the role of publicly funded organisations for accelerated innovation and their role in sustainable transition. This paper contributes to this understanding by refining a framework of ten principles for accelerated innovation organisation design, originally developed by Haley (2016; 2017). This is achieved by better aligning the principles with the sustainable transition literature and emerging literature on innovation organisation design. The framework is applied to critically investigate a detailed case study of the UK's Energy Technologies Institute (ETI) to address the research question: what was the role of the ETI in accelerating sustainable energy transition in the UK?

Results demonstrate that whilst the ETI aimed to accelerate revolutionary innovation, its design reflected the power and relationships within the broader system. This impeded its ability to pursue its mission, with its design more closely favouring the production of incremental innovation outputs, leading to technologies that served to 'fit-and-conform' as oppose to a 'stretch-and-transform' (Raven et al., 2016).

The paper is structured as follows. Section 2 provides an overview of the ten principles for organisation design framed within the sustainable transitions literature. Section 3 discusses the methodological approach and section 4 introduces the ETI case study. Section 5 presents the empirical results, with section 6 providing a discussion of these in relation to the research question. The paper concludes with Section 7.

3.2. Ten principles for innovation organisation design

This section introduces the ten principles for design for accelerated, publicly funded innovation organisations, which provide the framework of analysis used in this paper. Originally developed by Haley (2016; 2017) the principles draw on a range of disciplines including *"public administration; political economy; industrial policy; developmental economics; sustainability transitions and innovation studies"* (2017, p.109). This interdisciplinary approach makes the principles stand out in the sustainable transition literature as one that frames the design and approach of an innovation organisation within the socio-technical system of which it is a part. The contributes to Jacobsson & Bergek's (2011) call for the organisation of public bodies to become a transitions research priority. Initial application of the principles to the energy innovation organisation ARPA-E yielded insights that Haley intended to act as a springboard for further analysis (Haley, 2017).

A refined version of the principles is displayed in Table 3. Here the author has developed descriptions of each principle to summarise work by Haley (2016; 2017) and re-ordered them to reflect the timeline over which they impact an organisation's positioning, operation and outputs, in order to provide greater ease of use[4]. The name of principle 1 has been changed

[4] The original order in which they were presented was: Comprehensiveness, Flexibility, Autonomy from Short-term Political Pressure, Mission Orientation, Embeddedness within Policy Networks, Autonomy from Private Interests, Competence, Credibility, Stability and Accountability (Haley, 2017)

from ‘Comprehensiveness’ to ‘Policy environment’, to better communicate its relevance to the description.

No.	Organisational principle	Description
1	**Policy environment**	• Organisation based in a policy mix as oppose to relying on individual policy instruments • Involves a variety of actors to explore multiple approaches to managing policy uncertainty • Networked with other system actors to ensure the diffusion of knowledge and technologies
2	**Embeddedness of private sector actors in policy networks**	• Builds private sector linkages for knowledge capture and sharing between sectors • Creates better understanding and building of trust across sectors • Aims to embed these relationships in civil society to ensure that resulting technological trajectories align with public interest
3	**Mission**	• Defines a clear organisational aim and strategy for implementation • Focuses on aims and performance as oppose to beurocracy and procedure, encouraging an entrepreneurial ethos • Attracts talented staff members through the autonomy a strong mission provides
4	**Autonomy from short term political pressure**	• Decouples organisation from political interferece to enable mission focus • Prevents civil servants and Ministers from contracting blame for failures in experimental technology development • Retains access to wider resources to implement intended policy outputs
5	**Autonomy from private sector**	• Engagement with firms on public sector terms, without civil servants being captuerd by particular interests • State retains the ability to shape technological trajectory • Involves emerging firms to counter incumbent influence over exisitng systems
6	**Competence**	• Builds public sector knowledge and technology specific competencies to prevent succumbing to technology fads and hype • Understands how technologies will sit within the wider innovation system and any cross-sector linkages • Develops competencies related only to specific organisational mission, as changing or overloading focus will effect performance

7	**Flexibility**	• Able to respond to emerging innovation system dynamics and take advantage of windows of opportunity • Civil servants able to cancel failing projects- seen as an integral element of operaitng in an uncertain policy environment
8	**Credibility**	• Organisational cohehrence that builds private sector trust • Reduces perception of financial risk by demonstrating sustained commitment • Involves private sector in policy developments for effective navigation
9	**Stability**	• Long term organisational focus, unaffected by changing funding cycles and political prioritisation • Funds that remain sufficient and predictable for innovation projects that take many years
10	**Accountability**	• Transparent outputs on what is being achieved and how • Capacity dedicated to monitoring and communicting outputs to the appropriate audiences • Generaton of a non-ambiguous view of success that stands up against different ideologies and narratives

Table 3- 10 principles for accelerated innovation organisation design. Descriptions developed by author from Haley (2016; 2017)

The following sections align the principles' relevance to the sustainability transitions literature and emerging literature on innovation organisation design, specifically in relation to energy. This serves to demonstrate the utility of the framework in understanding how innovation organisations can be designed and positioned within a system to accelerate sustainable energy transition.

3.2.1. Policy comprehensiveness and industry embeddedness

The first two principles consider the broader political context and industry relationships within which an innovation organisation is formed. This brings attention to the influence of broader, underlying conditions such as political economy and polity on the positioning and operation of an innovation organisation.

Recent work on sustainable transition has sought to incorporate insights from political science to address a lack of understanding of political economy relationships (Godthau & Sovacool, 2012; Meadowcroft, 2011), especially in relation to the deliberate acceleration of transition

(Kern & Rogge, 2018). In particular, the role of the State and broader institutional structures on innovation policy has started to receive attention (Roberts et al., 2018; Cherp et al., 2018; Johnstone & Newell, 2018). Indeed, research demonstrates that clean energy innovation policy is impacted by polity (Schmidt & Sewerin, 2017; Lockwood et al., 2013; Baccini & Urpelanien, 2012), political economy (Bonvillian, 2015; Lachapelle et al., 2013; Ćetković et al. 2017) and the way in which these evolve over time (Bird, 2015; Keay et al., 2012; Geels et al., 2016; van der Steen et al., 2008).

These broader contexts have been demonstrated to shape policy maker perceptions on the acceptability of different approaches that an organisation can take to clean energy innovation (Anadon, 2012; Karo & Kattel, 2016). This impacts an organisation's technology focus, allocation of funding to different innovation stages and the stability of the support available (Glennie & Bound, 2016).

Clean energy innovation organisations are additionally affected by national attitudes toward energy, in which policy needs to address energy security, economic competitiveness and natural resource availability (Anadon, 2012). The policy environment in which an organisation is created is therefore not fixed, as attitudes towards innovation and technologies shift dependent on the party in power and the way policy priorities change over time (Cetkovic & Buzogancy, 2016). Edmondson et al. (2018) for example, discuss the importance of developing comprehensive policy environments able to withstand changes in these broader conditions, which can evolve and accumulate positive feedback and so become more stable over time.

Indeed, this research further demonstrates the linkages between layers 2 and 3 in Framework 1 discussed in Section 2.3 and how these characteristics affect the design adopted by individual organisations in layer 4. These broader contexts influence both the kind of relationships and focus that are viable, as well as the positioning and connectedness of an organisation within the surrounding innovation system.

3.2.2. Mission

The third principle addresses the importance of defining a clear organisational mission, enabling an organisation to focus its performance around achieving a specific aim. Empirical observations indicate that multiple innovation organisations that each take a specific focus are more effective than a broader catch all approach (Glennie & Bound, 2016), with decentralised, specialised organisations more effective in delivering innovation policy than monolithic, hierarchical approaches (Karo & Kattel, 2016).

The sustainable transitions literature has begun to more deeply conceptualise how protective spaces are created for different innovative technologies, which explores the role of technology specific policy and public programmes in creating these shielded niches (Raven et al., 2016). These technology specific spaces that are able to operate in a nimbler way have the potential to exercise agency to produce innovations that can transform the existing system (Smith & Raven; 2012).

Indeed, whilst all organisations have a specific aim or mission, the role of mission-orientated organisations is being increasingly discussed as a way to accelerate technology-specific, transformative innovation (Mazzucato, 2018). In past, policy makers have adopted mission-oriented approaches focused on achieving a top-down, specific technology output for public procurement (see Foray et al., 2012). Mission-oriented approaches are now shifting focus toward tackling complex, societal issues (Mazzucato, 2018; Kattel & Mazzucato, 2018) such as climate change and clean electricity innovation, which requires a plurality of actors to urgently come together to create and shape new markets for multiple emerging technologies (Mowrey et al., 2010; Mazzucato & Semieniuk, 2017). This in turn requires new ways of configuring and building public support for mission-oriented innovation (Hekkert et al., 2020) and opportunities for innovation organisations to create protective spaces for specific facets of sustainable transition.

3.2.3. Public and private sector autonomy

Principles four and five address the extent to which an organisation is designed to retain autonomy from political and private sector capture. Depending on the aim, an organisation will seek to involve public and private actors in different ways at different levels of engagement, and so needs to carefully balance the dynamics of power within this relationship.

The sustainable transitions literature has engaged in better understanding the impact of politics and power (Avelino & Rotmans, 2009; Grin, 2012), and actors and their interests on innovation trajectory (Markard et al., 2016). The power inherent in the dominant regime, especially legacy sectors like energy, accumulates across structural dimensions over time (Wilson & Grubler, 2014), which can lead to self-reinforcement (Unruh, 2000) and innovation system failure, as new forms of technology or knowledge are devalued by dominant actors (Foxon et al., 2005). Strong private sector actors such as oil and gas companies are acknowledged to cause inertia against sustainable energy transition (Gallagher et al., 2012; Geels et al., 2016).

The role of existing regime actors in driving sustainable transition however is just as important as that of disruptive niches (Schot & Geels, 2007; Hölsgens et al., 2018). Incumbent energy companies for example have demonstrated that they are able to react as system conditions change to facilitate clean energy transition (Heiskanen et al., 2018; Kungl, 2015; Richter, 2013). Indeed, Winskel & Radcliffe (2014) identify that accelerated energy innovation policy in the UK was largely led by regime actors in a continuity-based approach. The role of these firms in facilitating the technology transfer needed to move outputs closer to commercial markets can therefore be of key importance (Chan et al., 2017).

There are many ways in which an organisation can facilitate public and private engagement in a mutually beneficial way. Public private partnerships (PPPs) can be utilised as a way to reduce public spending and share project risk with private partners (Wall & Connolly, 2012; Lam & Javed, 2014). NASA for example is engaged in developing PPPs to drive the creation of markets for low-Earth orbit innovation involving the creation of several public, private and not-for-profit organisations (Mazzucato & Robinson, 2018). Analysis of traditional PPPs however demonstrates that private members are more incentivised to invest in low risk, incremental innovation (Roumboutsos & Saussier, 2014).

Public sector engagement also effects the way in which an innovation organisation will operate, with policy makers presenting a non-neutral actor also interested in certain outcomes (Johnstone & Newell, 2018; Azar & Sanden, 2011) and interested in protecting themselves against perceived failure (Lerner, 2012; Lipsey & Carlaw, 1998). Indeed, Breznitz et al. (2018) demonstrate that an organisation seeking to drive revolutionary innovation is best designed to sit at the periphery of government and involve emerging firms, with lack of political engagement needed to continue to pursue more radical aims (Breznitz & Ornston, 2013).

3.2.4. Operational approach

Principles six to ten discuss aspects of operational design identified by Haley (2016; 2017) as important for accelerating innovation. Whilst there is a large amount of variation in the operation of successful innovation organisations (Breznitz et al., 2018), empirical studies are emerging that provide insight on more generalisable characteristics for accelerated outputs. An understanding of these principles within sustainable transitions in particular are useful in understanding how policy implementation is shaped by and can shape the system in which transition takes place (Dasgupta et al., 2016; Bonvillian, 2015).

Principle six identifies that high levels of competence and human capital is of clear importance. This facilitates researcher autonomy and influence over funding decisions, which is a successful feature of revolutionary energy innovation organisation ARPA-E in the US (Bonvillian, 2018; Azoulay et al., 2019). Incentivising internal collaboration is also identified by Chan et al. (2017) as key to success, with these qualities contributing to flexibility in principle seven, enabling collaboration with other system actors, and adopting adaptive learning strategies as projects can be cancelled in a timely way (Anadon et al., 2011; Chan et al., 2017).

It is important that high levels of competence and flexibility are balanced with stability in principle seven, which is required to provide consistent access to funding and political resources to operate effectively over time (Anadon et al., 2011; Chan et al., 2017; Bonvillian, 2015). Stability greatly assists the development of credibility in principle eight, which is essential in building ongoing trust between system actors. Finally, it is key to maintain accountability to public stakeholders in principle ten, which requires organisational capacity dedicated to analysing and reporting progress (Taanman, 2012) and for metrics to evolve over time as transition unfolds (Glennie & Bound, 2016).

3.3. Methodology

This paper utilises the ten principles for accelerated innovation organisation design as a framework through which to analyse the context specific details of a qualitative case study of the Energy Technologies Institute (ETI), UK (Flyvbjerg, 2001; Yin, 2014).

Primary data was collected via 22 semi-structured interviews, conducted between January and August 2018. Participants are summarised in Table 4. Ten interviewees had direct involvement with the ETI, including staff, board members and those involved in project consortia. Interview questions for these participants were designed to operationalise each of the ten organisational design principles outlined in Table 3 (see Annex D for question examples). 12 interviews were conducted with non-ETI affiliated actors operating in the broader clean energy innovation system. These subjects were interviewed more broadly about their perceptions of the ETI and the role it has played in accelerating clean energy innovation.

No.	Job function	Organisation
1	Senior staff member	ETI
2	Senior staff member	ETI
3	Senior staff member	ETI
4	Staff member	ETI
5	Staff member	ETI
6	Private member	ETI
7	Private member	ETI
8	Consortia member	ETI
9	Staff member	ETI
10	Staff member	ETI
11	Lecturer	Academic
12	Director	Government
13	Head	Government
14	Head	Government
15	Head	Research Council
16	Chair	Public research organisation
17	Managing Director	Private sector
18	Director	Private sector
19	Chief Executive Officer	Public funding organisation
20	Head of Secretariat	Government
21	Executive Director	Public funding organisation
22	Advisor	Government

Table 4- ETI case study Interviewees

Interview data was transcribed and coded using NVivo software to correspond with the principles in Table 3, enabling key trends to be identified within each principle. Interview data was triangulated where appropriate with existing academic and grey literatures, including policy documents and materials published by the ETI.

Where interview data is directly quoted or utilised to support a statement, the number of the interviewee is listed in brackets in correspondence with Table 4.

3.4 The Energy Technologies Institute (ETI)

3.4.1. Background

As concern over climate change grew in the early 2000s, a Royal Commission report identified that decarbonisation of the energy sector represented a radical future challenge to the UK (RCEP, 2000). Public and private investment in energy innovation had rapidly declined in the early 1990s after electricity system privatisation, reaching a historic low in 2003 (see Jamasb & Pollitt, 2015).

The government started to develop new clean energy innovation organisations to address these concerns, including the Carbon Trust, a private organisation that worked with businesses to reinvest money raised from the climate change levy to reduce carbon emissions (Kern, 2009). The UK Energy Research Centre was established in 2004 to lead and better coordinate energy innovation research, but as a distributed, academic consortium it took a niche role in innovation system building (Winskel & Radcliffe, 2014). These organisations were reflective of the UK's highly liberalised energy markets and weakened institutional base (Kern, 2008; Anadon, 2012; Winskel & Radcliffe, 2014).

In 2003, a legally binding target of a 60% carbon emission reduction below 1990 levels by 2050 was enacted (DTI, 2003). It soon became apparent that that relatively moderate decarbonisation interventions made to date were not producing the desired results (Winskel & Radcliffe, 2014). These concerns coalesced with increasing alarm over energy security, leading to renewed innovation policy efforts (Winskel & Radcliffe, 2014).

The 2006 Climate Change UK Programme aimed to provide a roadmap to the UK's 2050 carbon reduction target, acknowledging that successful implementation required additional support beyond the existing market-oriented framework (DEFRA, 2006). In 2007, new Prime Minister Gordon Brown recognised that a stronger policy approach was required to engage the firms it was assumed would ultimately invest in deploying and operating new clean energy technologies (Winskel & Radcliffe, 2014). The ETI was created as a mechanism to achieve this step change in funding, heralded as *'the most important in UK energy research and innovation for decades'* (DTI, 2006b, p.2). It was hoped that the ETI would galvanise strategic focus and provide a pull for research from university to demonstration level (DTI, 2007).

This approach was supported by findings of the Energy Research Partnership (ERP), formed in 2005 by Gordon Brown as a public-private strategy forum (Winskel & Radcliffe, 2014). The ERP recommended that RD&D focus more on market needs and encourage greater collaboration with the private sector for demonstration and deployment support, if the UK was to have the required technologies in place (ERP, 2007). These companies represent the first private members of the ETI.

3.4.2. Organisation overview

The ETI represented a public-private partnership (PPP) between the UK government and six global energy and engineering companies. Private sector members comprised British Petroleum (BP), Caterpillar, Electricité de France (EDF), E.ON, Rolls-Royce and Shell[5]. These firms were represented on the Board alongside public sector partners from the Department of Business, Energy and Industrial Strategy (BEIS)[6], Innovate UK[7] and the Engineering and Physical Sciences Research Council (EPSRC)[8]. The ETI was a limited liability partnership sat at arm's length from the government and contracted to run for ten years. The ETI adopted a 50:50 funding model, aiming to attract a total of 10 private partners investing a maximum of £1bn over its lifetime (DTI, 2006b). Funding consisted of up to a maximum of £5m per annum from each private member, which was then match funded by the government. This provided a maximum budget of £60m per annum for research activities (ETI, 2018a).

The ETI sought to invest in technology readiness levels (TRLs) 3-6, traditionally known as 'the valley of death' (ETI, 2018b). To deliver projects, the ETI created consortia comprising a range of national and international firms, SMEs, universities and research bodies (Ragsdell et al., 2013). The funding model used enabled the ETI provided 100% of funding for projects, which is

[5] E.ON were a member until 2014, pulling out after the 2011 Fukushima nuclear accident impacted German energy policy toward nuclear (interviewee 5). Hitachi joined as an Associate Member of the Smart Systems and Heat technology programme in 2012: https://www.eti.co.uk/news/eti-signs-lease-on-new-birmingham-office-and-announces-director-smart-systems-heat Accessed: 10/05/19.
[6] This is the current department responsible for energy innovation. 2007- 2008 it was Business, Innovation and Skills (BIS). 2008- 2016 it was the Department of Energy and Climate Change (DECC).
[7] Between 2007- 2014 this was known as the Technology Strategy Board.
[8] ETI Board Members. Available at: https://www.eti.co.uk/about/members Accessed: 04/03/19.

normally prohibited under State Aid rules (ETI, 2018b). This enabled the ETI to procure innovation as opposed to tender for grants, and so was able to start with a problem and conduct smaller projects to assess where the best innovation opportunities might lie, picking teams at its own discretion. The organisation took five years to meet its maximum funding capacity of £60m a year in 2012 (ETI, 2018a).

3.4.3. Outputs

The ETI was discontinued in 2017 after ten years of operation[9] and has since released a review reflecting on its operation (ETI, 2018a; 2018b). The ETI states that it spent £400m on *"whole energy system modelling and analysis alongside the practical delivery of over 150 complex energy innovation projects",* with additional demonstration activities in other fields complete by mid-2019[10]. It will likely be difficult to judge the ultimate success of the ETI's outputs until big energy infrastructure decisions are made over the next ten years (ETI, 2018b). Knowledge and capacity built by the ETI has been allocated to organisations including the Energy Systems and Offshore Renewable Energy Catapult (ETI, 2017). Table 5 displays the metrics available on the ETI's outputs over its ten years of operation, indicating its engagement in knowledge generation, education and training and policy making.

ETI by numbers	
146 projects	929 citations of our work over 4 years
19 demonstrations	12 select committees
27 technology developments	131 staff employed (averaging 60)
103 knowledge building	41 models and tools developed
63 ETI publications by 2019	537 documents and data sets made public
62 PhDs sponsored	21 student placements
42 constitution responses	

Table 5- ETI by numbers (ETI, 2017)

Of the 146 projects indicated in Table 5, there is information publicly available for 98, which account for £283m of funding across 11 technology areas[11], displayed in Figure 20. Offshore wind projects received the largest amount of funding, with the seven projects conducted consisting of the development of test equipment, a commercially viable blade product, three

[9] Despite an independent review recommending that it should continue operation for an additional five years to 2022 (Technopolis & Mott Macdonald, 2013)

[10] 'Lessons Learnt Jonathan Wills, Chief Executive Officer' 24 October 2018. Available at: https://www.eti.co.uk/news/lessons-learnt-jonathan-wills-chief-executive-officer Accessed: 23.04.19

[11] ETI Technology Programmes. Available at: https://www.eti.co.uk/programmes Accessed 10.08.20

to-scale component technology tests and development of monitoring and analysis tools[12]. Whilst 19 projects also focused on demonstration, as indicated in Table 5, the majority of ETI projects related to the scaling technology components, developing software tools, and evaluating or analysing information.

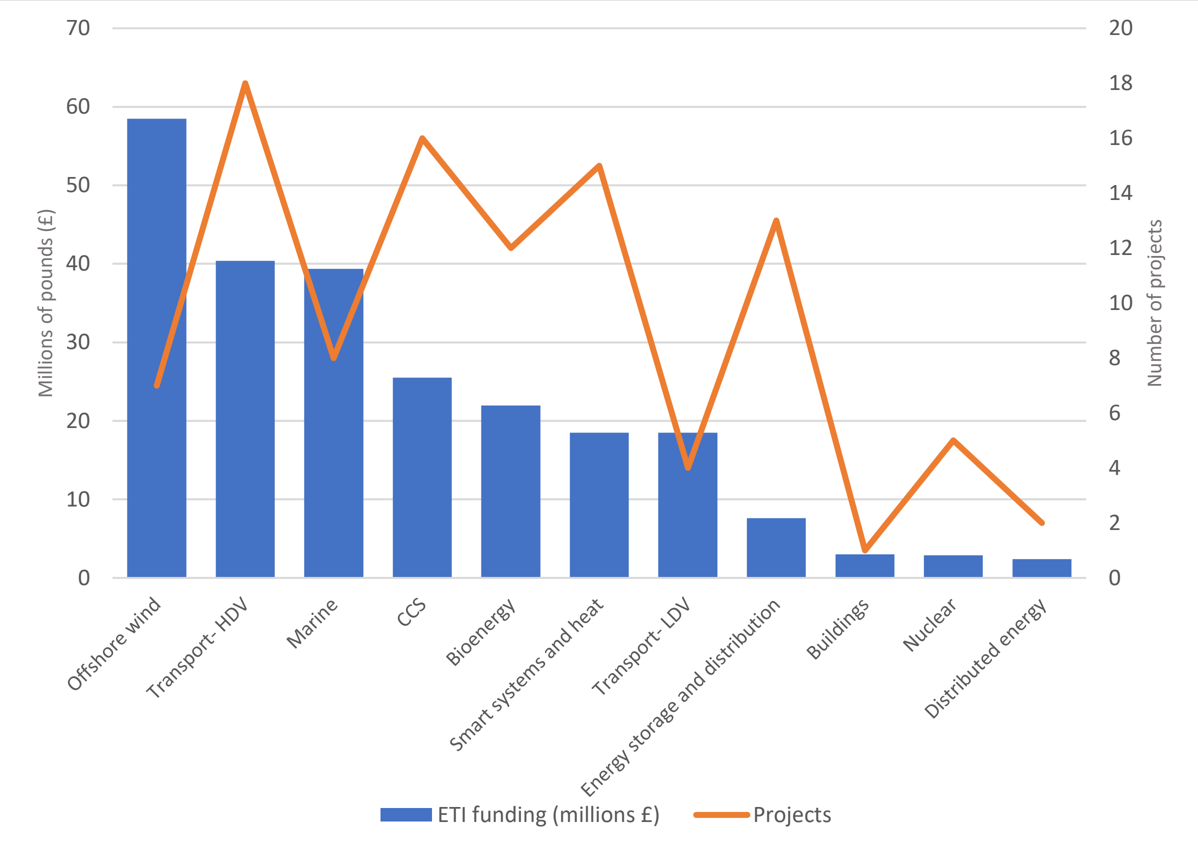


Figure 20- ETI Programme Area summary

3.5. Results

The ten principles identified in Table 3 are now applied to the ETI. Quote tables are utilised at the end of each subsection to add additional context to key points or to emerge from interview data.

[12] ETI Technology Programmes, Offshore Wind. Available at: https://www.eti.co.uk/programmes/offshore-wind Accessed 10.08.20

3.5.1. Policy environment

As discussed in 3.4.1, the ETI emerged from the government's broader climate change agenda and energy policy mix around decarbonisation, energy security and promoting competitive markets in the UK (DTI, 2006b). Utilising a PPP approach sought to engage a cross-section of large energy industry actors that had the capabilities to fund and deploy solutions, and build government understanding of what a future energy system could look like. This approach reflected that of the Carbon Trust in developing a private, arm's length organisation, with the PPP structure common across several other industries, including education, health and transport (Lam & Javed, 2014).

A government interviewee described the ETI as an experiment characteristic of this time, during which a desire to engage energy firms in accelerating clean energy technology development made a private, arms-length organisation politically attractive. An ETI staff member discussed that investing public money alongside incumbent private sector companies was considered a reasonable trade-off for the achievement of this partnership. The ETI's Board also engaged other public bodies including the EPSRC and Innovate UK (BIS, 2008), with an interviewee discussing that this created consistent dialogue with these actors on how to move innovation outputs forward. The ETI proved durable through a policy environment effected by multiple general elections (ETI, 2018b) as accelerating energy innovation remained politically relevant to changing governments.

Based in policy mix	*"My understanding is that in 2007, looking at the energy sector not just electricity, Gordon Brown recognised you need to have strong balance sheets and market presence in order to effect changes. So in order to do that you need a different model that engages large players and industry, who have… a financial interest. They can innovate and pull through some of the smaller things and effectively afford to spread the bet amongst themselves, to pull the whole thing up."* (1) *"In the RD&D space an interesting experiment that I think was very successful for its time was the ETI… that actually was a great vehicle for government understanding in RD&D of where the private sector was coming from, or 6 of the biggest, so that was a powerful model."* (20) *"The ETI, I think there was quite a lot of that type of organisation being set up and played around with at the time."* (16)

Involves a variety of actors	*"The ETI came out of something called the Energy Research Partnership, so the government had effectively an industry council with a broad range of energy companies, so Rolls Royce were there, generators, users- nicely put together and they agreed that not enough money was going into innovation, they should put in more and government should match it. And Gordon Brown the Chancellor at the time was the sponsor, he got it…"* (2) "(The ETI)… *was to forge closer links between the public and private sector. So the ETI is a PPP and with quite major industrial players and these companies and those like them were seen as one of the best ways of pulling through the early stage R&D, as they are the ones ultimately that in many cases actually deploy and use the technologies. So getting those links between industry and the public sector to help drive that innovation was basically the concept of the ETI."* (13)

Table 6- Exemplary quotes for key observations regarding the ETI's comprehensiveness

3.5.2. Industry embeddedness

Interviewees identified that when the ETI formed in 2007, the private sector was grappling to understand and align themselves with the UK's climate change targets. Some firms were therefore willing to commit to investing a relatively small amount of money into gaining knowledge across a large range of future technologies, as well as good visibility and footing in the UK market.

Paul Golby, Chief Executive Officer of E.ON UK and member of the ERP, worked with David King, Chief Scientific Advisor, to drive the creation of the ETI, demonstrating interest from both sectors in working with and learning from one another. Two ETI interviewees mentioned that the formal and informal relationships built between public and private sector members generated greater understanding both within and beyond the immediate boundaries of the ETI, building trust between members.

The ETI however embedded a small number of incumbent firms into policy networks, limiting the extent to which knowledge could be shared and trust built across sectors. To join, a £50m commitment was required over 10 years, immediately prohibitive to smaller firms and so reducing the diversity of private sector voices at the table. Additionally, many large firms did not see the value of working with the government in this specific way. It was commented by a government interviewee that this created tension between the ETI and other firms, as it was seen to represent a privileged members club.

The structure of the ETI was premised on a strict, legal deal between members, that one Interviewee described as *"quite cumbersome and authoritarian"* (1). A senior staff member described that this relationship was initially characterised by multiple lawyers deliberating over their client's access to IP. These agreements impacted the sharing of information with the broader energy innovation system. An ETI interviewee commented that whilst the organisation arguably possessed the best knowledge network in the UK, its ability to disseminate outputs remains deeply impaired. This stifling of IP is discussed as being damaging to clean energy innovation (Rissman & Marcacci, 2019), with the ETI 2018 Review agreeing that this was a key barrier in the organisation's successful operation (ETI, 2018b).

Built linkages for knowledge sharing between sectors	*"I think the ETI had a really interesting template for taking things forward. It was quite brave to work right across the energy spectrum so to have kit manufacturers like Rolls-Royce and Caterpillar, right up to electric utilities like EDF and E.ON... That was quite a broad span, but having that partnership at the time did make it very interesting. It was certainly a source of good learning for us."* (6)
Built understanding and trust between actors	*"Once they (*the government) *got past the first five or six companies, they found it difficult to get other people to come in because they wrote such difficult IP agreements. They created a body around it that actually prevented new people for coming in. It had a natural size."* (5) *"The ETI could have done so much good if it had been less closed shop and more open about what it was doing and shared it's IP."* (16) *"I don't think that we'd repeat the closed IP model, so that proved to be a real problem, because if you get a whole chunk of the industry not wanting to play that is a problem…* (The closed IP model) *creates more aggravation than value, because of those not in the loop complaining and throwing stones at it."* (12)
Issues related to ETI embeddedness	*"… we could never recruit any other members. They would need to commit to spending £50m of their money on something that they can't control and don't know what they'll get for it- would rather keep the money and individually match government funded projects."* (2) "*Something like the ETI was set up and led by a limited number of incumbents- some had their arm twisted to be there, some saw the advantages- so it was never the independent organisation it hoped to*

	be, but I can't think of any other way it would have gotten off the ground" (18).

Table 7- Exemplary quotes for key observations regarding the ETI's embeddedness

3.5.3. Mission

The ETI's mission was: *"To accelerate the development, demonstration and eventual commercial deployment of a focused portfolio of energy technologies, which will increase energy efficiency, reduce greenhouse gas emissions and help achieve energy and climate change goals"* (ETI, 2018b, p.3). This went unchanged and according to all interviewees was consistent in guiding the ETI's operations. As an arms-length organisation, a private member highlighted the importance of this in ensuring that all members remained oriented around a specific aim.

It was highlighted that the ETI's mission enabled it to attract high quality senior staff members. The two Strategy Directors employed over the organisation's lifetime were acknowledged by three ETI interviewees to be exceptional people, with a private member commenting that the board comprised thousands of man-hours across some of the brightest in the sector. The ETI's Chief Executive Officer, David Clarke, was recruited from his role as Head of Technology Strategy at Rolls-Royce as he was perceived to possess the skillset required to provide strong strategy in the pursuit of the ETI's mission. Project managers were primarily recruited from industry, with only a small proportion of staff seconded from industry members.

The ambiguity of 'accelerate' as a mission however has created issues over the accountability of the ETI's outputs, which interviewees acknowledge had not produced or led to the technology demonstration envisaged with the mission initially formulated. This is further discussed in section 3.5.10.

Focus on mission	*"And there wasn't that much change as things went forward, the overarching mission never changed it was always very focused on low carbon and trialling technology, the governments targets haven't changed through that period either, so the overarching political backdrop didn't change at all even though the emphasis and priorities did with the colour of the government."* (4) *"…the economists, including people that have carried out audits, are saying that ETI are a serious organisation as we don't just come and give money to*

	people that want it. We decide what it is that we want, and we make the people we give money deliver this as best they can." (2)
Initial mission strategy	*"I can tell you what the intention was at least in my mind in setting up the ETI.. what we needed was a joint PPP for the accelerated development of new technologies, and the ETI emerged from that. What we believe it ought to be focusing on is all of the low to net zero carbon technologies that we need, so this means for example energy storage, smart grids- all of the technologies that we still haven't got really into the market."* (11)
Evolving strategy	*"One of the interesting things was it started out very much as money for funding technology demonstrators. Anyone who works in technology will tell you it's all well and good having a shiny, half-scale demonstrator that proves the concept and represents the full-scale one, but if you haven't got all of the underlying tools, then that all becomes academic. The best example of this is the PerAWaT project which was a project to understand the interaction between tidal turbines when they're configured in an array. If you can imagine a load of tidal turbines, wind turbines underwater, and you connect them all together, you can't extract the energy twice, but when you put them into a configuration, they interact with each other. There is no model that exists in the world that understood these interactions and how a tidal velocity and direction could be converted into an output in terms of megawatt hours."* (7) *"In this world of optimism in 2007- 8 before the crash, there was a view that if we just spent money developing and demonstrating technology, everything would work. ... Suddenly, as the credit crunch hit and you started to have a greater emphasis on employment, great agenda, et cetera, the original focus... all about having technology, irrespective of where that comes from, was possibly diluted".* (3) *"How many technologies have emerged from the ETI? They've done some very good work…* (but) *in terms of new technologies… I need some persuading."* (11)

Table 8- Exemplary quotes for key observations regarding the ETI's mission

3.5.4. Autonomy from short term political pressure

ETI interviewees discussed that the organisation was designed to be run as a business, able to take risks and set clear funding priorities. Senior staff members were industry recruits, with experience of developing long-term strategies to ensure that public money was spent accountably. The Strategy Director was viewed as responsible for project failures as opposed to civil servants, with all investment decisions passing through them. The operation of individual projects was solely presided over by ETI staff members, removing board-level input over day-to-day operation.

Whilst initially endowed with political prestige, a senior staff member described that ETI involvement in high level government meetings waned as it became clear that the direction of the organisation could not be swayed by different policy makers. Another senior staff member described that over time, the organisation received the support of a number of senior civil servants in more oblique ways, as the ETI was perceived that as able to stand up for itself and act as a *"sand grain in the oyster"* (2) in terms of driving innovation outputs.

Whilst throughout its lifetime the ETI remained relevant to political aims around climate change and clean energy innovation, it was not completely insulated from political pressure. Several staff members highlighted that the 2008 financial crisis created political pressure to support UK based companies as opposed to those that might be available at a lower cost in different countries, as well as those technologies closer to market.

Decoupling from prestige	*"We always have been and will continue to be to our dying breath evidence-based, so we try and get to understand the technology, understand the markets, understand the costs, put it all into a model and figure out what is most likely… and then where can we intervene to accelerate the technology. I don't care what the policy is because policy will change, but CO2 doesn't."* (1) *"So you have this strange thing where the government deliberately created something to be like the sand grain in the oyster and then in a way you could argue that a number of quite senior civil servants thought* 'this is a good idea and we don't have to stick up for it because it can stick up for itself, so I'm just going to let it happen'. *I have the sense that at a number of points there were quite a lot of civil servants that thought the ETI was a good thing and have been really quite helpful in oblique ways."* (2)
Changing access to broader resources	*"Suddenly, as the credit crunch hit, and you started to have a greater emphasis on employment etc… The original focus of having technology, irrespective of where that comes from, was possibly diluted."* (7)

Table 9- Exemplary quotes for key observations regarding the ETI's autonomy from short term political pressure

3.5.5. Autonomy from the private sector

Senior ETI staff members unanimously described the process of allocating money to different projects as uninfluenced by individual private sector members. This was coordinated by the Portfolio Advisory Group, where board members would vote on focus areas, with the Strategy Director having final say if disagreement arose. It was commented no one private member was able to or interested in the *"gaming of the system"*' (3), enabling the board to work collaboratively toward the best whole system outcome. In the first years of operation, it was agreed that a focus on offshore wind and marine energy were key areas of focus for initial investment.

Private members however did have the ability to present a project to the board at their own volition if it cost under a certain amount of money and fit the ETI's overarching strategy. These projects were unlikely to be blocked, demonstrating that there was some scope for certain member interests to be explored over other technologies.

A more important effect of private member influence was over the ETI's broader technology trajectory. Interviewees discussed that it became apparent that whilst private members had committed to funding earlier stage projects in principle, worries over financial return exceeded willingness to accept uncertainty. This was especially apparent after the 2008 financial crash, which caused firms to focus less on long term strategy and more on short term survival. This impacted the ETI's ability to pursue riskier demonstration scale projects, with those focused on evaluation or component testing preferred.

The presence of multiple large firms additionally impacted the engagement of smaller firms in project consortia, with all ETI staff members discussing that the presence of incumbents on the board led the organisation to be viewed with suspicion. Several interviewees described that smaller firms feared the loss of their IP, making them reluctant to participate. A senior staff member stated that assuring smaller firms that their IP would not be exploited once exposed was quite a difficult process and whilst no projects fell through because of this, they took longer to initiate.

Interviewees outside of the ETI were more explicit in expressing their opinion on the influence of private members, expressing that public sector money had been captured by private interests and not delivered the initial mission of the organisation. One government interviewee described the ETI as the private sector taking ownership of public money and another as *“essentially a state aid avoidance club for some large companies”* (22).

Engaging on public sector terms	*“We took the assessment a bit seriously. We mapped out priorities against each other. Generally, there were some clear winners in it where both public and private said,* "This is something that's important that we do."*… In that respect, I suppose they wanted to each get something out of it that was important to them, but they were not gaming the system. They were trying to get the best outcome for the whole system, really. They did work collaboratively.”* (3) *“I can't remember what we called it, but you could put in a project at your own volition. As long as it was less than a certain amount of money and it fitted with the strategy of the ETI, it was a bit hard for them to block it. That was one of the ones where we threatened to do that. Actually, we didn't need to because they said that's something that's incredibly powerful.”* (7)
State retains control of technological trajectory	*“Well in the early days in my opinion we were overly focused on trying to do large scale commercial technology projects, of course when we came to the board with this they didn't want to do it because it was a lot of money and risky, and the energy industry doesn't like risk. And even though we worked quite hard to persuade them that they were there to take risks and each only had a small share of it, they weren't risky and the engineering of something was horrendous.”* (2) *“But here’s what actually happened- a public private partnership with 6-7 private companies and one government representative representing half the funding- and so the private companies were delighted they’d picked the side they had... I’d say they didn’t feel safe delivering what the intention was.”* (11) *“Impact of the crash on the large partners… they suddenly needed to keep their own companies surviving, activities with the ETI reduced—changed to survival from strategy.” (10)*
Loss of autonomy from private sector	*“Yes, I think that the private sector took ownership of the public money, so they were putting 50/50 in, but the government didn’t foresee they should have equal representation of public and private board members”* (11) *“But the problem with ETI was that it was essentially a state aid avoidance club for some large companies”* (22)
SME mistrust	*“… so because you’ve got people like Rolls Royce and EDF as shareholders, particularly to the SME community these are not people*

	to be trusted- so there's basically a trust problem, and then some of the way they operate is very big corporate and that exacerbates the trust problem... And so some quite prominent people said I'm just not engaging with this at all- they said I don't want to play with these players…" (12) *"The issue with the PPP model discussed the most that impacted its functioning and outputs was that around the intellectual property (IP) produced by smaller companies and their feeling of being out of control of this, which made these companies more reluctant to participate. This perception endured, and it was very difficult to dispel even over the ten years of the ETI."* (4) *"They* (private sector partners) *shifted their thinking over time* (about IP ownership), *but I think what did impede delivery was the time that it therefore took to sign contracts and negotiate contracts, and it scared off, I would say, a number of SMEs who found ETI difficult to work with that were just scared of big industry coming in and stealing their ideas. It probably would have been whatever the IP construct was."* (3)

Table 10- Exemplary quotes for key observations regarding the ETI's autonomy from the private sector

3.5.6. Competence

The ETI employed 131 staff members over its lifetime, averaging 60 at any one time (ETI, 2017). The organisation possessed a high level of engineering competencies, with interviewees highlighting that most of the board and executive staff possessed engineering backgrounds developed in the private sector. One private member commented that these skills in combination with those of the policy makers and academics on the board led to a very high level, dynamic mix of skills that would not easily succumb to technology hype.

It was also however commented that this high weighting of engineering competencies led to a very technical approach to project delivery and organisational culture. The Energy Systems Modelling Environment (ESME) for example was a key competence developed by the ETI, which facilitated identification of where investment would be most impactful across power, heat and transport networks (Heaton, 2014; ETI, 2018b). Interviewees discussed that ESME became key in uniting members around different project areas and technology trajectories, reducing the importance of marine energy, highlighting the benefits of focusing on smart systems and heat and identifying nuclear energy as an area of technology focus. Two interviewees commented that this fostered less of a collaborative environment on discussing technologies in relation to broader societal impacts and facilitated more siloed working by individual teams.

Building public sector knowledge	*"…it's opened our eyes to a number of areas that we probably would have been a bit blindsided by. Things like the importance of hydrogen and importance of understanding biomass and indirect land use."* (6) *"You can't underestimate the potential impact of all of the expertise that the ETI amassed. As the ETI winds up, and all of those people are released back into the low-carbon sector… There will be an impact from all of that collective expertise being some kind of Constantinople Effect where they go out into the world and take ideas and things that they've learned in the ETI, and then take it to start-ups, or government, or consultancies, or back into real companies and utilities. It will have a big impact."* (7)
Positioning technologies in the wider innovation system	*"… in order to focus on what we thought were the most important levers in decarbonisation, we developed quite a strong in house analytic capability, driven by modelling to produce our own energy system modelling, so that gives us clues as to 'that is more important than that', which then informs our project identification, and we go out and commission those projects, and then the data we get from these projects then goes back into the modelling tool to readjust where we go." (1)* *"Originally, nuclear energy was going to be off limits because the view was that nuclear energy was relatively mature. It was quite late in the life of the ETI when the potential impact of nuclear energy was made most apparent by things by things like ESME. The beauty of ESME is you can take a technology out of the portfolio. You can switch it off, and then you can look to see what that did to the overall system price. ESME was able to demonstrate that if you don't have a particular technology at your disposal, whether it's CCS or biomass or whatever, then that is going to mean that meeting the 20 different targets is much, much more expensive than would otherwise would be."* (7) *"The thing that came as a surprise was the analytical bit."* (2)

Table 11- Exemplary quotes for key observations regarding the ETI's competencies

3.5.7. Flexibility

ETI staff members discussed that the organisation primarily engaged with policy makers via the science and innovation teams and Chief Scientific Advisor at BEIS, who sat on the ETI board. It is through these channels that Ministers were brought ideas with which to engage. This enabled outputs to be communicated directly to public sector decision makers, whilst retaining the public sector links required to rapidly respond to windows of opportunity.

A senior ETI staff member discussed that there was flexibility at board level to assess and cancel projects during the annual Portfolio Advisory Group meeting. Upcoming and existing projects were scored by board members on the extent to which they aligned with the aims and interests of the ETI. This process enabled projects to be prioritised or dropped depending on budget or other investors entering the space.

Whilst the Portfolio Advisory Group met annually to assess overarching progress, projects were designed in such a way to incorporate ongoing assessment, each with a strategy advisory group that would meet every 2-3 months to manage various project stage gates. These were treated as milestones to assess as to whether a project was on track or needed to be cut or better managed. The advisory groups were the custodians of all data and information form members and so had high visibility and were well informed in making decisions. This prevented failures from being hidden and for the ETI to intervene to improve where necessary.

Whilst one staff member discussed that the ETI viewed failure not only as tolerable but as an expected element of an innovation organisation, another reflected that very few projects were needed to be stopped due to the lower risk profile of technologies pursued.

Ability to respond to windows of opportunity	*"The good* (thing) *about the ETI delivery model is the real ability to identify an industrial problem and go for it, and try and solve it, and if you look at a typical government funding body that strategic element just isn't there."* (12) *"If I was setting out to do something but someone else comes in and does it, that's fantastic. That's great news, we just stop and will spend our money somewhere else... Part of our benefit is that we are very able to measure as we go out with our analysis and commission projects, sometimes that stirs up interest in a particular area, and someone else will often do it."* (1)
Ability to cancel projects	*"…we're turning one project off at the moment. If it's not working out the way we want it to go then it will stop."* (1)

Table 12- Exemplary quotes for key observations regarding the ETI's flexibility

3.5.8. Credibility

As discussed in 5.6, the use of ESME provided coherence at board level on the most beneficial technology investments for the UK energy system and the Portfolio Advisory Groups enabled ongoing board level engagement on project areas. Once technology areas had been identified, potential projects were assessed against five clear investment criteria summarised in Table 13. This process generally revealed clear winners from both public and private perspectives, with a senior staff member commenting that the success of the organisation should also be judged against what it didn't pursue in navigating policy and responding to changing windows of opportunity. This assisted in the ETI perceiving itself to build a reputation for quality, objectivity and a strong brand to be associated with that's voice became increasingly trusted overtime (ETI, 2017).

This sits in contrast however with the issues discussed in section 3.5.5 in relation to consortia firms and concerns over IP. Credibility amongst these specific firms affected the way in which they engaged, with ETI staff members commenting that projects took longer to initiate and start as concerns were placated.

No.	**Criteria**
1	Assess the value of the innovation from the UK's energy system perspective, using ESME
2	Understand any major misalignments with policy
3	Ensure that there is additionality in the ETI's involvement
4	Member interests *"Each of the private sector members held 10% of the vote, and the government held 50% of the vote, because it was in line with their funding. What you ended up with was a merged view of the collective prioritization of the members."*
5	Durability and risk Can it be delivered in the timeframe required and are the risks manageable?

Table 13- Summary of ETI project investment criteria, paraphrased from interview 3

3.5.9. Stability

The stability of the ETI was a positive feature highlighted by all ETI interviewees. Contracted to run for a ten-year period, if a member wished to pull out then two years notice was required, after which they would be precluded from any project outputs. A senior staff member emphasised it was therefore both costly and embarrassing to withdraw with other members looking on. This stability proved durable through the financial crisis of 2008 and the 2010 Conservative Government's 'bonfire of the quangos'[13] (Porter, 2010), at which point the ETI was considered for termination.

The ETI's ten-year timeframe however was not considered long enough to reach its full potential, with an independent Mid Term Review undertaken 2015 recommending its remit therefore be extended (ETI, 2013). Staff members discussed that it took the ETI until mid-2008 to reach full operational capacity, limiting maximum project length to 7 years. Funding however remained stable throughout this period, with unused budget available to roll over into the next year.

The decision as to why another round of the ETI was not funded is unclear even to senior staff members. Government interviewees expressed that private sector partners were not willing to continue funding the organisation, however ETI staff members and private sector partners highlighted that there was a two-year delay in the government committing to a second round of funding. A senior staff member also mentioned the impact of government funding cycles that impacted the ability to explore re-funding options with the government. Quotes in relation to discontinuation of the ETI are included in Table 15 below.

Long term organisational focus	*"So then we had the crash and the government had the bonfire of the quangos and we were on their list and they were going to get rid of it… if the government shutdown* (the ETI) *then they would have to give the private sector the money anyway to do with which whatever they wanted… therefore, if it was a financial issue then the best thing to do was to carry on running it."* (2) *"…in the early ETI it was very difficult to get decisions made and projects sanctioned, but over time again the luxury of having 10 years as oppose to 2-3 we can figure out with the members what they value, they get comfortable with the model and the governance then adapts to what makes the org work, so right now we're in a much lighter governance and decision making, there's much more delegated to us here than there was in the beginning that allows us to move a bit more quickly, but we're still answerable to the members."* (1)
Sufficient, predictable funding	*"I think the nature of the portfolio has changed over the years, it's not been a deliberate policy, but you might end up with one you where are you are contracting 15 very large projects, and the next year your*

[13] 'Quango' is short for quasi-autonomous non-governmental organisation.

	contracting 30 very small projects, so there might be hundreds of thousands a year rather than millions. And that's just being the nature of the way the portfolio has evolved and the time it takes for projects to come forward. So yes, cash flow is never been an issue which is nice, it's not a typical business environment where I'm worried about have I got cash, what I'm worried about it's can I make sure that I can deliver maximum value under the umbrella window that I have at a budget level." (1)
Stability over too short a time period	*"The reality was it took around 18 months for the organisation to get into a position to start doing the projects, so it went from nothing to about 60 people in 12 months, so just getting a company up and running meant that things couldn't happen immediately." (5)* *"My watch word is always 'value for money for the members' and if it runs late it runs late, that's fine because I roll over into the next year. At some point you run out of years to roll into and then you have to worry about can I do everything I want to do. But in practice we never run out of money we've run out of time, so you can't start something you don't think you can finish."* (1)

Table 14- Exemplary quotes for key observations regarding the ETI's stability

Discontinuation	*"As time has gone on, most companies have evolved their strategies and they know what they want to invest in. They don't necessarily want to put their money into things that are not of interest to them. I think a more flexible model would have been needed, but with more membership and a lighter core membership, but then with the option to invest in demonstration money on things that were of interest to you."* (3) *Other big driver with the ETI, why it couldn't exist now as it did 10 years ago, is that now there's more specific targeting by these larger companies. 10 years ago clean energy was still this new and unknown territory to them, so ETI was great for likes of Shell and BP for a relatively small amount of money get their toe in quite a wide variety of different things and share the burden of things with their competition, but overtime they've evolved their company strategies and they know what it is that they want to focus on, and what they do and don't want to do and therefore have been able to be much more targeted..."* (20) *So the ETI model I think illustrates that it was of its time, in that major industrial actors were prepared to put money into what was effectively a membership model and play into a basket of stuff and see what came out of it… and one of the reasons they didn't all feel able to commit to*

	phase 2 is that we now know what we want to do in place of this other stuff and our R&D budgets are being slashed so…" (12) *"Personally, I felt here was value in extending the life of the ETI. I'm not sure whether I would have got organisational-level support for that."* (7)

Table 15- Quotes in relation to the discontinuation of the ETI

3.5.10. Accountability

ETI staff members reflected that the high project completion rate was viewed as the core mechanism of the organisation's 'success' as opposed to how outputs were communicated or how that technology moved to the next stage of innovation. This was hampered by the PPP structure, which created a focus on protecting IP and outputs for members as opposed to engaging the broader innovation system (ETI, 2018a). Whilst the organisations innovation outputs were considered in accordance with the ETI's mission to accelerate innovation by all interviewees, the closed nature and lack of large-scale technology outputs leave these achievements open to interpretation from different viewpoints and narratives.

Senior staff members discussed that the ETI was initially slow to communicate outputs, as it was felt that the long-term nature of projects rendered short term communication less important. Three staff members however suggested that this was also due to the high weighting of staff with engineering backgrounds, which impeded knowledge sharing both within and beyond the organisation. In the later stages of the ETI this issue was recognised and efforts made to rectify this. The online Reference Library now contains 396 documents[14], with publication rate increasing rapidly from 2015 onwards. Additionally, the ETI 10 event held in November 2017 showcased the outputs to the broader innovation community[15].

The combination of a lack of clear success metrics to communicate and the issues associated with this contributed to several interviewees highlighting that there appeared to be a mismatch between the ETI's mission and what it ultimately achieved. A government interviewee stated that the initial aim of the ETI was to bring key technologies to demonstration over its ten-year lifetime. As this vision shifted however, the expectations of

[14] ETI, Reference Library. Available at: https://www.eti.co.uk/library Accessed: 13.05.19
[15] ETI 10 Years of Innovation Conference and Exhibition. Available at: https://www.eti.co.uk/library/10-years-of-innovation-conference-and-exhibition-jonathan-wills Accessed: 14.06.19

public stakeholders were not managed effectively, leading the lack of technology demonstration and commercial products produced to be viewed as a failure. This is despite the ETI's outputs adding significant value to aspects of its mission that were not expected, such as the development of ESME and multiple other testing and modelling projects (ETI, 2018a).

Transparency of outputs	*"We've probably 80 or 90% success rate to getting project to the end. Now if you consider the higher level of technical risk we take that's incredible. But that's because we took a lot of time setting them up and we're quite interventionist when we need to be"* (1) *"These guys were all worried about their own profit loss and their own careers and so on, but I think that particularly for the analytics side and an understanding of how the market in the different technologies interact at a systems-level. I think all of the members without exception have got a lot of value out of that."* (1)
Informing policy	*"Part of the success of the ETI is that we've been at the vanguard of the change in dialogue on low carbon transition. People talk about low carbon transition now, whereas when we started it was very much tidal turbines- we've got lots of offshore wind and wave resource that now the dialogue is about the whole energy system."* (1)
Organisation's view of success	*"The problem is it's hard to know what success looks like, we certainly didn't fail in the sense of not getting any traction or wasting all the money. Innovation is a messy thing if you look at the outcome" (2).* *"… no matter how people judge the ETI I know what we did, and I will be able to judge in my own mind where it's had an impact. I shall be a stern critic of this."* (2) *"I think with a mission like 'accelerate', whilst I think everybody thought that the decarbonisation journey in the UK and the world would go quicker than it has over the last ten years, is it accelerated against where it would have been? Have we got a clearer view of what technologies we need to invest in the UK? Absolutely, very definitely. Could you draw our trajectory and go,* "This would have happened, and this is where we are today" *- probably not, but we do know that we've got a much deeper understanding, and we have advanced technologies in key areas as a result, or partially as a result, of the ETI funding."* (3)
Long term outputs continuing with other organisations	*"I think the ETI's done some amazing things. If anyone ever writes a book about it in the future, I'd like to think that they'd get to the bottom of all of the studies and the deployments and the skills and the insights that were being developed, and so on, and that that will have knock-on effects for several decades to come."* (7)

	"In many ways, I said the ETI is not going to finish, its component parts are going to homes to kick them up the stages of the TRL." (6)

Table 16- Exemplary quotes for key observations regarding the ETI's accountability

3.6. Discussion

This section explores the way in which features of the ten organisational design principles have interacted to inform the ETI's role in accelerating energy transition.

The ETI's design was greatly impacted by the broader policy environment explored in principle one. A combination of urgency around climate change targets and low public sector knowledge of clean energy innovation made investing alongside and sharing risk with large energy firms an attractive policy option. Equally, as demonstrated in principle two, there was a large enough number of incumbent firms seeking to align themselves with legally binding climate targets that were willing to position themselves as leaders in developing the UK's clean energy future. The familiarity of the PPP approach in the development of cross-sector projects of public interest led to this approach being utilised, embedding six incumbent firms into the funding and strategic approach of the ETI.

Harnessing the engagement and influence of large energy companies in the ETI was therefore viewed as a key selling point, with results indicating that trust was built between cross sector partners. This approach however proved detrimental to the mission of the ETI, identified in principle three as interested in accelerating the deployment of transformative, pre-commercial technologies required by 2030. Principle five identifies that this more revolutionary aim was poorly matched with the characteristics of member firms, which viewed the investment risk related with this endeavour too high and so shifted technology direction towards more incremental innovation in relation to more established technologies. Indeed, the outputs explored in section 3.4.3 reflect that these largely constitute software or component technologies for offshore wind, as opposed to the demonstration of large, more nascent technologies like CCS.

The 2008 financial crisis further reduced the risk appetite of private members, as well as reducing the ETI's autonomy from the public sector in principle four, as the organisation faced pressure to utilise its resources to support UK businesses and technologies closer to market.

These elements of private and public capture therefore impacted the ambition of the ETI, as short-term financial survival overtook longer term strategy aims.

The ETI's stability, explored in principle nine, was an important feature that facilitated steady funding over ten years despite a changing policy environment. This stability however was built on a bureaucratic PPP structure, which negatively impacted the way in which IP was perceived to be managed and credibility in principle eight amongst consortia firms, who feared their IP would not be protected. This further led to a seeming lack of autonomy from private partners in principle five.

The competencies of the ETI, developed in principle six, additionally served to have an internal impact on the organisation's ability to address its mission. Many staff members possessed engineering backgrounds, which led to the ETI to developing a technical organisational approach to energy innovation that was driven by modelling. A lack of skillsets around communication of outputs with stakeholders negatively affected the ETI's accountability in principle ten. This led to perceptions of the ETI as a *"closed shop"* (16) further fuelling perceptions of private member capture of interests.

The interplay of the different principles therefore demonstrates that whilst the ETI aimed to play a revolutionary role in accelerating sustainable energy transition in the UK, its design impeded its ability to achieve this. The organisation's utilisation of the PPP model was reflective of the political and economic relationships contained within the broader system at the time of its formation. This led to a design that embedded six incumbent energy firms that were poorly matched to the ETI's mission, failing to sufficiently challenge the market-led policy environment into which it was placed.

This contributed to the production of primarily incremental innovation, reflective of findings in both the PPP and innovation organisation literature (Breztitz et al., 2018; Roumboutsos & Saussier, 2014). This led the ETI to pursue a 'fit-and-conform' approach to innovation, by favouring technologies that would be competitive within the existing system, as opposed to the 'stretch-and-transform' aspirations of the initial mission (Raven et al., 2016). This reflects the importance of understanding the broader political conditions that shape the system and resulting organisational path dependencies that this produces (Anadon, 2012; Karo & Kattel, 2016).

The internal competencies of the ETI also affected its approach to the way in which innovation was conducted and communicated. Important aspects of operational approach discussed in Section 2.4, especially in relation to dedicating resources to accountability (Taanman, 2012) and flexibility in developing new approaches (Anadon et al., 2011), were not addressed in the ETI's design. The disproportionate number of engineering competencies led to a very technical approach to technology development and further contributed to the organisation's perception as a closed shop.

This impeded the ETI's ability to accelerate transformative energy transition, demonstrating that these aspects of on the ground implementation of innovation policy within publicly funded organisations is of interest to the literature, if innovative technology development is to be sufficiently shielded.

The design of the ETI was reflective of a less mature, well-established energy innovation system, within which it sought to embed the resources of incumbent firms as a means to accelerate innovation. This design created the conditions for private capture to occur, which in turn affected policy maker perceptions of the ETI and its use of public money. This contributed to its discontinuation in 2015, as the policy environment had evolved in relation to building skills and knowledge on effective energy innovation policy making. These changes reflect how the actions of an organisation can upwardly effect institutional change, as explored in Section 1.4.4.1. Different aspects of institutional layers 2, 3 and 4 co-evolved over the lifetime ETI (explored in-depth in Section 2.5.4), reflecting that its design was a result of a particular political moment in time and lessons from its design mean that it would not be repeated as a means to accelerate transformative innovation.

Despite the lessons learnt form the design of the ETI and ongoing evolution of the innovation organisation landscape, there remains a 'valley of death' in relation to creating commercial pull through for transformative technologies. This could reflect that values embedded in layer 1 in relation to supporting demonstration stage, pre-commercial technologies like wave and CCS mean that transformative technologies continue to find it difficult to bridge this gap. UK progress on delivering net zero continues to be driven by centralised renewables technologies like offshore wind, presided over by large utilities and energy suppliers. The ongoing lack of institutional support for more transformative innovation reflects that even if the ETI had been designed differently, as a lone organisation it would struggle to overcome this more systemic barrier to accelerating transformative change.

Additional learnings from the ETI case demonstrate that embedding the correct competencies is key in creating a company culture and appropriate levels of flexibility to deliver the innovation outcomes desired. This is an aspect of organisation design that is able to exert the upward institutional change described in Section 1.1.1.4, as it enables actors within the organisation to action new changes and approaches. Regardless of the top down, external pressures effecting the ETI's design, this could have had a less severe impact if a CEO had been recruited from an entrepreneurial background as opposed to an incumbent member organisation. If the ETI had developed greater communication competencies for example, this could make lessons from its operations more immediately accessible to actors operating in other institutional layers and its contribution to accelerating energy innovation much clearer.

3.6.1. Further refining the principles

Whilst detailed empirical application of the ten principles has demonstrated their usefulness in revealing the insights above, it has also highlighted opportunities for their further refinement. These primarily relate to exploring the internal dynamics of an innovation organisation, two examples of which are explored below[16]. This demonstrates that further integration of literature on organisation design could improve understanding of the role of organisations in accelerating sustainable transition.

Competence

Haley's understanding of competence primarily addresses the knowledge that an organisation builds and shares with its stakeholders, as opposed to whether the ETI possessed the right suite of skills to best achieve its mission. This limited analysis of the way in which these internal competencies effected the ETI's operation.

Two interviewees for example, mentioned that the personality of the founding Chief Executive Officer obstructed the ability of the ETI to reflect on its leadership approach, which may have impacted the extent to which the organisation could operate in a flexible manner. Interviewees also discussed the impact of a heavy weighting of staff members with engineering backgrounds affected company culture and the accountability of how knowledge was managed and shared within the organisation. For example, work by Ragsdell et al. (2013)

[16] Exemplary quotes are available in Annex E

utilises literature on knowledge management to reveal that whilst the ETI was good at generating knowledge it was less able to *"decide what to do with it"* (p.8). Additionally, Ahmed (2017) concludes that whilst it was initially felt that the PPP structure of the ETI would not impact knowledge management, empirical findings demonstrated that this had a significant impact. The assimilation of a broader range of competencies from multiple disciplines would therefore have benefitted the framing of the ETI's mission and, work toward and communication of its outputs. This was a key issue identified in the ETI 2018 review (ETI, 2018b).

Flexibility

Flexibility is understood within the existing principles as the ability to engage policy makers and feed information into the wider innovation system, as opposed to the ability to change ways of working or organisational culture.

A consortia member for example reflected on the ETI's lack of flexibility in working with different types of firm, all of which were held to strict, pre-prescribed project criteria. Two senior staff members acknowledged that a high burden was placed on SMEs, who would have benefitted from a more flexible way of working. A private member mentioned that an increased amount of venture capital funding could have created greater project flexibility for example, which constituted just two of the ETI's investments.

There was a lack of internal flexibility to respond to issues relating to this and those around competence identified above prevented a more entrepreneurial, fast moving approach to innovation discussed as important by Anadon et al., (2011), as culture became mismatched with the organisations mission (ETI, 2018a).

3.7. Conclusions

If clean energy innovation is to be accelerated at the pace required, new approaches to designing public innovation organisations need to be developed. Despite the importance of these organisations in accelerating sustainable transition, their role has not yet been explored in the literature. This paper addresses this gap by refining ten principles for innovation organisation design within the sustainable transitions and innovation organisation literature, applying them to a case study of the ETI, UK.

Results demonstrate that whilst the ETI intended to accelerate energy transition, its design as a PPP that embedded six incumbent energy firms was informed by prevailing system dynamics, leading to incremental innovation outputs. This impeded the pursuit of its mission, which aimed to develop the revolutionary technologies needed to accelerate transition beyond 2030. Application of the principles also highlights that a lack of a diverse staff competencies and communication of accountable outputs also affected the ETI's operation; as these factors contributed to the development of a highly technical, less collaborative approach to innovation, and the organisation's role in accelerating energy transition to be unclear.
These results indicate that certain aspects of the design of publicly funded innovation organisations may be important in accelerating sustainable transition. These include the value of:

- Attracting a diverse range of staff competencies
- Involving a diverse range of firms able to support the innovation outputs desired
- Developing clear, accountable metrics on successful progress towards a mission
- Effectively communicating innovation outputs and engendering the support of broader system actors

Future research should seek to explore the utility of these insights through further empirical application of the principles. The results indicate that this would be best achieved by further refining the principles with insights from literature on organisation operation, in order to better understand these internal design aspects on the acceleration of innovative outputs.

4. Paper 3: Publicly funded organisations for accelerated low carbon innovation: A comparative case study of the ETI, UK and ARPA-E, US

4.1. Introduction

If the aims of the Paris Agreement are to be met, a range of nascent clean energy technologies need to be commercially deployed by 2050 (IPCC, 2018; IEA, 2020a). Studies indicate that energy technology innovation normally takes place over many decades (Kazaglis et al., 2019; Gross et al., 2018), requiring increased policy engagement to accelerate innovation at the speed and scale required (Kattel & Mazzucato, 2018; Sanden & Azar, 2005; IEA, 2020a). The role of innovation organisations in implementing innovation policy is receiving increasing attention (Bonvillian, 2018; Karo & Kattel, 2016; Azoulay et al., 2019; Breznitz et al., 2018; Kattel & Mazzucato, 2018). Organisations have the ability to act as agents of change within their broader institutional environment (Scott, 2008), which is especially important in legacy sectors like energy in overcoming the 'valley of death' (Grubb, 2004) and challenging existing technology regimes (Bonvillian, 2018).

Due to different national contexts and priorities in which organisations are developed, a 'one size fits all' approach is not possible (Glennie & Bound, 2016). Policy makers therefore face high levels of complexity in understanding what will work in their given context (Brezntiz et al., 2018; Anadon, 2012). There is however currently little research addressing how publicly funded organisations could be designed to achieve accelerated innovation. Addressing this gap in knowledge, this paper undertakes a comparative case study of the Energy Technologies Institute (ETI) in the UK and the Advanced Research Projects Agency– Energy (ARPA-E) in the US. This is with the aim of addressing the research question: how did the design of the ETI and ARPA-E affect their ability to accelerate innovation?

The paper is organised as follows. Section 2 introduces the analytical framework and section 3 the case study context. Section 4 outlines the methodology and section 5 presents the results. Section 6 discusses key similarities and differences revealed and impacts of this on the innovation pursued. Section 7 provides the conclusions and policy implications of this work.

4.2. Analytical framework

This paper utilises an analytical framework of ten principles for accelerated innovation organisation design. Originally developed by Haley (2016; 2017), the author presents a refined version in Figure 21. The framework does not seek to prescribe a specific funding model or type of innovation approach. Rather, it provides policy makers with a tool to understand how an organisation sits within its specific national institutional context and how different design features should be considered and balanced to accelerate the desired outputs. The principles are ordered and grouped into four categories discussed in turn below.

4.2.1. National institutional context

The first three principles address the influence of the broader policy environment, industry relationships and innovation system characteristics in which an organisation is formed and positioned.

1. Policy environment

Innovation organisations emerge as vehicles to deliver the aims of different policy approaches. As policies change and are potentially contradictory over time (Kern et al., 2014), a policy environment containing multiple instruments that address accelerated innovation can make gaps in policy effectiveness less likely to emerge (Edmondson et al., 2019; Kivimaa & Kern, 2016). If an organisation is part of a strong policy environment it is therefore more likely to avoid disruption and receive ongoing support. The strength of the policy environment can in turn be affected by the broader political institutions in which it sits, including departmental structures and the changing ideologies of different governments (Lockwood et al., 2017; Kuzemko et al., 2016). An organisation's design should therefore be considered within the changing priorities and approaches of different policy makers and seek to build cross-party support.

2. Industry embeddedness

It is essential that innovation organisations can engage the right firms at the right time for public money to be spent effectively (Savoie, 2015; Breznitz et al., 2018). Anadon (2012) demonstrates that existing government-industry relationships can impact how these

Category	No.	Organisational principle	Description
National institutional context	1	**Policy environment**	• Takes an innovation approach supported by multiple policy instruments • Aims to build cross party narrative around its activities
	2	**Industry embeddedness**	• Engages relevant private sector actors in an equitable way • Builds cross-sector trust and understanding on direction of technology development
	3	**Innovation system characteristics**	• Forms part of a coherent innovation system that contains complementary institutions and organisations • Interacts to facilitate resource and knowledge flow between stages of technology development
Vision and outcomes	4	**Mission**	• Defines a clear organisational aim • Attracts talented employees through the autonomy of a strong mission • Focuses on performance as opposed to bureaucracy and procedure
	5	**Stability**	• Takes a long-term innovation focus • Retains sufficient and predictable funding for long term project development
	6	**Accountability**	• Is transparent on what has been achieved • Adopts non-ambiguous success metrics • Dedicates capacity to communicating outputs to the appropriate audiences
Public and private relationships	7	**Autonomy from political pressure**	• Decouples organisation from the agenda of individual policy makers • Protects policy makers from failure • Retains access to broader public resources
	8	**Autonomy from private sector capture**	• Engages with firms on public sector terms • Ensures that policy makers retain the ability to decide technology trajectory • Protects intellectual property from private capture
Operational approach	9	**Competence**	• Engages high-quality leadership with the skills to develop an appropriate vision • Empowers staff to act autonomously to develop projects • Develops strong and appropriate knowledge and skill sets • Understands how technologies will sit within the wider innovation system and the cross-sector linkages created
	10	**Flexibility**	• Creates a nimble, entrepreneurial organisational culture • Encourages evaluation and change of internal processes • Ability to pivot away from failure, or to fail quickly • Responds to changes in innovation system dynamics and technological windows of opportunity

Figure 21- Ten principles for accelerated innovation organisation design

interactions take place, meaning that organisation design should consider how to navigate existing private sector relationships in meeting its aims. Trust between public and private sector stakeholders should be enhanced by the approach to collaboration taken, requiring an organisation design that can facilitate equitable relationships (Doblinger et al., 2019).

3. *Innovation system characteristics*

Technology development alone is not enough to accelerate innovation (Roberts & Geels, 2019; Markard et al., 2020). Successful innovation organisations enable knowledge exchange between actors, facilitating linkages between basic and applied research and the technology transfer required to accelerate deployment (Anadon et al., 2011; Chan et al., 2017). An organisation should therefore be designed to operate coherently with other innovation system actors if innovation is to be accelerated effectively.

4.2.2. Vision and outcomes

Principles four, five and six address overarching organisational features in relation to developing a clear aim, the stability required to deliver this and how accountability to this aim will be measured and communicated over time.

4. Mission

The presence of multiple different innovation organisations pursuing specific innovation aims has proven more effective than one taking a 'catch all' approach (Glennie & Bound, 2016; Karo & Kattel, 2016). A strong aim or mission assists in positioning an organisation beyond typical bureaucratic models, signalling to talented individuals a focus on agency and performance (Narayanamurti et al., 2009). In the context of this paper, mission refers to a specific aim in relation to accelerating innovation, however both the ETI and ARPA-E can be viewed as mission-oriented in their efforts to address the broader societal issue of climate change (see Mazzucato, 2018).

5. Stability

The availability of stable, predictable funding is important in enabling energy innovation organisations to achieve their aims (Chan et al., 2017; Anadon et al., 2011). Boom-bust funding can decrease organisational competencies, as skills and project infrastructure cannot be reliably built at the pace required over longer periods (Haley, 2017). Organisations should therefore be designed in a way that secures stable funding.

6. Accountability

To continue to receive public support, an organisation needs to remain accountable to specific objectives (Rodrik, 2014). Glennie & Bound (2016) identify that metrics of accountability can be difficult to identify, as these shift over the long-time frames required to innovate new technologies. Capacity dedicated to tracking and communicating outputs to policy makers however can strengthen an organisation's political position, having positive effects on stability (Haley, 2017). Organisations should therefore seek to develop metrics that demonstrate accountability to their mission, even in the early stages of their operation, and effectively communicate these to stakeholders.

4.2.3. Public and private relationships

Principles seven and eight address the way in which an organisation engages with public and private actors as not to become overly influenced or captured by their interests.

7. Autonomy from political pressure

An accelerated innovation organisation should seek to avoid political prestige, which can affect its ability to pursue projects aligned with its mission (Rodrik, 2014). Breznitz & Ornston (2013) for example, demonstrate that radical innovation is more likely to take place in organisations peripheral to government, which do not implicate individual policy makers in project failures. The organisation however also needs to retain the ability to attract resources and communicate outputs with civil servants in order to maintain support (Haley, 2017), requiring a balanced approach to this aspect of design.

8. Autonomy from private sector capture

Firm engagement in an organisation may enable them to lobby the technology outputs produced (Haley, 2017). This is particularly important to consider in legacy sectors like energy, which contain strong actors like utilities and oil and gas majors (Gallagher et al., 2012). Developing and protecting the intellectual property (IP) of emerging firms is of key importance, which the public sector is recognised as in a key position to do (Doblinger et al., 2019). Perceived private capture over this process may therefore reduce the engagement of the firms essential to an organisation's mission. Organisation design should seek to facilitate equitable collaboration and operation between public and private sector stakeholders.

4.2.4. Operational approach

Finally, principles nine and ten are primarily concerned with the internal operation of an organisation. This includes the skills and culture it cultivates and how this shapes external interactions with public and private stakeholders.

9. Competence

Internally, competence encompasses the skills and working practices of staff required for the effective delivery of the organisation's mission. Leadership approach in particular contributes to the success of an organisation (Lok & Crawford, 2004), with clear, charismatic articulation of a vision for mission delivery key in engaging staff and broader stakeholders (Narayanamurti et al., 2009; Surucu & Yesilda, 2017; Ratana & Yan, 2008). Empowered staff members have been positively associated with increased innovative organisational capacity (Hoch, 2013; Pieterse et al., 2010; Cakar & Erturk, 2010), which also increases the likelihood of the internal collaboration required to accelerate innovative outputs (Chan et al., 2017; Velo et al., 2014). These competencies should extend externally to better equip public and private stakeholders with technology-specific knowledge and build cross sector linkages (Verbong et al., 2008; Haley, 2017). Organisation design should therefore seek to develop strong leadership and staff competencies in line with a clear vision for mission delivery.

10. Flexibility

Innovation organisations should remain responsive to shifting internal and external priorities over time. Anadon et al. (2011) for example, discuss that flexible leadership and entrepreneurial approaches to accepting risk are beneficial in accelerating innovation. The ability to examine and change internal processes should therefore be maintained over time (Chan et al., 2017). This internal flexibility enables an organisation to respond to external signals, like a time specific window to scale a particular technology niche (Geels, 2002) or in response to changing government priorities and support over time (Glennie & Bound, 2016). Organisation design should seek to encourage flexible, entrepreneurial working and the ability to respond to external change.

4.3. Methodology

This paper utilises a case study approach to gain in-depth insight into the social phenomenon of organisation design (Flyvbjerg, 2006). A comparative analysis of two cases provides contrastable datasets, yielding a more rigorous results and testing of the analytical framework introduced above (Yin, 2014). This section introduces the case study context, identifying why organisations in the UK and US were selected for comparison. It goes on to place the ETI and ARPA-E within their broader national contexts, concluding with a brief overview of each organisation.

4.3.1. Country selection

Organisations were selected from the UK and US, as countries that possess similar national historic energy system and innovation policy trajectories. These similarities mean that differences in innovation organisation design are less likely to be related to intrinsic differences in energy resources or political landscape, which would reduce the validity of theoretical observations (Miles & Huberman, 1994). By holding these elements constant, results are more easily comparable between case studies and generalisable to similar countries (Yin, 2014).

The UK and US have a history of plentiful domestic fossil fuel supply, which has shaped the development of centralised systems powered by coal, nuclear and natural gas (Pearson & Watson, 2012; Carley, 2011). Both countries are identified as liberal market economies, which favour technology policy that drives entrepreneurial activity and a diversity of different solutions (Hall & Soskice, 2001; Vasudeva, 2009). This causes aversion to the government 'picking technology winners', with innovation support traditionally provided at earlier phases of development. These market values have also led to the privatisation and liberalisation of energy systems beginning in the 1980s, with incumbent system actors becoming engaged in the process of energy policy making (Kuzemko, 2016; Stokes & Breetz, 2018). A combination of energy security and system privatisation led to a dip in public energy innovation spending throughout the 1980s and 90s, as depicted in Figures 22 and 23 below.

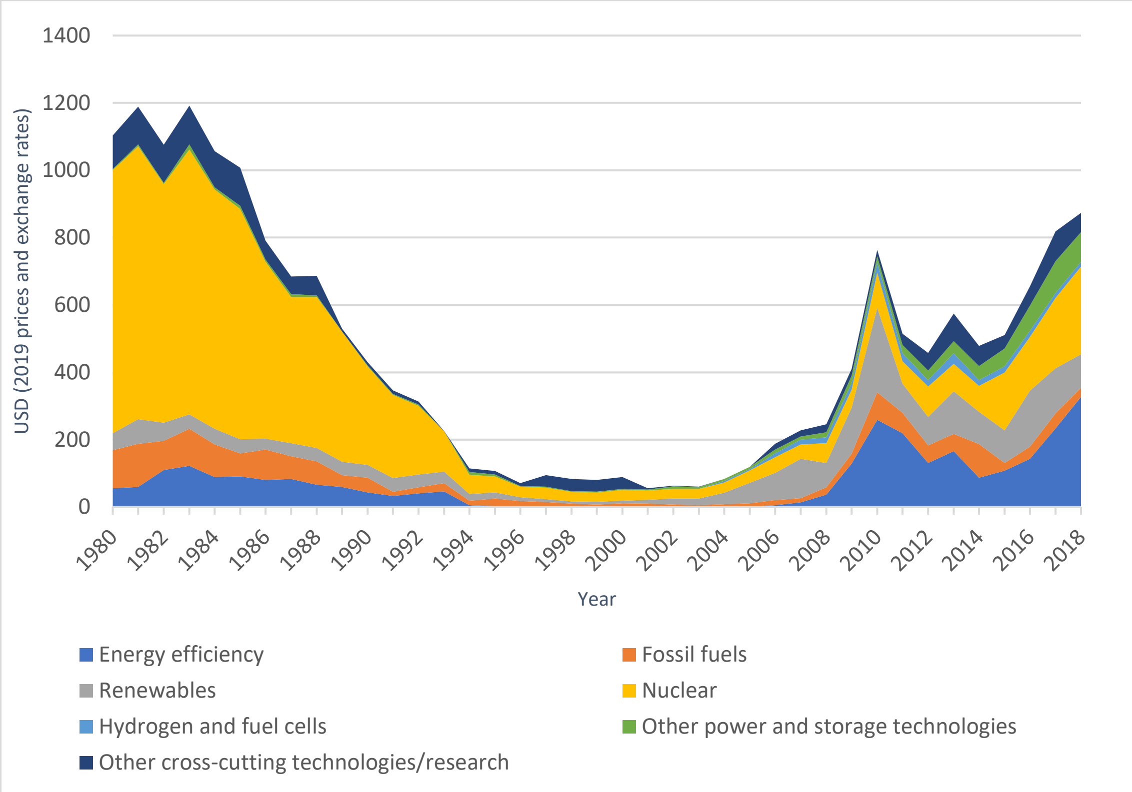


Figure 22- UK energy RD&D spend, 1980-2018 (IEA, 2019d)

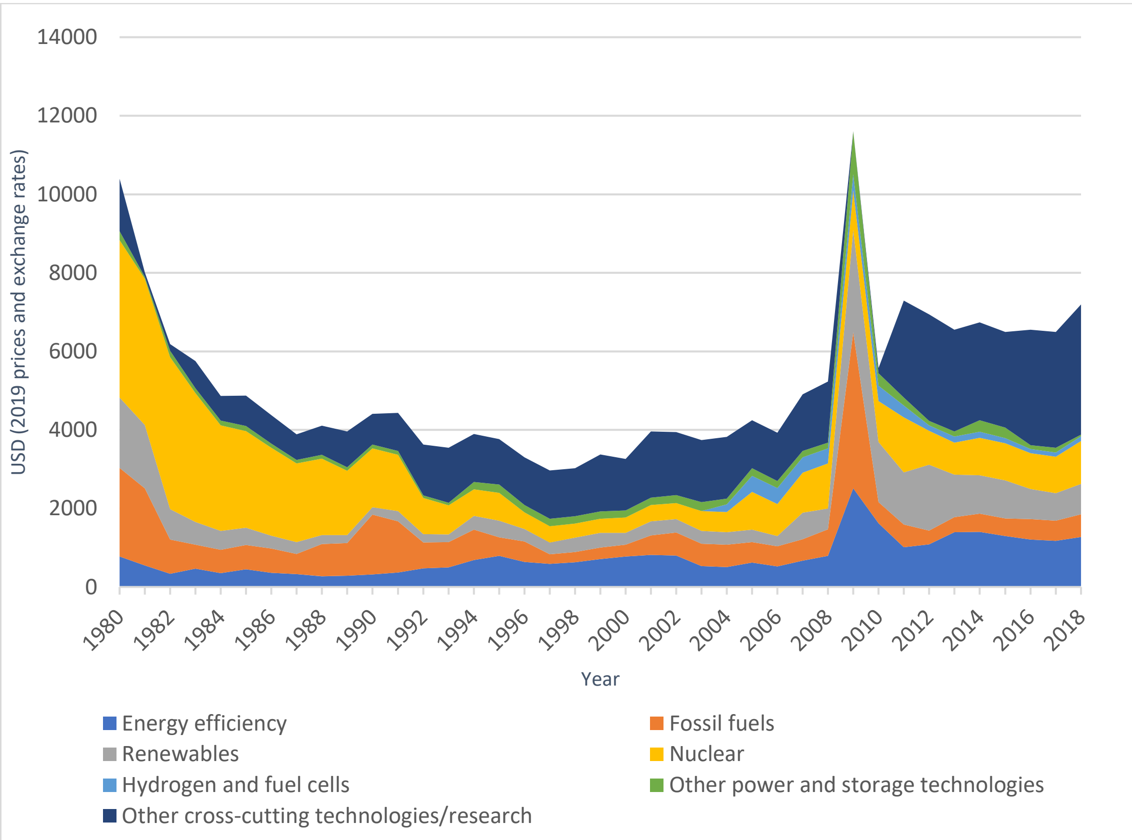


Figure 23- US energy RD&D spend, 1980- 2018 (IEA, 2019d)

Centralised policy making in the UK led to more pervasive system privatisation and liberalisation than in the US, where the Federal State system causes this to vary from State to State (EIA, 2019). This contributed to a greater dip in energy innovation funding in the UK, as national RD&D infrastructure was privatised and largely closed, whereas the US has maintained 17 national laboratories that conduct the basic energy science (Anadon et al., 2011).

As energy security and climate change concerns have increased since the early 2000s, both UK and US energy innovation funding levels have recovered in response. Both countries currently spend roughly the same percentage of GDP per capita on energy innovation, ranking in 12th and 10th respectively in global energy innovation investment rankings (IEA, 2020b).

4.3.2. Organisation selection

The ETI and ARPA-E were selected as the subject of this paper as both emerged from the resurgence in clean electricity innovation funding that took place in both countries from the early 2000s. Representing new approaches to accelerating clean electricity innovation (DTI, 2006; Anadon et al., 2011), both were formulated in 2007 and have operated for over ten years, creating direct points of comparison between their missions and timeframe of operation. A brief overview and a side-by-side comparison of these organisations is provided in Table 17 below.

Characteristic	ETI	ARPA-E
Idea developed	2006	2007
Founded	2007	2009
TRL focus	3-6, with a focus on 4-5	1-3
Innovation focus	Deploying established technologies that have the potential to transform the current energy system.	Developing new technologies and processes that have the potential to transform the current energy system.
Basic structure	50:50 public private partnership between UK government and six incumbent energy firms.	Entirely publicly funded.
Positioning to the government	Limited liability partnership; BEIS as a board member.	Separate department within the DOE; reports directly to the Secretary of Energy.
Funding received	£400m (2007- 2017)	$2.227b (2009- 2019)

Status	Ceased funding in 2017, fully closed in 2019.	Still in operation.

Table 17- Comparison of key features of the ETI and ARPA-E

ETI

The ETI took the form of a 50:50 public-private partnership (PPP) between six private energy firms and the UK government. The private members comprised British Petroleum (BP), Caterpillar, Electricité de France (EDF), E.ON, Rolls-Royce and Shell[17], who were represented on the board alongside the Department of Business, Energy and Industrial Strategy (BEIS)[18], Innovate UK[19] and the Engineering and Physical Sciences Research Council (EPSRC)[20]. The organisation was a limited liability partnership contracted to run for ten years, positioned at arm's length from the government (ETI, 2018a). The ETI aimed to accelerate the commercialisation of clean energy technologies, funding projects at technology readiness levels (TRLs) 3-6 with an emphasis on 4-5 across eleven technology programmes (ETI, 2018a). After a review in 2012 the decision to discontinue the ETI was announced in 2015, with operation ceasing completely in 2019.

ARPA-E

ARPA-E was authorized in the 2007 America COMPETES Act (2007) and funded by the Department of Energy (DOE) as part of the American Recovery and Reinvestment Act in 2009. The organisation is positioned as its own department at arm's length of the three main DOE offices, reporting directly to the Secretary of Energy (Azoulay et al., 2019). ARPA-E's structure and approach is modelled on the Defence Advanced Research Projects Agency (DARPA), a successful transformational innovation organisation credited as playing a critical role in the ICT revolution (Bonvillian, 2018). DARPA has been credited for contributing to the development of the internet and GPs, with its approach also adapted to intelligence (IARPA) and homeland security (HSARPA). A key difference between ARPA-E and DARPA is that its outputs need to be commercialised within a legacy sector, whereas at least 50% of DARPA projects are publicly procured (Watson & Watson, 2020). ARPA-E is focused primarily on technologies between TRLs 1-3, aiming to mitigate risk associated with the technology valley of death and driving transformational innovation to market (ARPA-E, 2010; Bonvillian & Atta, 2011). ARPA-E underwent an extensive independent review in 2017 and continues to operate (NASEM, 2017).

[17] E.ON were a member until 2014. Hitachi joined as an Associate Member of the Smart Systems and Heat technology programme in 2012. Available at: https://www.eti.co.uk/news/eti-signs-lease-on-new-birmingham-office-and-announces-director-smart-systems-heat Accessed: 10/05/19

[18] This is the current department responsible for energy innovation. 2007- 2008 it was Business, Innovation and Skills (BIS). 2008-2016 it was the Department of Energy and Climate Change (DECC)

[19] Between 2007- 2014 this was known as the Technology Strategy Board

[20] ETI Board Members. Available at: https://www.eti.co.uk/about/members Accessed: 04/03/19

4.3.3. Data collection and analysis

Primary data was collected from 35 semi-structured interviews, with participants detailed in Tables 18 and 19 below. The ETI required greater primary data collection than ARPA-E, on which there exists substantial academic and grey resources on its structure and operation. Utilising semi-structured interviews enabled the use of both planned questions and a more conversational and flexible approach to data collection (Rubin & Rubin, 2011; Kvale, 2008). This approach maximised the time spent with high-level interviewees, where time was limited and so the use of tailored questions framed within conversation enabled the most relevant information to be explored (Yin, 2014). Interview data was transcribed and coded using NVivo 11 software, enabling detailed comparison between design principles. Interview data is referred to in the text where relevant using the number indicated in Tables 18 and 19.

No.	Job function	Organisation
1	Senior staff member	ETI
2	Senior staff member	ETI
3	Senior staff member	ETI
4	Staff member	ETI
5	Staff member	ETI
6	Private member	ETI
7	Private member	ETI
8	Consortia member	ETI
9	Senior Lecturer	University
10	Staff member	ETI
11	Advisor	Government
12	Director	Government
13	Head	Government
14	Head	Government
15	Head	Research Council
16	Chair	Publicly funded research organisation
17	Managing Director	Firm
18	Director	Firm
19	Chief Executive Officer	Publicly funded innovation organisation
20	Head of Secretariat	Government
21	Executive Director	Publicly funded innovation organisation
22	Advisor	Government

Table 18- UK interviewees

No.	Job function	Organisation
23	ARPA-E concept developer	Not-for-profit
24	ARPA-E concept developer	Not-for-profit
25	Professor	University
26	Professor	University
27	Senior Vice President	Research Institute
28	Director	Regulator
29	Chief Research Officer	National Laboratory
30	Chief Executive Officer	Technology Incubator
31	Former Chief of Staff	Department of Energy
32	Professor	University
33	Director	Firm
34	Principal	Philanthropic Fund
35	Director	Technology Incubator

Table 19- US interviewees

Additional primary data was collected via attendance of the ETI 10 Years of Innovation conference and exhibition in 2017, and the tenth annual ARPA-E Energy Innovation Summit in 2019. This provided additional access to high level discussion on the operation of each organisation and contextual knowledge of stakeholder engagement.

Extensive secondary data was collected in the form of policy documents, independent reviews, organisational literature and academic papers. These provided detailed case study context and enabled primary data to be situated and explored within this broader environment.

4.4. Results

4.4.1. Broader institutional context

1. Policy environment

The ETI and ARPA-E represented new approaches to accelerating transformative innovation in a strengthening policy environment throughout the 2000s. The ETI's relevance was framed throughout its lifetime by strengthening consensus on tackling climate change. Greater political polarisation in the US on environmental issues however has caused ARPA-E to be framed as driving economic competitiveness to receive stronger cross- party support.

In the UK, the first climate change targets were set in 2000 (DETR, 2000), with the 2002 Energy Review highlighting the need for new energy innovation policy for electricity system decarbonisation (PIU, 2002). The government developed market-pull focused policies, such as the Renewables Obligation, which aimed to create markets without picking technology winners (PIU, 2002). These however proved insufficient in driving the level of innovation required to meet climate change targets or tackle energy security concerns as domestic natural gas supply peaked (DTI, 2007). The ETI was developed as part of a broader policy response to accelerating this progress, seeking to directly engage firms in creating a strategic pathway for technology deployment (DTI, 2007). Its focus on TRLs 3-6 reflected the Labour government's willingness to shift policy and funding toward supporting pre-market technologies, aiming to help them through the 'valley of death' (4). The organisation remained politically relevant throughout its lifetime due to strengthening consensus on the need to tackle climate change, for example with the passing of the Climate Change Act in 2008.

Whilst the US has been historically strong in basic science investment, by 2005 there was mounting cross-party concern over the US's declining energy science and technology base (Augustine, 2005; Nemet & Kammen, 2007). This coincided with growing concerns around energy security and the growing prominence of climate change. The 2005 National Research Council *'Rising Above the Gathering Storm'* report therefore recommended that the federal government develop a new way to drive technology breakthroughs in the energy sector (Augustine, 2005). ARPA-E was developed with these converging challenges in mind, framed as an opportunity to drive revolutionary technology breakthroughs in the style of the successful DARPA organisation (Anadon & Nemet, 2013). A Democratic President was elected in 2009 who utilised clean energy investment as a campaign vehicle (Manser et al., 2016). At this time a commitment was made to invest $150bn over ten years in energy research on low carbon transition, which included the funding of ARPA-E (Alexander, 2009). Ongoing political disagreement around the validity of climate change however has placed greater policy emphasis on framing ARPA-E in its role of enhancing economic competitiveness (Dunlap et al., 2018; Bonvillian, 2014).

2. Industry embeddedness

The ETI took a public-private partnership approach to driving later stage innovation, whilst ARPA-E remained fully publicly funded and has created demand via public procurement. This represents a key point of departure in their respective designs.

At the time of the ETI's formation, incumbent energy firms were seeking to understand how they could align their operations with the UK's climate change targets. The Energy Research Partnership (ERP) was developed in 2005 as a public-private strategy forum, comprising large energy firms and government bodies (Winskel & Radcliffe, 2014). The ERP recommended innovation efforts focus on developing greater public-private collaboration to deliver technologies at scale (ERP, 2007). The CEO of E.ON UK and the government's Chief Scientific Advisor developed the idea of the ETI as a means to fulfil this need (11; 20). Five of the six original private members of the ETI were also ERP members, creating an industry led organisation that enabled the government to not be accused of 'picking winners' (5). The ETI proved effective in building trust between public and private members, facilitating cross-sector exchange of knowledge on a broad range of future technologies important to the UK market (2; 6; 7). This however caused issues around *which* firms were engaged, discussed further in section 4.4.3.

ARPA-E is entirely publicly funded and engages with a diversity of firms to move outputs to the next stage of development. This has required greater emphasis on relationship building to ensure industry relevance, constituting a key difference in its approach to DARPA, which largely relies on public procurement of its outputs (Bonvillian, 2018; Crespi & Guarascio, 2019). ARPA-E initially sought to work with the venture capital community, however clean energy markets collapsed in 2011 due to poor rates of return, requiring a new way to create market demand (11; Hart & Kearney, 2017; Singer & Bonvillian, 2017). In 2010, a memorandum of understanding with the Department of Defense (DOD) was developed, offering initial markets for technologies that match their need for energy access in remote areas (Hart & Kearney, 2017). Large firms have been engaged more broadly in ARPA-E's outputs via cross-company consortia that identify common issues that a new technology could address (Bonvillian & Atta, 2011). These activities have enabled ARPA-E to build trust with a broad range of relevant firms.

3. Innovation system characteristics

By the 2000s, the capacity of the UK energy innovation system had dipped very low, requiring the formation of multiple new institutions and organisations to 'remake' its capabilities (Winskel & Radcliffe, 2014). Whilst the US also developed several institutions and organisations during this time to accelerate innovation, these supplemented long standing system actors.

The ETI formed part of a rapidly evolving clean energy innovation system. By 2007, the EPSRC's Research Council Energy Programme had been developed to deliver increased support at TRLs 1-3, whilst the Carbon Trust and Innovate UK supported businesses in adopting low carbon solutions (Kern, 2009). In 2008, the Department of Energy and Climate Change (DECC) was established to give energy and climate change greater visibility in UK policy making and had its own innovation programme, which grew over time (6; 7; 9). The ETI's focus on TRLs 3-6 sought partially to respond to the UK's lack of national lab infrastructure, where innovation system capacity remained particularly low (11). Figure 24 demonstrates the niche that the ETI occupied as this landscape evolved over time.

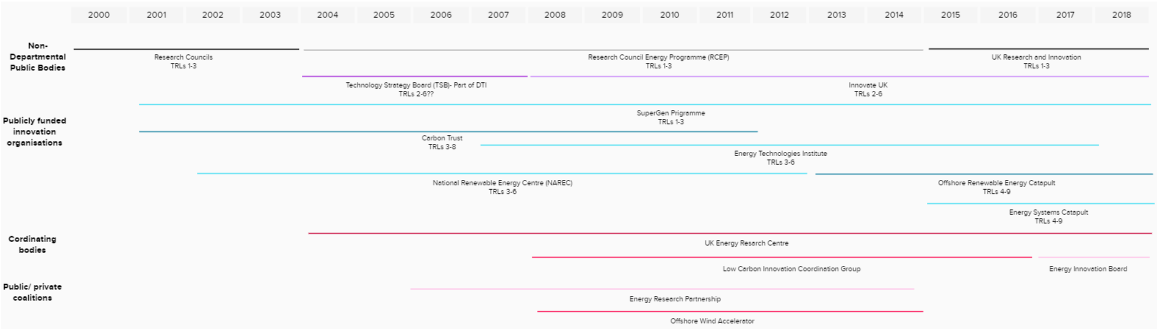


Figure 24- Overview of the UK clean electricity innovation system

The ETI built strong links with DECC, Innovate UK and the EPSRC, involving them as board members who sought to create as much public technology pull through as possible (5). Whilst the ETI occupied a specific niche and directly engaged these key actors however, innovation system support for technology deployment remained low and programmes somewhat disjointed, as these young institutions evolved over time (12; 20).

In the early 2000s, the US energy innovation system possessed a strong the Basic Energy Sciences (BES) programme at TRLs 1-3 and 17 national labs supporting applied and demonstration level energy research (Anadon et al., 2011). In 2009, several new institutions supplemented this landscape with the aim of overcoming gaps in early stage and applied research to accelerate innovation (25; Hart & Kearney, 2017). BES introduced 46 Energy Frontier Research Centers uniting public expertise around grand challenges at TRLs 1-3 (27), and the Energy Innovation Hubs united interdisciplinary researchers around five key energy challenges at TRLs 3-5 (27; Logar et al., 2014).

ARPA-E was positioned to occupy a space for revolutionary RD&D, defined as linking basic and applied research to accelerate the development of breakthrough technologies (Anadon et al., 2011). The organisation has benefitted from historically robust and porous connections between universities and businesses, creating strong capacity and competition for technology transfer alongside more formal institutions like the national labs (Policy Exchange, 2020). ARPA-E has also created specific processes to drive effective engagement across institutions, for example encouraging project directors to work with universities involved in the Energy Frontier Research Centers (Bonvillian & Atta, 2011). The positioning of ARPA-E in relation to the EFRCs and Innovation hubs illustrated in Figure 25 below.

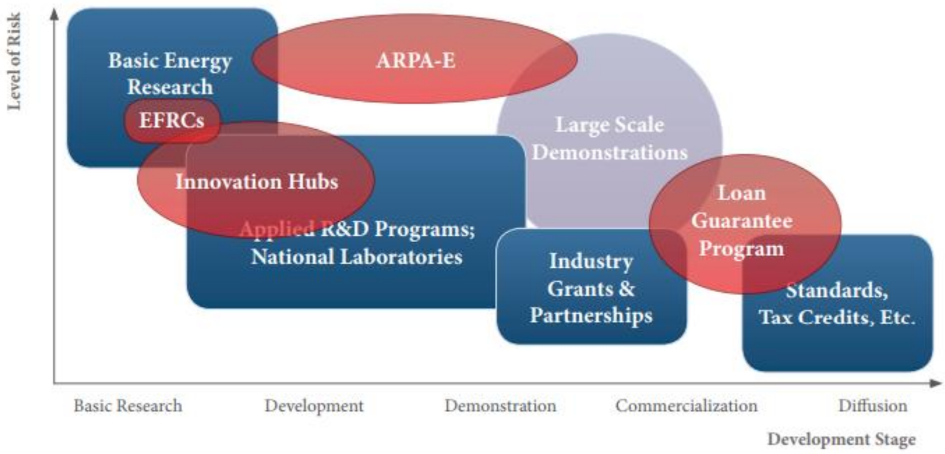


Figure 25- Overview of the US clean electricity innovation system (Anadon et al. 2011)

This has been further strengthened over the lifetime of ARPA-E via the development of organisations like Cyclotron Road, which connects smaller projects with national lab resources, and the Prime Coalition that crowds in philanthropic capital. These have continued to support ARPA-E as clean tech venture capital markets have weakened, as discussed above.

Within the differing political economy structure of the US, it is important to note that individual states incorporate their own energy innovation organisations and actors. These include incubators and networks specific to the region that support small firms in scaling innovations, an example being the Massachusetts Clean Energy Center that connects actors with a range of local technology accelerators and incubators (13).

4.4.2. Vision and outcomes

4. Mission

Both the ETI and ARPA-E have been guided by strong missions over their lifetimes. Both organisations adopted similar structures, aiming to minimise bureaucratic drag and empower project leads.

The ETI's mission was: *'To accelerate the development, demonstration and eventual commercial deployment of a focused portfolio of energy technologies, which will increase energy efficiency, reduce greenhouse gas emissions and help achieve energy and climate change goals'* (ETI, 2018a, p.3). Project managers were head hunted primarily from industry, with a small proportion of staff also seconded from industry members (5). Two interviewees commented on the high levels of talent on the board and across the organisation, however the diversity of skill set of employees became an issue, discussed in section 4.4.4.

ARPA-E's mission was refined by Congress as *"to overcome the long-term and high-risk technology barriers in the development of energy technologies"* which involved *"accelerating transformational technological advances in areas that industry by itself is not likely to undertake because of technical and financial uncertainty"* (COMPETES Act, 2007, p.50). The organisation aimed to be Programme Director driven, creating a spirit and culture of staff members coming together to do something new and exciting around a sense of purpose (Stine, 2009; ARPA-E, 2019a; ARPA-E, 2016). This spirit was combined with rigorous technology selection processes to ensure the mission was adhered to (ARPA-E, 2010). Ensuring that Programme Director have this zeal alongside technical expertise has been key in ARPA-E being able to drive technologies forward to implementation (Bonvillian & Atta, 2011).

5. Stability

The stability of the ETI was guaranteed by a ten-year contractual arrangement, whereas ARPA-E has sought to develop strong relationships with politicians and innovation system actors to secure federal funding year on year. The ETI benefitted from this stability, however its cumbersome nature contributed to it not being refunded after ten years. Conversely, ARPA-E remains nimble but suffers ongoing funding uncertainty.

The ETI's stability was a positive feature highlighted by all ETI interviewees. The organisation proved politically durable over, withstanding three changes of government and the 2008 financial crisis. Funding remained sufficient and predictable, as members were obliged to adhere to contractual contributions or face a two-year withdrawal period. This stability was premised on a strict, legal deal between members described by one interviewee as *"quite cumbersome and authoritarian*" (1), designed this way to ensure that all committed to securing the organisations strategic, long term contribution (5). In 2012, a public review recommended that the ETI should be extended for another five years to 2022, with a further review after five years (5). There is however no publicly available record of this review, nor the independent review that informed it (Technopolis, 2013). The government took two years to respond affirmatively to extending the ETI, by which time the confidence of private members had reduced and their strategies changed. The decision was therefore taken in 2015 to discontinue the organisation after 2017.

ARPA-E has struggled to create stability, as differing political narratives around environmental issues, levels of government engagement in applied R&D and annual federal budget battles impact the organisation's political and financial certainty (Azoulay et al., 2019; Hart & Kearney, 2017). Receiving an initial budget of $400m in 2009 under the American Recovery Act, over the last ten years ARPA-E has actively sought to develop cross-party support to secure ongoing funding, including building relationships both within the DOE and broader research community (Wurzelmann, 2012; Bonvillian, 2018). Whilst experiencing some fluctuation, funding has avoided large cuts in project budgets, which would disrupt the organisation's effectiveness (NASEM, 2017; Alexander, 2009). Congress was petitioned to give ARPA-E enough time to succeed when launched (24) and an independent report recommended the organisation's continuation after seven years of operation (NASEM, 2017). Under the current Republican administration however, ARPA-E faces ongoing funding uncertainty despite contributing toward economic competitiveness (26; Worland, 2017).

6. Accountability

The ETI did not develop specific metrics in relation to how its operation contributed to 'accelerating' innovation, which creates issues in matching its outputs to its mission. The organisation also placed less emphasis on developing external accountability, primarily focusing on completing projects and communicating outputs to members. Conversely, ARPA-E has developed relevant performance metrics to monitor its outputs in relation to mission, consistently communicating these to a broad range of stakeholders.

The ETI states that over its lifetime it *"delivered whole energy system modelling and analysis alongside the practical delivery of over 150 complex energy innovation projects"* (ETI, 2018a, p.29). Available metrics are detailed in Table 19. The focus on the generation of knowledge, tools and data is different from its initial mission, which sought to drive technology demonstration. Whilst the ETI did not develop a concrete definition of what successfully 'accelerating' innovation would encompass, the interpretation above ignores aspects of the original mission, making it difficult to subjectively measure the ETI's success and leaving its outputs open to interpretation. Several ETI staff members discussed that the organisation viewed success as timely project completion, with less emphasis on how outputs were communicated to a wider audience or moved to the next stage of innovation (1; 4; 5). There was additionally a focus on protecting IP for use by ETI members as opposed to sharing with the broader innovation system, which contributed to the organisation being viewed as a 'closed club' (2; 5; ETI, 2018a).

ETI by numbers	
146 projects	929 citations of our work over 4 years
19 demonstrations	12 select committees
27 technology developments	131 staff employed (averaging 60)
103 knowledge building	41 models and tools developed
63 ETI publications by 2019	537 documents and data sets made public
62 PhDs sponsored	21 student placements
42 constitution responses	

Table 20- ETI by numbers (ETI, 2017)

ARPA-E has had a strong focus on communicating its activities over its lifetime, with visibility of outputs key to continued funding (Bonvillian & Atta, 2011). To convince Congress of success, metrics have been defined that detail company creation and follow-on funding, as well as patent and publication numbers, which demonstrate the organisation is overcoming risk barriers and driving economic growth. These metrics, detailed in Table 20, have remained consistent, with staff focused on reporting on these elements (ARPA-E, 2019b).

The annual ARPA-E Innovation Summit is utilised to engage and build further credibility with policy makers and the broader research and investment community (NASEM, 2017; Bonvillian, 2018). An independent review concluded that ARPA-E's current outputs support its mission (NASEM, 2017), whilst peer-reviewed work demonstrates that in comparison to other parts of the DOE, ARPA-E is more likely to generate both publications and technology patents (Goldstein & Narayanamurti, 2018) and enhance the productivity of project funding (Goldstein & Kearney, 2020). It was recommended however that ARPA-E should develop longer term success metrics given the high turnover of leadership (NASEM, 2017), discussed in section 4.4.2.

ARPA-E Impact	
$2.3 billion R&D funding	850 projects
82 companies formed by ARPA-E projects	219 projects have partnered with other government agencies to further development
161 projects have attracted $3.2 billion in private sector follow on funding	3658 peer-reviewed journal articles
385 patents issued by the U.S. Patent and Trademark Office	

Table 21- ARPA-E Impact[21]

4.4.3. Public and private relationships

7. Autonomy from short term political pressure

Both the ETI and ARPA-E sit at arm's length of the government. The ETI's public-private partnership structure embedded policy makers in its operation however, which affected the organisation's focus after the financial crisis. Ongoing engagement however also contributed to its funding stability. In contrast, ARPA-E retains high operational autonomy but struggles to maintain stable access to funding as the policy environment shifts.

The ETI was designed to run as a business, able to take risks and set its own funding priorities, and so distancing civil servants from project failure (1; 3; 5). Technology selection was driven by a rigorous process, uniting public and private members in identifying areas for support. Political engagement was retained via the organisation's board members, through which Ministers were brought ideas and outputs to be communicated directly to public sector decision makers. Whilst the ETI was initially involved in many high-level government meetings, this reduced as it became clear that the organisation could not be swayed by the agendas of individual policy makers (1; 2). The ETI's operation however was impacted by the 2008

[21] ARPA-E Impact. Available at: https://arpa-e.energy.gov/?q=site-page/arpa-e-impact Accessed: 14.09.20

financial crisis, with interviewees commenting that broader political pressure caused project consortia to tend toward supporting UK firms and technology needs closer to market (3; 5).

ARPA-E has very high political autonomy, designed to be decoupled from Congressional interference and left to deliver its mission (Alexander, 2009). This is achieved via an ‘island-bridge’ model, positioning ARPA-E as a standalone department outside of traditional DOE structures, reporting directly to the Secretary of Energy (Bonvillian, 2018; Sen, 2017). This creates a protected ‘island’ on which to experiment away from political interference whilst maintaining a direct ‘bridge’ to a key politician able to champion the organisation and provide it with the required resources (Bonvillian & Atta, 2011). ARPA-E therefore has lower levels of political embeddedness than other DOE departments, reflected in the lack of stability discussed in section 4.4.2.

8. Autonomy from the private sector

The ETI’s design as a public-private partnership utilised private sector influence as a key strength. The industry members however overly influenced over its operation, impacting other aspects of its design. Whilst ARPA-E is required to perform greater outreach to engage private partners, it has not experienced these issues, especially due to its earlier TRL focus.

In 2007, developing a PPP was a common way for the UK government to engage private sector actors in public projects, reducing public borrowing and sharing risk (Wall & Connolly, 2012). An interviewee highlighted that this approach enabled the ETI’s mission to be infused with hundreds of hours of knowledge and expertise from energy firms and up to £500m of private funding for high-risk projects (2). Private members primarily joined to strengthen their strategic position in the energy system, making an affordable, ten-year commitment to understanding and contributing to new energy markets (1; 3; 7). Whilst the ETI hoped to attract ten private partners it failed to do so, with interviewees discussing that many firms did not see the value of working with the government in this way (2; 18) and the impact of the financial crash on the changing attitudes from strategy to survival (9; 5).

Whilst engagement in project consortia was described by four interviewees as equitable (1; 3; 5; 7), the presence of six large incumbents exerted influence on overall technology trajectory. There was a lack of appetite to invest in the higher risk, revolutionary technologies that the ETI had set out to fund, as concerns over financial returns exceeded willingness to accept uncertainty (2; 5; ETI, 2018a). The perception of the organisation by smaller firms was also affected by the direct engagement of 6 incumbents, who were reluctant to engage in project consortia as they felt out of control of their IP. This concern endured, making engagement of these firms more challenging despite IP not being compromised on any project (3; 4; 5; ETI, 2018a).

As a solely publicly funded organisation, ARPA-E's development and operation has not been overtly influenced by specific firms. The organisation was designed to develop industry-tailored strategies to IP, which acknowledge that different patent processes and trade secrets impact the extent to which a technology output will be received (Alexander, 2009). Experienced project directors match this with a knowledge of the risk and cost share an industry can take, enabling firms to be engaged without being directly captured by their interests (NASEM, 2017).

4.4.4. Operational approach

9. Competencies

The ETI's recruitment of a CEO from an incumbent firm and a high proportion of engineering staff caused it to adopt a more technical, inward-facing approach to innovation. Conversely, ARPA-E ensured that it engaged staff with the competencies matched to the development of high risk, transformational technologies, which connected with the broader needs of the innovation system.

The position of ETI's CEO was filled by the Head of Technology Strategy at Rolls-Royce, as an individual perceived to have the skills to provide a strong strategy for the pursuit of the organisation's mission (2; 5). As the ETI's operation progressed however, the style of leadership that had proven successful within a large incumbent firm was not effective in creating the agile organisation that the ETI had aimed to be (5), discussed below in *flexibility.*

ETI interviewees discussed that senior staff members were industry recruits, with experience of developing long-term strategies to ensure that public money was spent accountably (5; 6; 7). Issues arose however as subsequent staff members became disproportionally recruited from engineering backgrounds (5; ETI, 2018a). This affected the development of the organisation's competencies for addressing its mission, as innovation became viewed as a technical *"problem to solve"* (5), with less consideration of the broader social or political implications of project development. A high weighting of engineering competencies also contributed to an initial lack of effective external communication of project outputs, preventing the organisation from fully telling its story to stakeholders and sharing insights into its failures and achievements (5; 9; 10; ETI, 2018a).

The first Director of ARPA-E, Arun Majumdar, was nominated by the President due to his strong background in materials science innovation and experience of running an entrepreneurial arm of Berkeley Lab (Berkley Lab, 2009; Abramson & Lawrence, 2014). Without a leader with this high degree of technical knowledge and ability to deliver entrepreneurial leadership, it was identified at the outset that ARPA-E would fail (24, Alexander, 2009). Over his three-year term as Director, Arun was recognised as a charismatic leader, rapidly establishing an atmosphere of openness and urgency within the organisation and building effective links across the DOE in support of ARPA-E (Yin, 2012; Abramson & Lawrence, 2014). Arun served as Director until 2012, after which six additional permanent and temporary Directors have further refined and streamlined his original vision (ARPA-E, 2019b).

A key element of Majumdar's vision was the recruitment and empowerment of Programme Directors (NASEM, 2017). They were to have what was referred to as 'religion'- *"a vision of where they want to take their portfolios, performing as vision champions, in order to sell their projects both inside and outside ARPA-E"* (Bonvillian & Atta, 2011, p.489). Programme Directors are given the authority to develop technology programmes in collaboration with the Director and their peers in the pursuit of novel ideas (NASEM, 2017). Bonvillian (2018) discusses that they are empowered to actively manage project progress, facilitating ongoing adaptation and growth.

This process is complemented by competencies developed by the technology-to-market team, which works with Programme Directors to engage the wider innovation system in projects from the outset, maximising commercial development opportunities (NASEM, 2017). This process assists in forcing technologists out of their silos to understand how to work with actors from a range of different disciplines and sectors to ensure projects have market impact (ARPA-E, 2017).

10. Flexibility

The design of the ETI placed high constraints on its operational flexibility, acknowledged as regimented and inflexible in relation to its size (ETI, 2018a). ARPA-E is more successful in embracing a balance between technological rigour and the flexibility to experiment and fail.

Whilst the ETI intended to operate in a flexible manner, the organisational culture did not incorporate a diversity of views and skills and became dominated by an engineering mindset. Interviewees commented that internally, this caused projects to be conducted in silos with little information shared internally about their progress (9; 10). This created a somewhat cautious, siloed office culture that was not addressed over the organisation's lifetime (ETI, 2018a). This was exacerbated by there being no fixed time periods over which staff served, enabling this culture to become ingrained (ETI, 2018a). In combination with the lower risk appetite discussed in section 4.4.2, very few of the ETI's projects were stopped due to potential failure as they were more incremental in their approach (2; ETI, 2018a). Interviewees also highlighted a lack of flexibility in the way that firms were engaged in project consortia. Partners were held to very prescriptive, strict criteria around project funding, which often did not match the needs and resources of smaller firms. This atmosphere of heavy governance in combination with concerns over IP discussed in 4.4.3 caused the ETI to be perceived as difficult to work with by potential partners (4; 8).

In contrast, ARPA-E has been observed to create an innovative, entrepreneurial culture, driven by the skills and agency of the Programme Directors (NASEM, 2017). Portfolio creation is unhampered by peer-review processes, enabling projects to be launched quickly in response to emerging opportunities (Bonvillian & Atta, 2011; Azoulay et al., 2019). The Programme Directors have tenures of just five years, driving a sense of urgency around portfolio development and project completion (Bonvillian & Atta, 2011).

ARPA-E has also demonstrated willingness to assess its operations and experiment with changes aimed at improving outcomes (NASEM, 2017), for example advancing its process of working with smaller firms to ensure that they are equitably engaged in contracts (ARPA-E, 2019b). This has enabled ARPA-E to create a culture in which 'ideas fail, but people don't' (Sagar & Majumdar, 2014; Haley, 2017), with failures viewed as part of the plan and an opportunity to learn (Biello, 2013; ARPA-E, 2016; ARPA-E Summit, 2019b).

4.5. Discussion

This discussion explores how the design of ETI and ARPA-E led to different interactions between the design principles, affecting their operation and outputs. Here 'p' is used to reference the different principles, with its number corresponding to those in Figure 21, summarised again in Table 21 below.

National institutional context			**Vison and outcomes**			**Public and private relationships**		**Operational approach**	
p1	p2	p3	p4	p5	p6	p7	p8	p9	p10
Policy environment	Industry embedded -ness	Innovation system Connected -ness	Mission	Stability	Account -ability	Public autonomy	Private autonomy	Competencies	Flexibility

Table 21- Summary of the ten principles (p) for accelerated innovation organisation design

A key difference in design between the ETI and ARPA-E was ETI's engagement of the private sector in its funding and operation. The ETI embedded incumbent firms as funders in a PPP model, seeking to equitably engage private partners to build cross sector knowledge at p2. The approach of engaging private partners was common at the time, as the innovation system in p3 sought to rebuild public capacity after many years of low investment. The PPP approach also proved attractive to some incumbent energy firms, enabling them to strengthen government relationships and understand climate change policy priorities in p1.

Whilst this approach was effective in creating long term stability at p5, aspects of private sector capture occurred in p8, as private members shied away from the risk required to deliver the ETI's mission in p3, and smaller firms lacked trust around the protection of their IP. The PPP structure also affected the ETI's accountability at p7, due to a focus on the protection of knowledge for its members. The operational approach was also impacted, as the CEO developed a vision for the ETI's operation based on experience developed within an incumbent firm, affecting the competencies developed in p9. These design aspects combined to contribute to developing a cautious company culture, that lacked the flexibility the ETI had hoped to embody in p10.

As discussed in Section 3.6 above, the national institutional context at the time of the ETI's development meant that its design emerged as an experiment within an immature energy innovation system. Whilst the ETI did not deliver the desired vision and outcomes it has influenced the design of proceeding organisations, with policy makers not wishing to replicate the same private sector relationships and operational approach which led to concerns over capture of public money. Indeed, the ongoing accumulation of skills and knowledge as the energy innovation system has evolved means that organisations no not need to be designed to rely on private sector resources and so pursue more balanced public/private relationships. An example is the Energy Systems Catapult, which houses expertise initially developed within the ETI but has a more balanced investment structure.

Conversely, the design of ARPA-E seeks to engage a diversity of firms in scaling technology outputs into early markets at p2. To achieve this, the organisation has developed strong technology-to-market competencies at p9 to ensure that projects generate high commercial interest from the outset. Whilst initially designed to utilise venture capital, as the role of this within the innovation system reduced at p3, ARPA-E has utilised public procurement to assist in creating early market demand. In this regard, ARPA-E has been able to avoid the aspects of capture at p8 that affected the ETI's ability to pursue its mission.

ARPA-E was able to engage relevant firms and flexibly respond to the unexpected collapse of venture capital for energy projects in 2011. This reflects both the robustness of its design in relation to being based on DARPA and having the correct mix of competencies, as well as being supported within a more coherent energy innovation space in which other institutions could help facilitate its mission. This is reflected in Section 4.3.1, with further context more deeply explored in Section 1.4.2. This coherence is reflective of the US's longer term public support for earlier stages of energy innovation that had been lost in the UK, whereas the ETI represented an experimental approach supported by a smaller, poorly linked system.

In contrast with the ETI, ARPA-E lacks guaranteed stability at p5. As the organisation's budget is determined annually by Congress, ARPA-E's funding is vulnerable to changes in the policy environment at p1, as political ideologies around climate change and clean energy are polarised between parties. In this regard, the 'Island Bridge' model that is successful in decoupling ARPA-E from the whims of individual policy makers does leave it potentially vulnerable in relation to retaining ongoing resources at p7, as it comes under greater scrutiny than other departments of the DOE. To counter this, the organisation has sought to build strong accountability at p6, building a strong presence in the energy innovation community by communicating accountable results and the annual Innovation Summit.

This demonstrates how the design of ARPA-E and its outputs are successfully exerting bottom-up influence in terms of demonstrating to policy makers that its vision and outcomes are accelerating clean energy innovation. Its purposeful design was more likely to emerge due to the scrutiny of the government in relation to investing in a specific area of the energy innovation and the need for an organisation to demonstrate clear links to economic growth as well as climate action to remain viable.

Internally, the operational approaches adopted by the ETI and ARPA-E also offer a key point of departure in their design. The ETI's competencies at p9 was affected by a high weighting of engineers in management positions. This caused innovation to be viewed through a technical lens and further contributed to a cautious company culture at p10, in which innovation took place in silos and project outputs were not openly shared. Accountability was affected as capacity was not initially dedicated to communicating outputs or managing external relations at p9, further contributing to the organisation appearing as a closed book beyond its members. Whilst the ETI sought to rectify this, this organisational culture had become ingrained and proved difficult to redress at p10, preventing the ETI in operating as the nimble, flexible organisation that it had aspired to be.

ARPA-E senior leadership and Programme Directors are carefully recruited based on both academic credentials and entrepreneurial experience, ensuring that they possess the skill set to create and thrive within an entrepreneurial environment. Short-term contracts within these positions led to projects being driven forward with urgency and mission focus, with fresh approaches regularly entering the organisation at p9 and p10. Whilst this has led to concerns over long term accountability, projects are highly visible to the Director, who has direct oversight. This operational approach has created a dynamic culture able to openly evaluate operation and adjust its approach.

As the ETI's PPP structure and the effects of the 2008 financial crisis shifted focus towards investing in lower risk, more incremental projects, this shift was also facilitated by organisational culture. As members sought these projects to support, ongoing engagement from a stable staff base was likely more suited than the higher turnover model adopted by ARPA-E. Additional to this, ARPA-E was launched in 2009 as a *response* to the financial crisis to accelerate economic recovery, framing its approach within this narrative. This demonstrates the effect of the wider economic system on the policy environment, which will affect the amount of risk an organisation is designed to take.

The interaction of these different principles has affected the way in which these two organisations have ultimately been able to accelerate innovation. The design of the ETI caused it to prioritise the support incremental clean electricity innovation, failing to operate as the agile, entrepreneurial organisation it hoped to be in the pursuit of its mission. Now having ceased operation, it faces ongoing accountability issues in linking its outputs to its mission, meaning that its legacy in relation to accelerating innovation remains poorly understood. Whilst the organisation has contributed to strengthening the energy innovation system, remaining stable for over ten years and building important competencies, its design was not conductive to actioning the more transformative aims of its mission

Conversely, ARPA-E has demonstrated its effectiveness in accelerating transformative innovation, developing the private sector relationships and operational approach that enable it to drive technologies toward commercialisation. The use of public procurement to create demand in the absence of expected venture capital markets has proven particularly important in providing early-stage market demand, alongside the emergence of a growing number of complementary organisations like Cyclotron Road. Whilst ARPA-E has been successful in maintaining the autonomy to enable its high-risk approach, the stability of its funding is affected by a shifting policy environment, leaving the delivery of its mission potentially vulnerable to budget cuts. This demonstrates the difficult balancing act between principles like flexibility and stability, which are both important in accelerating energy innovation.

Finally, it is important to observe that both the ETI and ARPA-E are a product of shifting priorities and understandings of the role and value of energy innovation, as opposed to being dictated by a static view or approach to accelerating innovation by a liberal market economy. During the lifetime of both organisations, there has been an increasing shift in values towards supporting climate action and the role of innovation in this, corresponding with layer 1 of the framework in Section 2.5. This is driving changes in political economy relationships and is shaped by ongoing change as policy environments change and individuals come and go in layers 2 and 3. This has demonstrated that there is not a rigid set of principles that the UK and the US can or cannot adopt, as this continues to shift. This is especially true of individual actors in Layer 5 that animate these organisations. This comparative case study serves to demonstrate the value of understanding how institutions shift and change, as outlined in Section 1.2.6 as a key contribution to this thesis, instead of assuming particular energy innovation approaches based on national political economy assumptions.

4.6. Conclusions and policy implications

This paper analyses the effect of organisation design on accelerating low carbon innovation via a comparative case study of the ETI and ARPA-E.

The design of the ETI caused it to prioritise incremental innovation, contrary to its mission to deploy transformative technologies. This was primarily due its relationship with industry as a PPP, which influenced a move toward lower risk projects; and its operational approach, which became technical and siloed, creating a cautious organisational culture. Conversely, ARPA-E has demonstrated its effectiveness in accelerating the transformative innovation that its mission set out to address. The organisation has developed an entrepreneurial, flexible operational approach whilst maintaining strong accountability to its mission. ARPA-E has established strong technology-to-market capabilities and utilised public procurement to create innovation demand, ensuring strong pull-through of early-stage projects. Despite this greater engagement with the surrounding innovation system than ETI, its ongoing lack of stability with the surrounding policy environment leaves it vulnerable despite strong efforts to build cross-party support.

These results have implications for policy makers seeking to design organisations that are effective in accelerating low carbon innovation, discussed in turn below. These considerations should guide design to help avoid path dependency and the implementation of existing approaches from a different industry or innovation stage without careful consideration of context. They should also be considered within the need to carefully make and balance trade-offs between potentially conflicting principles, such as those of stability and flexibility.

Match an organisation's operational approach to the aims of its mission

An organisation's design needs to encourage the competencies and flexibility required to accelerate the type of innovation desired. Senior leadership should create an appropriate vision, incorporating both high technical knowledge and that of working within the entrepreneurial environments in which innovation outputs will interact. Senior staff members should share this vision and participate in cultivating an organisational culture that supports this. Whilst the ETI likely had an impact on accelerating innovation, the internal culture cultivated by senior management did not encourage the skills needed to drive transformative innovation to market.

Engage a diversity of industry actors and create opportunities for equitable collaboration

Organisations should be designed to interact with a diversity of firms without placing restrictions on the knowledge it generates. This avoids cultivating the feeling of a 'closed club', (where certain privileged firms appear to receive government support) or that funds have been co-opted for private gain- both perceptions which continue to challenge the ETI's contribution. As explored by Doblinger et al. (2019), the government can act as a high-quality partner to emergent firms, able to deploy funding and other resources to scale up solutions without the self-interest of the private sector. This process of engagement should therefore be mindful of the resources of smaller, emergent firms if these equitable, collaborative opportunities are to be developed. An example of this could be the adoption of appropriate contracting practices tailored to specific firms or supply chains and ensuring that IP concerns are minimised. While the ETI for example, adopted a blanket approach to this across all partners, ARPA-E paid greater attention to the norms and expectations within which a smaller firm operated and tailored partnerships according to their capabilities.

Adopt clear performance metrics that link innovation outputs to mission, in order to build accountability and stability

Clear metrics that link the relevance of short-term innovation outputs to the delivery of an organisation's mission should be adopted and monitored throughout its life. As the full impact of most innovative outputs will not become apparent for many years, building this transparency and trust between policy makers and the wider innovation system is important. This entails dedicating resources to producing regular, targeted communications and holding events that facilitate ongoing outreach in relation to these achievements and learnings. For example, the ETI presented their outputs to the community in one final 10 year anniversary event that did not reflect on the organisation's operation, whereas ARPA-E hosts an annual summit during which leaders have publicly reflected on the organisation's progress. Together, these activities assist in building greater stability in a changing policy environment, as the value of the organisation remains relevant and transparent to key innovation system stakeholders.

Seek to balance autonomy from political pressure and maintaining stable funding

Autonomy is important in maintaining mission focus and distancing policy makers from project failure, which is especially relevant to accelerating more transformative innovation (Breznitz etal., 2018). High levels of autonomy however, can expose an organisation to challenges in retaining stable funding over the long time periods required to accelerate this innovation.

Policy environments constantly change as different parties are elected and economic conditions shift, with ARPA-E for example facing defunding after the Republican government came to power in 2017. It is therefore important for organisation design to carefully consider this dynamic relation to enabling the level of risk over the time period required.

Key to this is seeking to build cross-party support, which involves selecting an overarching issue or narrative that appeals across party lines. ARPA-E for example, was framed in the need to maintain economic competitiveness as well as tackling climate change, appealing to the priorities of both main political parties. Adopting a mission-oriented approach in relation to tackling a societal challenge may also provide a stable grand narrative around which long term innovation funding could be framed (see Mazzucato et al. 2018). This approach could help guide the focus of a new 'ARPA' style organisation in the UK, which is considering taking a specific focus on delivering net zero (Policy Exchange, 2020).

Organisation design is important, but needs to be supported by the broader policy environment and innovation system

Ultimately, an organisation is just one part of a constantly shifting policy environment and innovation system, in which it can only achieve so much on its own. If accelerated innovation is not supported by a broad range of policy instruments or public and private stakeholders, then even the best design will struggle to produce impactful outputs. For example, the ETI was unable to commercialise the wave energy technologies they developed due to lack of a supporting policy environment and resulting weak market pull-through (see Hannon et al., 2017).

Organisation design should therefore be considered in relation to how it will sit within a broader institutional environment that supports a coherent approach to accelerated innovation, creating stable, long term technology push and market demand. Policy makers should view their innovation priority within this broader systems context and consider how an new organisation might sit within this ecosystem to effectively support their aim. ARPA-E for example, represented a specific addition to a long-standing energy innovation system tackling a particular aspect of innovation. The use of public procurement meant that there was a guaranteed, stable market for transformative innovation after the venture market collapsed, meaning that its mission remained relevant and supported within surrounding innovation system activities.

Engaging markets and adopting funding that increases value and stability, such as public procurement opportunities, PPPs or levies from taxes on high carbon industries, should therefore be considered both in relation to individual and organisation design, as well as how these interact separately within a broader system.

5. Conclusion

This concluding chapter identifies how the research presented in this thesis addresses the aim of understanding how publicly funded innovation organisations can be designed to deliver accelerated clean electricity innovation within their national institutional context. Section 5.1 provides answers to the three individual research questions outlined in Section 3. Sections 5.2, 5.3 and 5.4 go on to identify the key theoretical, empirical and policy contributions of this thesis. Section 5.5 explores the limitations of this work and avenues for further research. Finally, Section 5.6 provides the concluding remarks of this thesis.

5.1. Answers to research questions

RQ1: How have national institutions influenced the evolution of clean electricity innovation systems?

The case study of the UK indicates the influence of enduring informal institutions that exert top-down influence on those developed beneath, which has caused clean electricity innovation to occur primarily within the existing, centralised energy system. Innovation policy is therefore not only influenced by a shifting policy environment, but is shaped by government structure and industry relationships, which in turn are shaped by informal norms and values. This is further reinforced by the technology regime that has evolved alongside this, especially in relation to centralised electricity infrastructure.

Institutions in the UK evolved over time at different speeds, creating a landscape of gradual, uneven change. This results in a complex institutional story, where the emerging cultural value of climate change has affected change or been met by inertia at different times. The UK case highlights that regulatory institutions have remained steeped in historic values and industry relationships, causing a bottleneck in recent innovation system development. The UK case additionally demonstrates how innovation organisations have embodied different designs over time, reflecting the different approaches of the governments that created them. This shifted from seeking to engage closely with firms as private, arms-length entities to the development of technology specific organisations guided by an Industrial Strategy.

The UK's centralised electricity system now faces increasing pressure to deliver clean electricity innovation, as concern over climate change and markets for new technology trajectories have gathered momentum. This will require increased institutional disruption, as more radical changes to system infrastructure, markets and regulation will be required. If firms and actors are unable to evolve or adapt at the same speed as these institutional changes, they may become obsolete, encouraging the emergence of further innovation. As centralised institutions and infrastructure remain dominant, past trajectory suggests that change may evolve slowly over time in a top-down manner, with decentralisation of markets for example likely to face ongoing political inertia.

RQ2: How does the design of publicly funded innovation organisations affect their role in accelerating clean electricity innovation?

Application of ten principles for organisation design to the ETI and ARPA-E demonstrates that it is essential to design an organisation in alignment with the aims of its mission.

Whilst the ETI intended to accelerate transformative energy innovation, its design caused it to prioritise the support of incremental innovation, failing to operate as the agile, entrepreneurial organisation it had initially hoped to be. This was due to two main factors. Firstly, whilst its public-private partnership approach created funding stability and strengthened links with private members, the influence of six incumbent energy firms led to capture of the ETI's technology trajectory as the risk profile of the mission proved too high. Embedding these industry members in its structure also affected accountability and the way the organisation was viewed in a changing policy environment, affecting the decision to discontinue its operation. Secondly, the ETI's operational approach was poorly matched to the aims of its mission. A lack of diverse staff competencies led to a technical and siloed approach to innovation, creating a cautious organisational culture. This contributed to external communication to be low, further affecting the organisation's accountability.

Conversely, ARPA-E engaged industry on a project-to-project basis via technology-to-market teams and drove initial market demand via public procurement by the Department of Defense. This ensured pull-through for its outputs whilst avoiding capture by the interests of specific firms. Lacking the stability of the ETI, which leaves it vulnerable in a more polarised policy environment, ARPAE- has sought to build strong accountability with the surrounding innovation system via active outreach and communications. Leadership has been focused on building these connections in order to deliver the vision of the organisation. ARPA-E also developed staff competencies well matched to driving its mission with urgency and flexibility, creating an operational approach that cultivated the culture needed to develop transformative innovation.

These findings demonstrate that organisations seeking to accelerate transformative innovation would benefit from adopting certain design aspects. These include attracting a diverse range of staff competencies that match the aim of the mission; involving a diverse range of firms able to support the desired innovation trajectory; securing funding independent from industry influence; developing clear, accountable metrics on successful progress towards a mission; effectively communicating innovation outputs; and engendering the support of broader institutional actors.

Some of the design principles require particular care in balancing, with natural tensions existing between them. For example, achieving stability of funding whilst maintaining flexibility and political autonomy proved difficult in both the case of the ETI and ARPA-E. This suggests that policy makers may need to make design trade-offs depending on their desired innovation trajectory.

RQ3: How has national context affected the design and approach of publicly funded innovation organisations?

Whilst the design of an organisation is important, ultimately it needs to be supported by the national institutions in which it operates, in relation to policy environment, role of industry and the wider innovation system. Whilst the UK and US share similarities in historic energy system development and approaches to innovation policy, these national institutions served to shape the design and operation of the ETI and ARPA-E differently. This further demonstrates the need for policy makers to develop nationally tailored organisations, with approaches that have worked in other countries a product of complex institutional interactions even if there are similarities in political economy, for example. It additionally reveals that organisation design is a product of shifting priorities and understandings of the role and value of energy innovation across complex institutions, as opposed to set liberal market economy values producing a set suite of design tools allowable to accelerate clean electricity innovation.

A key difference in national context is the higher levels of energy system privatisation and liberalisation in the UK, facilitated by centralised government decision making. This has led to the loss of publicly funded test infrastructure and for energy policy to become influenced by a small number of large incumbent firms throughout the 1990s. This process greatly diminished the strength of the UK's clean electricity innovation system, with the development of the ETI seeking to reinstate some demonstration capacity. Conversely the US maintained its national lab infrastructure and the levels of privatisation and liberalisation differ from State to State. This enabled ARPA-E to form part of a stronger innovation system, which included more porous ties between labs, universities and industry. The organisation prioritised networking with these actors and other DOE institutions to create technology pull through in a way that the UK innovation system could not facilitate for the ETI.

Another key difference was the political framing of the organisation's missions. The ETI was framed in relation to tackling climate change, an issue which became more politically relevant over its lifetime. It represented a new approach to engaging the private sector in aiming to de-risk the development of technologies at later TRLs to accelerate deployment. Conversely, US political polarisation around climate change led ARPA-E to be primarily framed as a means to regain an economic advantage in energy innovation. It sought to replicate DARPA, which had proven effective at earlier stage technology development where Federal intervention was viewed as politically appropriate. These national conditions therefore preconditioned the way the organisations were positioned in relation to innovation system engagement, based on political acceptability.

The knock-effects of institutional context on the ETI's design effected its ability to accelerate transformative energy innovation in several ways. Firstly, it embedded incumbent firms due to a lack of public knowledge on energy innovation; secondly, its approach was completely experimental in the space and ultimately ill-adapted to transformative innovation; thirdly, it was not supported by market pull through via complementary policies and organisation; and finally, the financial crisis of 2008 reduced the willingness of public and private partners to accelerate the riskier, transformative projects its mission alluded to. These broader institutional factors additionally contributed to the adoption of the wrong competencies to drive transformative innovation.

The ETI influenced the surrounding institutional landscape by contributing to the ongoing accumulation of skills and knowledge within the energy innovation system, which built public sector competencies in this area. For example, ESME has since been used by different government departments to understand the UK's energy system needs and competencies developed in low carbon heat have become part of the Energy Systems Catapult. Therefore, whilst the design of the ETI was not conductive to driving transformative innovation, its operation has influenced and strengthened surrounding institutions pursuing accelerated energy innovation.

The knock-effects of institutional context on the ARPA-E's design effected its ability to accelerate energy innovation in the following ways. Firstly, ARPA-E's design was closely based on the existing highly successful and longstanding innovation organisation (DARPA), meaning that the parameters and positioning of its mission within the innovation system were clear; secondly, it was supported within a coherent energy innovation system that contained well defined older and newer organisations and institutions that were well understood and networked; thirdly, its positioning as a means to boost economic advantage as a recovery response to the 2008 financial crisis meant that it gained cross party support and be viewed beyond its focus on climate change; and finally, as the availability of venture capital reduced the DoD stepped in to provide early stage market pull through, as it does for DARPA applications. These broader institutional factors enabled ARPA-E to adopt the right leadership and competencies needed to effectively network it into this space and drive transformative innovation, while having the flexibility to respond to changing markets and priorities.

ARPA-E has influenced the institutions around it by effectively communicating with and networking other innovation system to support the pull through of transformative energy innovation. It has created a level of political stability around the need to drive energy innovation by demonstrating its economic value and ability to accelerate innovation.

5.2. Theoretical contributions

This thesis makes a key contribution to the emerging literature on effective organisation design for accelerated innovation. By focusing on clean electricity innovation in the UK and US, which have both established major new organisations to support accelerated low carbon innovation, it analyses how these organisations fit into a changing innovation system for clean electricity. It also provides a new, in-depth understanding of the political factors that have shaped these systems and innovation organisations to date.

The theoretical contributions in this regard are twofold. Firstly, a refined layered institutional framework was applied to gaining a comprehensive understanding of the effect of national institutions on clean electricity innovation system development. Secondly, ten principles for accelerated innovation organisation design are refined and further developed, which are utilised to demonstrate the importance of design in effectively implementing desired innovation outputs. These are discussed in turn below.

1. Increases understanding of the impact of multiple layers of institutions on the development of clean electricity innovation systems

This thesis contributes to the innovation systems literature by refining a framework from the historical institutionalism literature, bringing new insights to the role of institutions in clean electricity innovation system development. This enables theoretical linkages to be made between innovation systems, political science, and the new institutionalism literature, increasing understanding of how institutions interact and change over time to affect innovation trajectories.

Via empirical application, paper 1 demonstrates that institutions evolve at different speeds across multiple layers, impacting the trajectory of and change within an innovation system. For example, it reveals the impact of longer lived, informal institutions in which formal institutions are nested. These enduring norms and values continue to favour particular technological, economic and political approaches over time. This affects the direction in which the innovation system evolves, leading to certain technology trajectories being more likely than others. Accelerated clean electricity innovation policy making should be considered within this broader institutional landscape if whole system change is to be achieved.

The application of a historic institutional lens therefore contributes to knowledge of how new facets of an innovation system emerge and link with existing aspects, demonstrating how issues related to lock-in can be overcome, as the institutions within which the innovation system sits evolve. This echoes the increasing interest in historical institutional approaches in the sustainability transitions literature, which have begun to yield useful results in relation to energy transition (Lockwood et al., 2017; Geels et al., 2016; McMeekin et al., 2019).

2. Refines and further develops a set of ten principles for accelerated innovation organisation design

A key theoretical contribution of this thesis is the refinement and further development of a framework of ten principles for publicly funded accelerated innovation organisation design. The framework bridges knowledge on the impact of national institutions on organisation design, evidenced in paper 1, with empirical research exploring external and internal design aspects on innovation delivery.

Paper 2 refines the principles in relation to the sustainability transitions literature, addressing a gap in knowledge in relation to the role of individual actors in transition and organisations in particular (Jacobsson & Bergek, 2011; Köhler et al., 2019). Paper 3 further develops the framework, refocusing the principles of competencies and flexibility on internal as opposed to external organisational operation. This was achieved by incorporating empirical observations from paper 2 and literature on effective innovation organisation design (Breznitz et al., 2018; Glennie & Bound, 2016; Chan et al., 2017; Anadon et al., 2011; Bonvillian, 2018; Azoulay et al., 2019).

Application of the principles demonstrates the importance of considering both the broader, national institutions in which an organisation is developed and the internal operational approach that it adopts. The balance of these will determine the extent to which it is able to pursue its mission in relation to accelerating innovation. They also demonstrate how organisations can create agency within the surrounding institutional environment, as identified by Scott (2008). These findings are particularly relevant to the emerging sustainability transitions literature which is interested in the role of innovation system actors and organisations in accelerating transition within a broader regime.

5.3. Empirical contributions

Application of the two frameworks discussed above have also yielded valuable empirical contributions.

Paper 1 constitutes the first in-depth analysis of the role of institutions in the development of the UK clean electricity innovation system, demonstrating how these interactions have changed and shaped its evolution over time. This contributes to a growing body of research exploring the dynamics of the UK's energy transition, such as that on changing policy paradigms (Kern et al., 2014) and the role of incumbent firms (Geels et al., 2016; Kattirtz et al., 2021), regulatory frameworks (Lockwood et al., 2013; 2015) and political institutions (Kuzemko et al., 2016) in shaping system change. It also builds on innovation studies literature that addresses UK clean electricity acceleration, as the landscape has continued to evolve (Winskel & Radcliffe, 2014; Winskel et al., 2014a; Foxon et al., 2007).

Paper 2 develops the first analysis of the ETI's effectiveness in accelerating innovation. This contributes to the emerging literature concerned with understanding effective innovation organisation design (Breznitz et al., 2018; Glennie & Bound, 2016; Chan et al., 2017). It is also relevant to the sustainability transitions literature identified above, as the role of actors and organisations become a growing research priority (Martiskainen & Kivimaa, 2018; Köhler et al., 2019).

Finally, paper 3 provides the first comparison of the design of the ETI and ARPA-E in relation to their role in accelerating innovation. Whilst the structure and operation of ARPA-E has received attention from several scholars interested in understanding its role in accelerating innovation (Azoulay et al., 2019; Bonvillian, 2018; Haley, 2017), it has not been compared in detail with another organisation for accelerated clean energy innovation. This offers new, comparative insights into the success of its design and how organisations in different national contexts might be able to integrate these.

These empirical findings demonstrate that these frameworks could also yield insights into the development of other sectoral innovation systems, like agriculture or water, and how this affects the design of innovation organisations within these sectors. Additionally, while the time periods studied ranged up to 18 years, so long as sufficient data is available these frameworks could be utilised to guide longer or shorter-term enquiries. The attention of this thesis on Layer 4 of framework 1 also indicates the opportunity to understand other institutional layers within their broader context. A focus could then be taken at any layer for example, with activity in the other layers framing and making sense of the evolution that has taken place.

5.4. Policy implications

The policy implications of this thesis centre around the need for policy makers to pay greater attention to institutional context when designing innovation systems and publicly funded organisations for accelerated innovation. These insights are particularly relevant given the urgent need for governments to develop new approaches to accelerate clean electricity innovation to meet climate change commitments (IEA, 2020a). Paper 1 primarily contributes to the navigation of broader institutions, whilst papers 2 and 3 focus on accelerated innovation organisation design. These broad themes are discussed in turn below, followed by more specific suggestions in relation to their application to the UK clean energy innovation system.

1. National institutional context

As policy makers seek to accelerate whole system change, innovation policy should be viewed within its broader institutional setting. This would enable institutional blocks within a system beyond policy environment to be identified and appropriate interventions acknowledged, for example specific to UK policy the need to address ongoing innovation bottlenecks created by regulatory structures and centralised electricity markets (Markard et al., 2020). Addressing these broader blockages is recognised as key by Markard et al. (2020) if whole systems innovation is to be accelerated.

For policy interventions to be effective in accelerating change across systems, they should be designed to work effectively with, or challenge actors in, other institutional layers. For example, a certain funding approach that appeals to both major political parties could be adopted, or a specific alliance of firms created. This requires a more transparent, systemic approach to clean electricity innovation policy making and an understanding of which actors should be engaged to facilitate this deeper coordination. In this regard, policy and organisational interventions should seek to transcend changes in administrations and civil servants. Policy makers should seek to adjust their aims and operation over time as opposed to scrapping them entirely, which led to the complex organisational landscape in the UK in the late 2000s. This would prevent breaks in continuity and market confidence, enabling specialised capacity and resources for accelerated innovation to develop.

Finally, policy makers should seek to engage a greater diversity of industry voices as the energy system continues to change. This will enable government actors to build the knowledge and competencies required to accelerate innovative progress and become less prone to incumbent lobbying. At present, UK policy makers are only able to engage with emerging firms at a low resolution, suggesting that greater investment in developing forums, events and links with industry associations could assist in increasing interaction.

Managing industry relationships to create greater consistency in a changing policy environment is key, as the timeline over which energy innovation takes place is generally longer than that of an incumbent government or the position of a civil servant. Policy makers should seek so send as strong a signal as possible to businesses on desired technology direction, to create confidence in investment and the accumulation of skills needed to drive market development. In the UK, the success of offshore wind represents how consistent, technology specific support can lead to the development of a new national and international clean electricity technology market. A technology specific approach to overcoming institutional barriers may therefore also prove effective in accelerating progress.

2. Designing publicly funded organisations for accelerated innovation

The findings of this thesis reinforce analysis by Breznitz et al. (2018), wherein organisation design enables some types of innovation while simultaneously constraining others. When designing an organisation to accelerate innovation therefore, policy makers should not seek to apply ‘the one most effective model’ and instead consider what approach matches their specific national innovation aim.

Policy makers should consider that while design is important, the ability for an organisation to address its mission is strongly dependent on the support of the broader institutional environment. This includes a conducive policy environment, surrounding innovation system actors and engagement of appropriate firms in market development. The vision and outcomes, public/ private relationships and operational approach that work within this to deliver its mission can then be balanced through careful consideration of how the external and internal dynamics of an organisation can facilitate progress towards this. The design of ARPA-E in delivering its mission was therefore much better aligned than that of the ETI, as its careful positioning within a pre-existing, well networked energy innovation system enabled it to pursue transformative innovation capable of delivering economic competitiveness via cooperation with national labs and early market off takers.

Via empirical application to the ETI and ARPA-E, more generalisable aspects of the ten principles for accelerated innovation organisation design emerge. These include: attracting a diverse range of staff competencies that match the aim of the mission; involving a diverse range of firms able to support the innovation outputs desired; securing funding independent from industry influence; developing clear, accountable metrics on successful progress towards a mission; effectively communicating innovation outputs; and engendering the support of broader system actors.

Empirical application also demonstrated that whilst the UK and US share overarching similarities in political economy and energy system development, their broader institutional environment shaped the emergence and success of very different organisations for accelerated clean energy innovation. This demonstrates that policy makers need to carefully consider how successful aspects of organisation design observed other different national settings may translate to their own. It additionally suggests that the generalisable aspects identified above may not be unique to one specific political economy setting and so applicable to a broad range of national settings.

3. Insights for strengthening the UK energy innovation system

In addition to the broader observations discussed above, the comparison between the UK and US clean energy innovation systems also reveal more specific insights into how the UK energy innovation system may benefit from learning from the US. Three suggestions are introduced below and, as discussed, would need to be contextually researched and grounded within the UK's national context to understand the extent to which they could be successfully implemented.

1. Strengthen and coordinate early-stage philanthropic and venture capital investment

The US energy innovation system seeks to leverage philanthropic capital in early innovation stages (as discussed in Section 4.4.1), an approach almost entirely absent from the UK system. A successful example from the US is that of the Prime Coalition, a charitable organisation that has worked with 150 philanthropic partners since 2014 to provide 'catalytic capital' for climate solutions[22]. This suggests that UK policy makers could seek to understand the current national philanthropic capital ecosystem and how to effectively leverage this to increase engagement in early-stage energy innovation projects.

The US also possesses a strong network of regionally focused and funded energy innovation incubators and entrepreneurial networks[23][24]. These increase access to government capital and resources whilst facilitating the development of regionally appropriate skills and technology (see Doblinger et al., 2019; Uyarra et al., 2016). In addition, organisations like Cyclotron Road[25], run as a national lab offshoot, seek to crowd venture capital into this space be

[22] Prime Coalition: What is the Prime Coalition? Available at: https://primecoalition.org/what-is-prime/ Accessed: 21.11.21
[23] National Renewable Energy Laboratory: Innovative Networks. Available at: https://www.nrel.gov/innovate/networks.html Accessed: 21.11.21
[24] US Department of Energy: List of national Incubators and Accelerators. Available at: https://www.energy.gov/eere/buildings/incubators-and-accelerators Accessed: 21.11.21
[25] Cyclotron Road. Available at: https://cyclotronroad.lbl.gov/ Accessed: 21.11.21

improving access to publicly owned national lab infrastructure. While the UK is geographically much smaller, greater support from Innovate UK for example could enable stronger regional business networks to emerge, which may assist and overcoming issues of low resolution at a government level by strengthening voice and coordination across the UK.

2. Support revolutionary, early-stage research

The insights in this thesis are particularly relevant in the current context of UK innovation policy making, where £800m has been ringfenced for the development of a British 'ARPA' style organisation (Makortoff, 2020). Indeed, the Science and Technology Committee recently requested written evidence on the design that this organisation could take, to which evidence from this thesis was submitted (Watson & Watson, 2020).

The UK energy innovation system not currently fund specifically revolutionary research at TRLs 2-5, which means that the ARPA model could prove complementary and effective in accelerating the progress of transformative technologies (see Azoulay et al., 2019). If funded, it could focus on a transformative 'net zero' focused mission concentrating on 'technological white spaces' where risks are too high for current funders (Bonvillian, 2018), avoiding duplication or competition with the UKRI and the Catapults. Indeed, outputs could go on to be supported by Innovate UK and the Catapults and potentially complement more specific, industry-led programmes being funded by the Industrial Strategy Challenge Fund (Watson & Watson, 2020). Given the complexity of delivering net zero, a mission-oriented ARPA organisation could support ongoing efforts in this area, which will benefit from a plurality of approaches to supporting innovation (Hekkert et al., 2020). A UK ARPA could therefore represent an important piece of the jigsaw in accelerating mission- oriented energy innovation policy (Policy Exchange, 2020).

3. Explore opportunities to create stronger routes to market

The UK could explore the potential of leveraging public procurement to accelerate the commercialisation of clean energy solutions. As discussed in Section 4.5, both ARPA-E and DARPA leveraged Defense procurement as a means to create early-stage markets and large scale pull though for their innovative outputs. Indeed, 'green public procurement' represents an emerging area of policy research, which seeks to understand the role of procurement in driving demand for low carbon innovation (Rainville, 2017; Cheng et al., 2018). Initial case studies have indicated its effectiveness in driving demand smaller European countries (Testa et al., 2016), demonstrating its potential applicability in the UK. These insights could be investigated by government departments in relation to incorporating innovative low carbon technologies into existing assets, such as buildings or vehicle fleets. This could assist in providing a sizable early-stage market for these technologies, generating pull-through and accelerating commercial adoption.

This is being complemented by the development of regulatory environments more conductive to encouraging and incorporating firm-led innovation. Since this thesis was researched in 2018, Ofgem have improved the regulatory environment to incentivise the development of new business models (see BEIS, 2021), with the Balancing Mechanism for example facilitating electric vehicle to grid demand response (Ofgem, 2021).

5.5. Avenues for further research

Contemplating the contribution of this thesis to the literature, and its ultimate limitations, this section provides some suggestions for future research.

Firstly, the conclusions of this thesis are drawn from qualitative data analysis, inevitably leading to qualitative bias. Several avenues for quantitative analysis that would further enhance findings are apparent. In the context of the UK innovation system, analysis of data available on public clean electricity innovation funding, from the EPSRC for example, could reveal further details of the relationship between technology policy and national research funding over time. Additionally, a quantitative analysis of the ETI would be particularly beneficial, to match research on its operational outcomes with greater detail on funding by technology and TRL; aspects of project consortia engagement; and how much follow-on funding has been received. These quantitative contributions would further contextualise qualitative findings and provide more technology specific evidence.

Secondly, this thesis represents the first application of a layered institutional framework to a sectoral innovation system. In future applications, this could be further refined via the integration of theories of institutional change, developed by Thelen (1999; 2004), to better theorise *how* upward change occurs between layers over time, as discussed in Section 1.4.4.1. This is especially relevant to better understanding how institutions and actors interact to both produce stability and change within innovation systems. Whilst individual instances are explored in papers 2 and 3 in relation to actor interactions within organisations and the effect of this on the ten principles for innovation organisation design, a link has not been made to how these may play out more broadly across sectoral layers to drive accelerated low carbon innovation. This would enhance the framework's utility beyond an initial heuristic for how institutions interact and change, enabling it to provide a more robust lens through which this process can be analysed.

Further application of the framework would also be useful in addressing the issues identified in section 2.6 in relation to distinguishing the boundaries of each institutional layer. This may also demonstrate the framework's adaptability beyond a focus on energy innovation, to be applicable to other researchers also interested in understanding the role of institutions in innovation system development.

Finally, both analytical frameworks would benefit from being applied in other national contexts, with the UK and US selected for their similarities in relation to clean electricity innovation. This would test their utility in navigating different national institutional contexts and the robustness of the empirical findings of this thesis. Whilst it is expected that both frameworks would remain broadly relevant, application in a coordinated market economy like Japan or Germany for example, may yield very different results.

In this regard, the frameworks applicability to geographies beyond 'WEIRD' countries (Western, educated, industrialized, rich, and democratic), such as Latin America or Sub-Saharan Africa, where levels of wealth and energy infrastructure are vastly different, should also be explored. This would reveal the extent to which the observations made in this thesis are more broadly generalisable to innovation organisation design in any institutional context.

Application in relation to the effect of COVID and the opportunities created for a green recovery could also yield interesting results, as this global crisis may have caused a system shock or signalled a layer 1 change in national values relating to low carbon innovation.

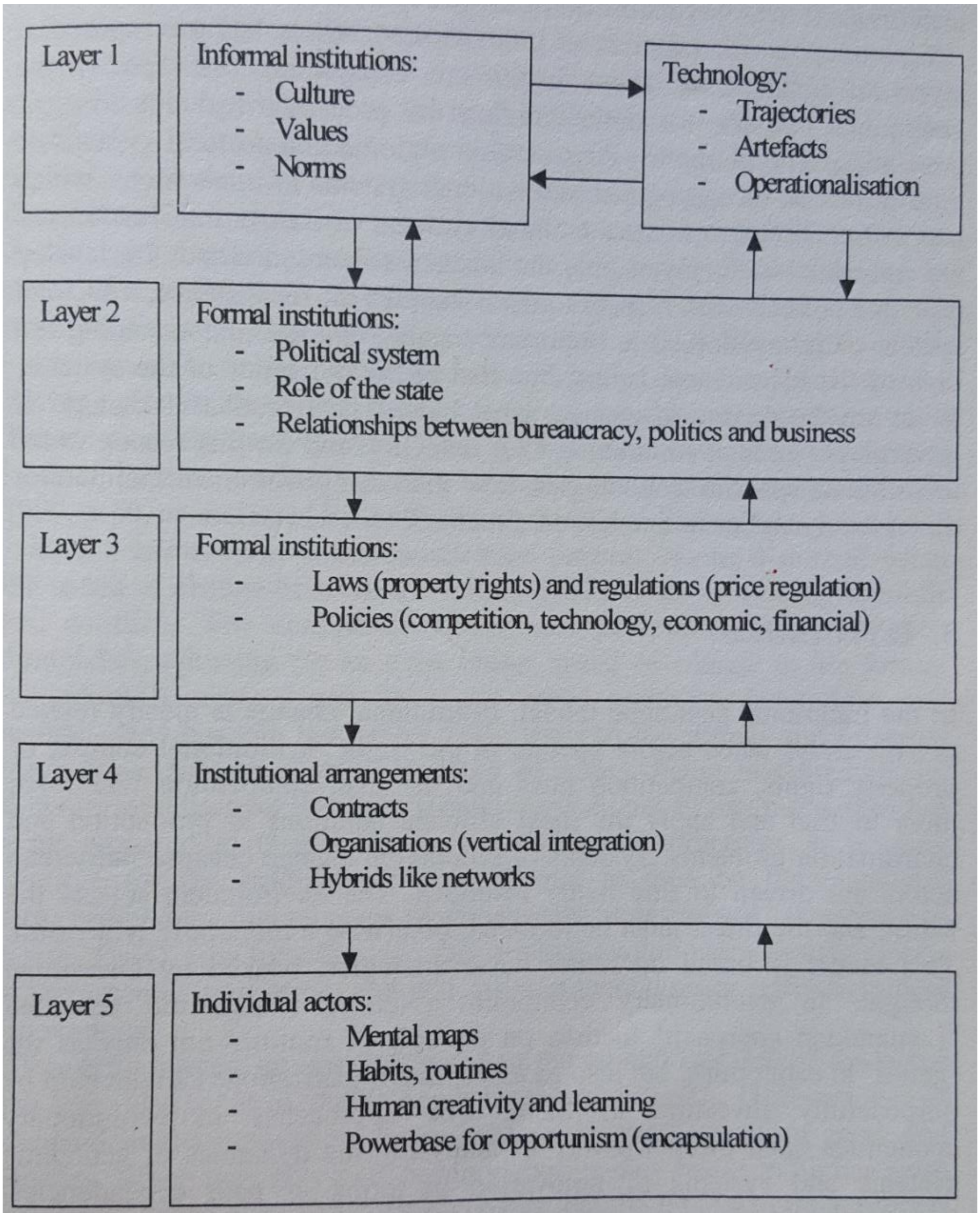
5.6. Concluding remarks

This thesis has demonstrated that publicly funded innovation organisations can adopt certain design principles to accelerate clean electricity innovation. National institutional context plays a key role in shaping the effectiveness of this, requiring policy makers to carefully balance different principles to match desired innovation outcomes. It is hoped that these findings assist policy makers in developing new approaches for supporting accelerated low carbon innovation, with well-designed innovation organisations essential to meeting national decarbonisation targets and the aims of the Paris Agreement.

6. Annexes

Annex A

Layered institutional model of an innovation system, developed by van der Steen et al. (2008, p.179).



Annex B

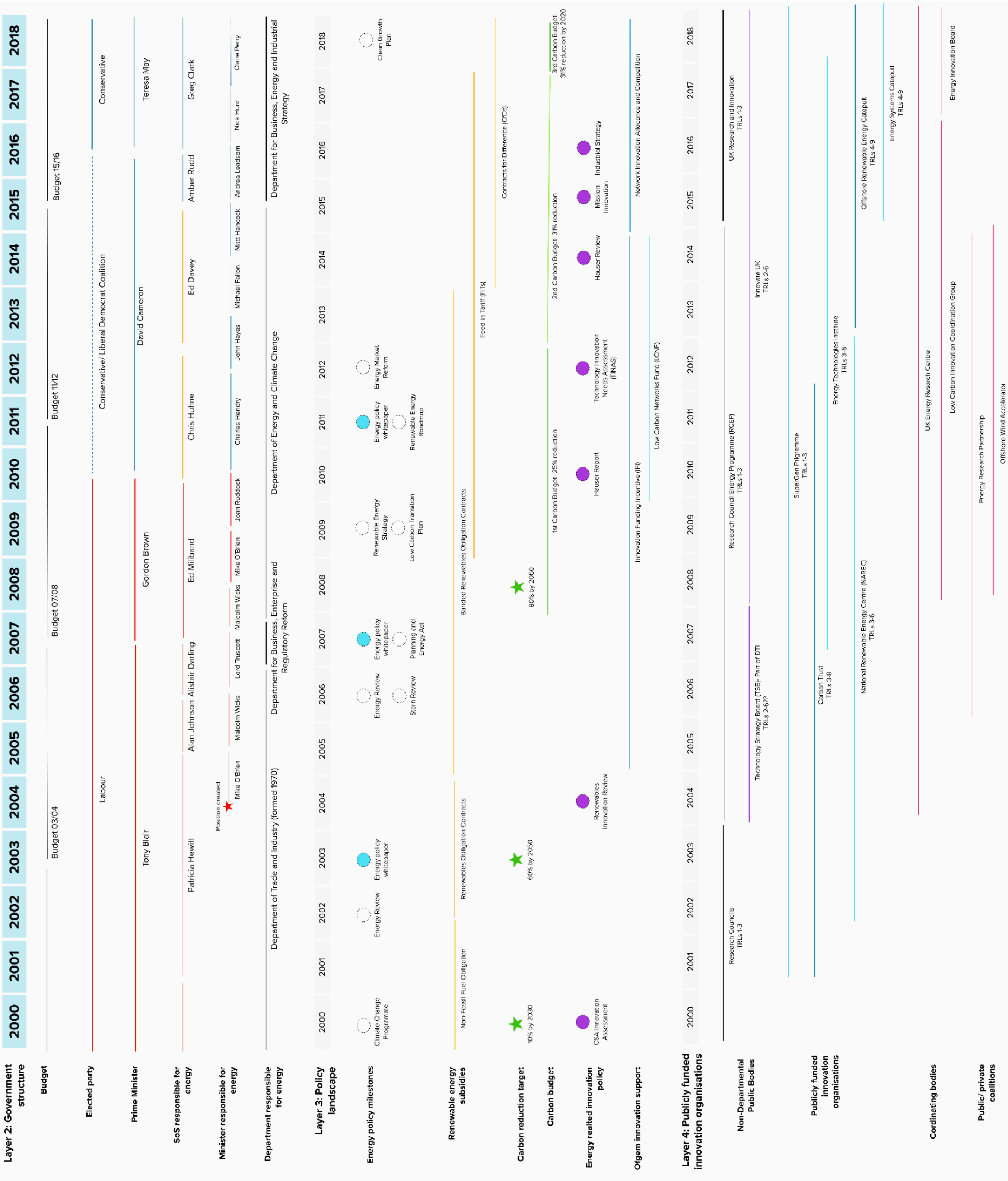
Examples of interview questions for paper 1.

Layer 1: Informal institutions- Culture, values, norms
What role do you see for the government in supporting clean electricity innovation? In what ways has political ideology impacted the approach of the government to addressing climate change and need for clean electricity innovation, as it has moved up the agenda since the early 2000s? How have visions for the future electricity system unfolded to impact the shape of current generation and infrastructure?
Layer 2: Formal institutions- Polity, structure of government, industry relationships
How does the government approach budget setting between different departments for innovation spending? What is the process through which energy innovation policies pass and are scrutinised? How easy is it to promote and pass policy? How did the creation of a specific Department for Energy and Climate Change impact the narrative around clean energy innovation? How do private sector actors engage with the government around innovation policy? - What is the influence of incumbent actors? - Are connections between government and industry largely informal? - Are there channels through which smaller, more innovative energy firms can input into future approaches?
Layer 3: Formal institutions- Policy, regulation
How does the government come up with innovation and R&D policies? Why are certain policies then picked to be supported and funded over others? How effectively has policy addressed support at the earlier research stages of technology development versus later stages of deployment and commericialisation? What processes or bodies exist to coordinate energy innovation strategy between governments departments and other stakeholders? What role has Ofgem played in shaping clean electricity RD&D?
Layer 4: Institutional arrangements- Public organisations, coordination
Who is it that decides to set up different organisations? What is the process of deciding what’s needed? What has driven different decisions at different times? Is the current organisational landscape effective in bringing the right funding and actors together? What kind of innovative outputs have these organisations produced? To ask people at a certain organisation: What are the key activities and priorities of your organisation? How has it been designed to fulfil these aims? How are R&D priorities and funding direction identified?

What impact does private sector engagement have on the innovation outputs of your organisation?
Layer 5: Individual actors- Habits and routines, creativity and learning
What approaches do incumbent system actors take towards pursuing clean energy innovation? To what extent have new actors been able to influence narratives and perceptions around approaches to clean electricity investment? To what extent have individual firms been able to embrace new approaches to clean electricity innovation? - Are firms able and willing to incorporate new ways of working in to their business models? - What support is there for this?

Annex C

Full diagram illustrating institutional change at Layer 2, 3 and 4, 2000- 2018.



Annex D

Examples of interview questions for paper 2.

1. Policy Environment
What were the policy conditions surrounding the creation of the ETI? - Was it created in response to a particular policy? - How did it sit within the existing policy mix? How does the ETI sit within the landscape of other innovation organisations? Is there any clash or overlap? To what extent is operation directly coordinated with government?
2. Embeddedness of Industry in Policy Networks
How is the ETI regarded by the private sector? What feedback have you received from partners? Is private sector engagement a simple, open process? Which other policy makers or organisations does the ETI actively look to engage?
3. Mission Orientation
What is the mission of the ETI? How has that mission been interpreted? Has the original mission been followed or has it changed? What aspects of achieving this mission does the ETI need to consider beyond itself?
4. Autonomy from Short-term Political Pressure
To what degree is the operation of ETI impacted by changes in political approach? How often does the ETI communicate with politicians? What sort of relationship does this facilitate? Is the ETI able to independently determine its own direction and supporting specific technologies?
5. Autonomy from Private Interests
How are funding decisions made within the ETI? What has been the influence of the private sector partners? Is the organisation able to fully align with achieving its mission? In what way do smaller private sector actors that receive funding influence the organisation?
6. Competence
How many staff members does the ETI have? Where were staff member generally recruited from? What is their level of expertise in their field? Is there a secretariat and a management board? How much influence does the management board have? Are there particular staff members that are called upon to deliver expert feedback to wider audiences?
7. Flexibility
How are decisions made around which projects are funded? - Is there a way of identifying ‘windows of opportunity’?

- How long does this process take? How is the success of projects monitored? If a project is under performing, can direction be changed? How many projects have failed? Is failure something that is seen as an intrinsic part of the organisation's operation or not something that's well tolerated?
8. Credibility
How does the ETI cultivate long term engagement with private sector partners? What has been the experience and feedback around this? What are the conditions around these relationships? Are they contractual, how much flexibility is there?
9. Stability
Has funding been stable over the ETI's ten-year lifetime? Has there been periods of high and low activity? Was this funding spent in such a way that it has left capacity for future organisations and industry to draw upon?
10. Accountability
How were the parameters for the success of the ETI initially set? How did the ETI seek to fulfil these? There is now a three year wrap up period, what will be judged as success at the end of this?

Annex E

Aspects of organisational flexibility and competence not addressed by Haley (2017).

Leadership	*"ETI was an obsession of one person, which is why it will come to an end"*
SME engagement	*"It was probably partly the introduction of sometimes multiple stages* (of partner selection) … *An initial selection which might then be shortlisted to two or three parties, which then led to another stage of the selection. There's s refinement of bids and so on, which obviously is time and overhead… There were plenty of other contractual aspects that we took time to work through, contractual negotiations."* (8) *"Then I think it takes longer to contract than we would like and the reason for that is that we want lots of leavers in our contracts to make sure that we can make the project successful"* (2)
Engaging new partners	*"I think that yes there is a role for PPPs but I think it needs to be more flexible as public interests change and you have M&A, individual projects come and go and a company may only be interested in X for as long as they're commissioning it or whatever's happening."* (12) *"I think this is where the current problem is, that if you had another ETI type arrangement then you are picking the people that are going to be playing ball at the start and you have to be flexible in order to be able to pull new people in as the innovation needs change and different things occur, and so I think there is an issue, and it will become increasingly an impediment over the next year or 2."* (21)
Competence	*"I think if there was any imbalance, the engineers around the table were mostly from an R&T-R&D background and, therefore, lacked some understanding of the difficulties of deployment… There was possibly a slight imbalance around the table in terms of the split between practical deployment skills and development skills… They were inherently a little bit more inclined to report back to the parent ship for authorization"* (7) *"The ETI came laterally to the idea of making venture capital investments… that's actually quite a quick way of testing technologies and deployments. One was very successful and the other one wasn't, but they only had a portfolio of two. That venture is actually a very good way of accessing deploying technology. I would suggest that, if we knew what we know now, the ETI portfolio may have been more balanced portfolio of ventures and, if you like, own projects."* (6)

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