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Facilitating and coordinating UK energy innovation through systemic innovation intermediaries

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Abstract

Research, development and demonstration (RD&D) can play a critical role in reducing the carbon emissions, costs and security concerns associated with the UK's energy supply, alongside supporting economic growth. However, the effectiveness of the UK's energy innovation system has been questioned and a number of entities have taken on system-level intermediary roles to help address these weaknesses. These entities operate at the interface between innovation actors, working to facilitate and coordinate innovation activities at the system-level. This paper examines how three such entities have served to foster energy innovation in the UK, namely the *Research Councils*, the *Technology Strategy Board* and the *Low Carbon Innovation and Coordination Group.*

Whilst there is some degree of overlap between these intermediaries' functions, they each perform their own valuable role in facilitating and coordinating energy innovation in the UK. Despite their relative strengths, this paper highlights a number of ways in which their functionality could be improved. Finally, a number of observations are made that theoretically contribute towards the systemic innovation intermediary literature. Most notably, the paper highlights that it is frequently direct RD&D funders who perform intermediary functions, that intermediaries tend to emerge in response to manifest needs and weaknesses rather than be purposively established, that both 'hard' and 'soft' intermediaries exist and that systemic intermediaries can be integrated and coordinated by 'super-intermediaries' that work at a higher system-level.

Key words: energy, systemic innovation intermediary, innovation, RD&D, UK

1 Intro

In light of the mounting challenges of climate change, energy security and energy affordability, the UK is facing growing pressure to accelerate its transition to a more sustainable energy system. This transformation will be facilitated by the research, development and demonstration (RD&D) of innovative energy products and services, which have the potential to reduce carbon emissions, costs and security concerns associated with its energy supply. Energy innovation can also boost economic growth by opening up new markets for novel energy products and services.

An innovation system can be defined as 'the elements and relationships, which interact in the production, diffusion and use of new and economically useful knowledge' (Lundvall, 1992 p.12) Various reports have highlighted concerns about the effectiveness of the UK's energy innovation system (CCC, 2010, IEA, 2012, NAO, 2010, Skea et al., 2013), emphasising that the UK's energy RD&D budgets are below the global average and that raising this level would put the UK in a much stronger position to meet its various energy and economic objectives. However, they also identify wider issues around a lack of integration, collaboration and coordination between key energy innovation actors. Therefore, raising RD&D funding is considered to represent only part of the solution and that complementary approaches to enhance the effectiveness of the UK's energy innovation system are also needed.

In this context a number of entities in the UK have either taken on, or have been established to play, *system-level innovation intermediary roles* (Howells, 2006, Klerkx and Leeuwis, 2008b, Klerkx and Leeuwis, 2009, van Lente et al., 2011). Systemic innovation intermediaries are defined in this paper as entities that operate at the interface between multiple innovation actors, working to facilitate and coordinate innovation activities at the system-level (Kilelu et al., 2011, Klerkx and Gildemacher). They perform a range of functions that are characteristically distinct from direct RD&D funding, characterised as *demand articulation, network building, capacity building, innovation process management, knowledge brokering, and institutional support* (Kilelu et al., 2011). Whilst bodies can be specifically established to perform these functions, in the UK they have typically taken the form of public or public-private entities that had initially been established to allocate public RD&D funding but have subsequently stepped into the role of innovation intermediary in response to manifest needs and weaknesses in the innovation system.

Previous research has examined how systemic innovation intermediaries have facilitated innovation in various sectors, the majority focusing on agriculture (Kilelu et al., 2011, Klerkx and Leeuwis, 2008b, Klerkx and Leeuwis, 2009, Klerkx and Leeuwis, 2008a), technology (Dalziel and Parjanen, 2012, Munkongsujarit and Srivannaboon, 2011) and health (Boon et al., 2011). Research in the energy sector has tended to view these entities as a form of governance mechanism, focusing on their ability to 'influence the pursuit of collective goals' (Marvin, 2011), rather than as a means of facilitating and coordinating energy RD&D (exceptions include: Chen et al., 2014, Kivimaa, in press, Hargreaves et al., 2013).

This paper examines the activities of three of the highest profile systemic innovation intermediaries in the UK: the *Research Councils;* the *Technology Strategy Board (TSB);* and the *Low Carbon Innovation and Coordination Group (LCICG)*. Evidence is drawn from the outputs from a series of workshops undertaken as part of the development of an energy research and training needs

Prospectus[1] to help the UK Research Councils plan their energy programme. The paper explores the conditions that led to the emergence of these bodies, the intermediary functions they perform and how they have worked alongside one another in light of their differing objectives and expertise. It also presents a number of recommendations to enhance the impact of the intermediaries on the effectiveness of the energy innovation system. Finally, the paper explores how these findings contribute towards our understanding of how systemic innovation intermediaries function and how they serve to support innovation.

The paper is structured as follows. Section 3 reviews the current literature on innovation systems and systemic innovation intermediaries, with a specific focus on the energy sector. Section 4 outlines the empirical methods used. Section 5 presents an overview of the UK's energy innovation system and the various innovation intermediaries operating in it. Section 6 presents the results of the empirical investigation. Section 7 presents a number of recommendations to improve the performance of the UK's energy innovation intermediaries. Section 8 presents the paper's conclusions.

2 Literature Review

2.1 Innovation systems

At first scholars understood the 'innovation journey' as a linear process, whereby basic research was followed by applied development, demonstration and diffusion. Today, it is widely understood that innovation does not necessarily proceed in a linear fashion and instead the stages of the innovation process are linked, with feedbacks between each stage (Kline and Rosenberg, 1986, Brooks, 1995). Consequently, while some basic research challenges are of a 'blue sky' nature, others may be defined by problems or solutions identified at later stages in the innovation process. This complex process is illustrated in Figure 1.

1 https://workspace.imperial.ac.uk/rcukenergystrategy/Public/reports/Final%20Reports/RCUK%20Brighter%20energy.pdf

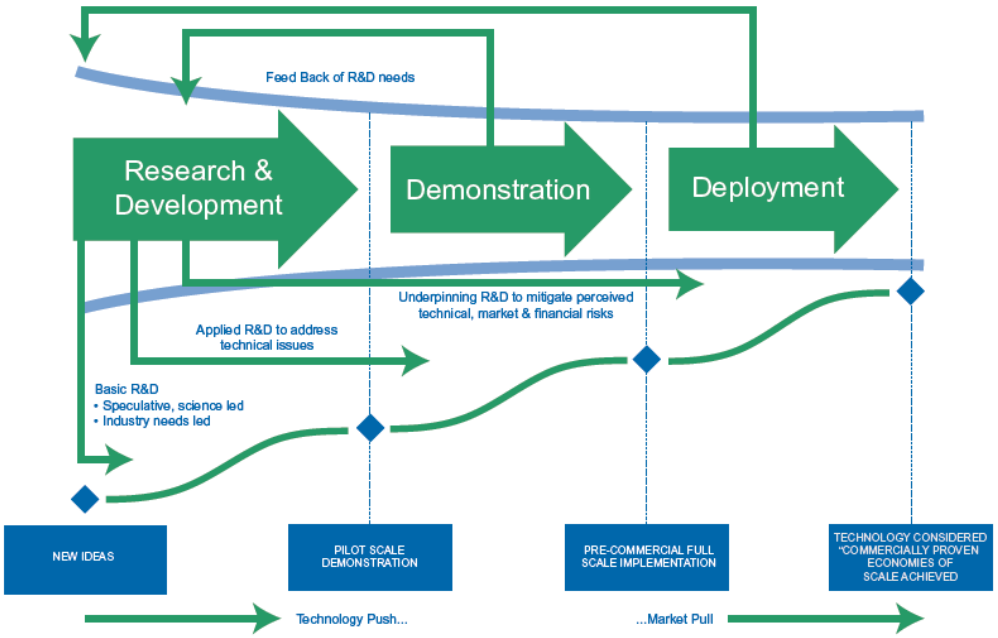

Figure 1: The non-linear innovation process (Energy Research Partnership, 2007)

Building upon this non-linear model of innovation, innovation scholars began to turn their attentions towards the institutional context within which innovation processes occurred (Nelson, 1993, Geels, 2004). These developments led to the emergence of a more systemic approach to innovation in the 1980s known as the innovation systems literature, which emphasised the evolutionary nature of the innovation process, as well as the critical importance of actors, networks and institutions to this process (Grubler et al., 2012, Truffer et al., 2012).

In its broadest sense an innovation system constitutes 'the elements and relationships, which interact in the production, diffusion and use of new and economically useful knowledge' (Lundvall, 1992 p.12). Grubler et al. (2012) 'unpack' this concept further to explain that:

> *'Innovation is understood as an interactive process involving a network of firms and other economic agents (most notably users) who, together with the institutions and policies that influence their innovation and adoption behaviour and performance, bring new products, processes, and forms of organization into economic use (Freeman and Perez, 1988, Nelson and Winter, 1982, Lundvall, 1992).'* (p.1676)

Various strands of theory make-up the innovation systems literature, each adopting a different unit of analysis. Whilst this paper does not explore these in detail (see Markard et al., 2012, Truffer et al., 2012), the four main categories are: technological innovation systems (TIS); national innovation systems (NIS); regional innovation systems (RIS); and sectoral innovation systems (SIS). Scholars have identified a number of key processes that are critical to the performance of these different types of innovation systems, commonly known as 'functions of innovation systems' (Bergek et al., 2008, Hekkert et al., 2007, Musiolik and Markard, 2011). These include: *knowledge creation and diffusion; influence on the direction of the search; entrepreneurial experimentation; market formation; creation of legitimacy; resource mobilization;* and *development of positive externalities* (see Truffer et al., 2012).

2.2 Innovation Intermediaries

2.2.1 The role of innovation intermediaries

It has long been acknowledged that intermediary organisations can play an important role in ensuring that an innovation system performs the functions listed in the previous section as effectively as possible. In the broadest sense, an intermediary organisation is a body that operates in the space between other actor groups (Moss, 2009). Hodson and Marvin (2008) explain that intermediaries mediate, 'they work in-between, make connections, enable a relationship between different persons or things' (p.2), playing an active role in ordering and defining relationships.

The intermediary concept has given rise to the term 'innovation intermediaries' i.e. organizations or bodies that act as agents or brokers between two or more parties in any aspect of the innovation process (Howells, 2006):

> *Intermediary activities include: helping to provide information about potential collaborators; brokering a transaction between two or more parties; acting as a mediator, or go-between, bodies or organizations that are already collaborating; and helping find advice, funding and support for the innovation outcomes of such collaborations'* (p.720).

Such bodies are 'focused neither on the generation nor the implementation of innovations, but on enabling organizations to innovate'(Klerkx and Leeuwis, 2009 p.851). Therefore, intermediary activities do not contribute substantively to the content of innovations, instead facilitating their development and deployment (Kilelu et al., 2011).

Traditionally the innovation intermediary has been understood to operate at the firm-level, establishing bi-lateral agreements between *knowledge producers* (e.g. experts who could provide creative solutions to these problems) and *knowledge users* (e.g. companies who want to solve a particular problem) (Abbate et al., 2013). van Lente et al. (2011) note that these 'traditional' innovation intermediaries normally operate bilaterally and focus on supporting individual organisations. In recent years however the concept of innovation intermediaries has developed to include those who operate at the level of clusters or networks of firms or even at 'higher system aggregation levels in innovation systems that involve complex constellations of business, government, and societal actors, dealing with complex problems (i.e. 'system innovation')' (Klerkx and Leeuwis, 2009 p.85). These *systemic innovation intermediaries* perform a more independent role, working to facilitate innovation at a higher system-level, such as a specific sector, region or nation. Other terms have also been used to refer to systemic intermediaries, including: 'third parties, brokers, bridging organizations, technology transfer intermediaries, -infrastructures or -organizations, and boundary organizations'(Klerkx and Leeuwis, 2009 p.850). This paper adopts the term 'systemic innovation intermediary' and defines it as an entity that operates at the interface between multiple innovation actors, working to *facilitate* and *coordinate* innovation activities at the system-level (Kilelu et al., 2011, Klerkx and Gildemacher, 2012).

In terms of *facilitation*, systemic innovation intermediaries are often regarded as innovation catalysts (Klerkx and Leeuwis, 2009) or the 'spark plugs' of innovation (Malecki and Tootle, 1996), helping to address innovation system weaknesses in order to foster innovation that might have otherwise not taken place (Johnson, 2008, Smits and Kuhlmann, 2004). These can include underdeveloped markets, misaligned institutional incentives, poorly structured actor networks and

limited resources to support innovation processes (Alkemade et al., 2007). On this basis Klerkx and Leeuwis (2009) argue that systemic innovation intermediaries 'create connectedness within the system, and have an 'animator' role of creating new possibilities and dynamism within a system, acting as a catalyst (Smits and Kuhlmann, 2004, Howells, 2006, Candemir and van Lente, 2007)' (p.852).

Systemic intermediaries also perform a more strategic role, *coordinating* or managing innovation processes (Klerkx and Leeuwis, 2009, Hearn and Rooney, 2002, Smith, 2000). Consequently, these bodies can be established by other organisations, most notably government, to help direct innovation in such a way that helps to meet their objectives. For instance, van Lente et al. (2011) argue that systemic intermediaries could play a key role in coordinating the efforts of industry, policy-makers, research institutes etc. towards developing and deploying the type of innovation that is concomitant with wide-scale sustainable production and consumption.

Drawing these ideas together as part of their in-depth literature review Kilelu et al. (2011) present six key functions these bodies perform (Klerkx and Leeuwis, 2008b, Klerkx and Leeuwis, 2009, van Lente et al., 2011, Smits and Kuhlmann, 2004, Howells, 2006, Kristjanson et al., 2009, Klerkx and Leeuwis, 2008a). These are presented in Table 1.

Table 1: Functions and specific activities of systemic innovation intermediaries (Kilelu et al., 2011)

Function	Related activities	Sub-activities
Demand articulation	Scanning and scoping	Gathering information
		Identify opportunities
	Foresight	Strategic planning
		Visioning
		Brainstorming
	Diagnosis	Needs assessment
		Knowledge gaps assessment
		Demand stimulation
Network building	Gate keeping	Filtering
		Selecting collaborators
	Match making	Linking and coordinating
		Forming partnerships
		Market linkages
Capacity building	Organisation development	Initiating organisations
		Organisations/group dynamics management
		Incubating enterprises
	Training and competence building	Managerial skills
		Certification/standards
		Technical skills
Innovation process management	Mediating and arbitrating	Managing conflict
		Negotiating
		Interface management
	Learning	Providing space/platforms
	Aligning agendas	Building trust
		Complementary assets sharing
Knowledge brokering	Disseminating knowledge	Transferring
		Advising
		Informing
	Communicating knowledge	Experimenting
		Peer exchange
		Demonstrating
	Matching knowledge demand and supply	Sourcing
		Articulating experiential/indigenous knowledge
Institutional support	Boundary work	Interfacing science and practice
		Platform for policy advocacy
	Institutional change	Facilitating changes in rules/regulation
		Working on attitudes and practice

2.2.2 The characteristics of innovation intermediaries

The core characteristics of innovation intermediaries are briefly explored in this section.

Firstly, innovations often struggle to progress from one stage in the innovation chain through to the next due to difficulties in securing the necessary funds to support their continued development. This phenomenon is often referred to as the 'valley of death' or the 'innovation gap' and can be explained by the mismatching objectives and incentive structures associated with the research and business communities (Partha and David, 1994). Consequently, systemic intermediaries typically

position themselves at these 'hand over' points or linkages along the innovation chain, such as between universities which undertake basic research and private-sector RD&D labs which further develop this research through applied RD&D and demonstration or between these labs and companies looking to commercialise these products or services at scale. Innovation intermediaries are the only organizations that purposefully position themselves in the innovation gap with the aim of enhancing innovation system capacity by intermediating on the intercommunity level between the business and research communities (Dalziel, 2010).

The second is that 'a key premise of the facilitator role of innovation brokers is an impartial or neutral and independent position, i.e. that these do not adhere to certain preferred suppliers, network partners, or preferred development strategies' (Klerkx and Leeuwis, 2009 p.852). For instance, both van Lente et al. (2011) and Winch and Courtney (2007) argue that in order to facilitate such independent thinking, systemic intermediaries are typically established as public or public-private organisations, operating on a not-for-profit basis. Kolodny et al. (2001) echo the importance of credibility, highlighting six design requirements that are essential in this regard: (1) visibility and accessibility to other organisations, (2) trustworthiness, (3) access to appropriate sources of knowledge and information relevant to the innovation process, (4) credibility of the intermediary organization with these sources, (5) quick response to the requests of organisations, and (6) complementarity to the weaknesses of the organisations it serves. However, both Hodson and Marvin (2008) and Kivimaa (in press) argue that the assumption of impartiality is problematic given that these organisations are often set up to facilitate and coordinate innovation in order to satisfy a specific set of objectives.

The third is that innovation intermediaries are typically 'founded especially to undertake an intermediary role, rather than performing that role as a by-product of their principal activities' (Winch and Courtney, 2007 p.747). However, it is possible for non-specialised bodies to also perform many of the functions associated with systemic intermediaries, such as research institutes or consultants (Klerkx and Leeuwis, 2009). Furthermore, bodies that have been established specifically to perform these tasks may not wholly restrict themselves to intermediary functions and might engage in a wider portfolio of activities. This may include for instance the direct provision of funds to undertake RD&D activities (Howells, 2006). Taking this one step further, some systemic intermediaries might have initially been established to deliver RD&D funding but have subsequently evolved to perform a range of intermediary functions. This idea is explored further in later in the paper.

2.2.3 Opportunities for further research

The literature review highlights two main criticisms of the extant literature. The first is that the literature is currently too fragmented (Howells, 2006, Van der Meulen et al., 2005) and that any efforts to further synthesise this literature should be welcomed. The other is that whilst there is a burgeoning literature on innovation intermediaries, we possess only a limited 'understanding of these entities, their role, their functions, and their activities in different contexts' (Abbate et al., 2013 p.235). In particular, Sapsed et al. (2007) assert that research is needed to understand specifically how bridging institutions, such as systemic intermediaries, are able to remedy weaknesses in innovation systems through their organisational activities. To help address this issue some scholars have emphasised the need for further empirical analysis. For example, Klerkx and Leeuwis (2009) call for empirical work that explores at which points along the innovation chain

innovation intermediaries typically operate and to provide a detailed account of how their activities relate to different innovation processes at different stages along this chain. They also emphasise the importance of understanding when intermediaries should perform certain activities and at what system level different types of innovation intermediaries 'fit' into the innovation system, e.g. international, national, regional, sectoral etc. Finally, they recommend that future research should examine the characteristic differences between different types of intermediaries.

In recent years scholars have afforded special attention to the empirical investigation of energy innovation systems in light of the mounting pressures of climate change, energy security and energy affordability. However, this work has focused predominantly on intermediaries as a governance mechanism, examining their ability to 'influence the pursuit of collective goals under shifting governance structures and processes' (Moss, 2009 p.1480), rather than their ability to facilitate and coordinate energy RD&D. Even so some empirical research has examined the role of systemic intermediaries in the energy innovation system, although this is limited. For example, Kivimaa (in press) undertook an empirical investigation of two government-affiliated Finnish intermediary organisations, Sitra and Motiva, specifying how their activities have contributed to the strategic niche management of energy innovations. Hargreaves et al. (2013) also employ this same framework to examine the role of 'intermediary actors' in consolidating, growing and diffusing novel 'grassroots innovations', namely community energy projects in the UK. In addition, Chen et al. (2014) have examined how innovation intermediaries have helped to promote PV solar energy industry in China.

On the basis of these recommendations and the opportunities to improve our understanding of the role of intermediaries in energy innovation systems this paper presents an empirical investigation of three systemic innovation intermediaries with in the UK energy system.

3 Methodology

The results are drawn from the outputs from a series of workshops undertaken by the authors as part of the RCUK Energy Strategy Fellowship team based at Imperial College London[2]. The Fellowship team was charged with producing a Prospectus for the UK Research Councils, articulating both priority energy research and training needs in the UK, covering the whole energy research landscape. The main input into this work was a series of workshop, which fell into the following categories: 1) four one day high-level strategic workshops that examined cross-cutting issues across the energy innovation system; 2) six two day expert workshops, which examined research and training needs in specific fields of research, such as bioenergy or energy infrastructure; and 3) two one day 'light touch' expert workshops, for subjects that had already been extensively covered by other needs assessments or where the research community was especially small. In total, the workshops involved 246 people and took place between October 2012 and September 2013. To help formulate the case studies presented in Section 5, data was also collected from the case study organisations' websites and other literature they have produced.

The scope of the empirical investigation is limited to three systemic innovation intermediaries: the Research Councils[3]; the Technology Strategy Board (TSB); and the Low Carbon Innovation and Coordination Group (LCICG). Whilst the authors acknowledge the primary role of these organisations

[2] http://www3.imperial.ac.uk/rcukenergystrategy

[3] These are separate legal entities that operate under the umbrella of Research Councils UK

is to fund energy research and development in the UK, this paper concentrates on the intermediary functions these bodies perform, i.e. the way in which they facilitate and coordinate energy innovation across the UK energy innovation system (see Table 1). Furthermore, the investigation focuses on government affiliated intermediary organisations, which Kivimaa (in press) describes as 'quasi-autonomous government agencies, government-owned companies or government-initiated foundations, as they fall between traditional public and private sector actors' (p.3). Crucially, these differ from private sector intermediaries whose actions are typically determined by profit (Kivimaa, in press). Finally, the investigation is only interested in innovation intermediaries that operate at a national or international level and are thus not confined to local or regional operations.

4 Overview of UK energy system and innovation intermediaries

The UK energy innovation system consists of public, private and third sector actors operating in academia, industry and government. Figure 2 provides a schematic of the current energy innovation landscape, classifying organisations according to the parts of the innovation chain[4] on which they are primarily focused. The majority of these innovation bodies operate within the applied RD&D and demonstration stages, apart from the Research Councils who are almost exclusively responsible for basic and applied research. Furthermore, all of these bodies conduct, facilitate or provide financial support to carry out research, development, demonstration and/or deployment. However, despite these similarities they all 'have their own missions and their own areas of expertise' (NAO, 2013). For instance, TSB's objectives focus on the economic benefits of innovation, whilst DECC is primarily concerned about how innovation could help to address climate change, energy security and affordability.

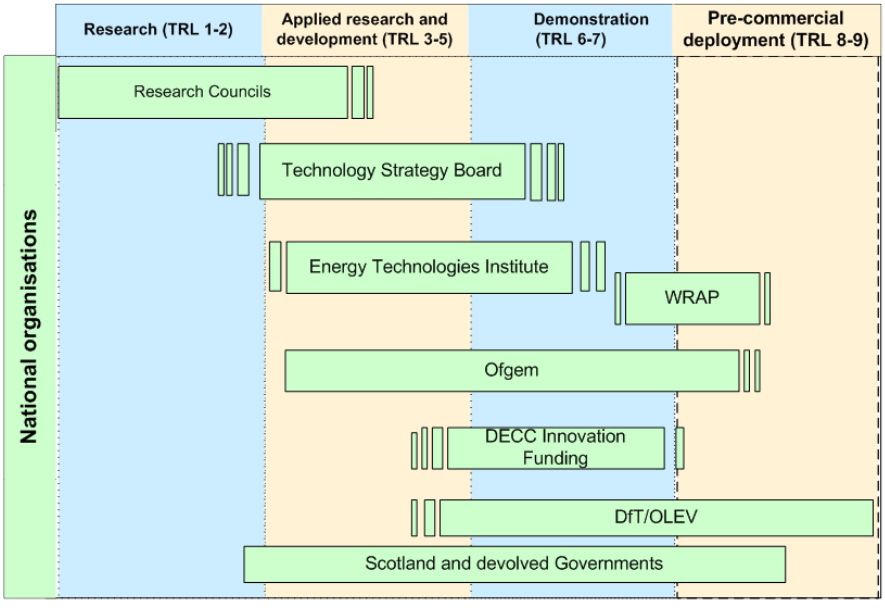

Figure 2: The UK energy technology funding landscape (Skea et al., 2013)

[4] Here the x-axis refers to Technology Readiness Levels (TRLs), a concept that was originally developed by NASA in the 1980s to characterise the technological maturity of components and sub-systems, which form part of a larger technical system

Besides a general lack of public sector energy RD&D support in comparison to other developed countries (IEA, 2012) a range of other weaknesses have been identified within the UK's energy innovation system, which are serving to undermine its effectiveness (CCC, 2010, IEA, 2012, NAO, 2010). The first is the lack of a long-term strategic plan that 'signposts' priority areas for energy innovation and the types of capabilities that will need to be leveraged to address these. The second is the disjointed nature of the UK's energy innovation system, emphasising the need for greater levels of communication, collaboration and coordination between key innovation bodies, both domestically and internationally, both within the same and between different stages of the innovation chain. This is on the basis that 'the most successful countries in technological innovation have effective approaches that align incentives and efforts across the innovation chain' (IEA p.160). The third is low levels of international research communication and collaboration that can help to share both the costs and risks of these activities and also accelerate technology development and diffusion by sharing experiences and expertise. An important part of the UK government's strategy to address these weaknesses has been to support the operations of a number of systemic innovation intermediaries, three of which are now examined in detail: the Research Councils, TSB and LCICG

5 Case Studies: UK Energy Innovation Intermediaries

5.1 Research Councils

5.1.1 Overview

Five Research Councils have an interest in energy research and participate in the RCUK Energy Programme (RCEP): the Biotechnology and Biological Sciences Research Council (BBSRC); Engineering and Physical Sciences Research Council (EPSRC); the Economic and Social Research Council (ESRC); the Natural Environment Research Council (NERC); and the Science and Technology Facilities Council (STFC). Energy research constitutes only one aspect of these councils' funding portfolio, which spans a variety of different areas of science. For example, ESRC supports economic and social energy research, whilst EPSRC is more focused on engineering energy research. Additionally, important nuances exist between their key objectives. For example, STFC is explicitly charged with developing and providing facilities and technical expertise in support of basic, strategic and applied research, unlike the other councils. Consequently, they do not develop their support strategy through a sectoral lens. According to their Royal Charters the Research Councils share the following main objectives:

- to promote and support high-quality basic, strategic and applied research and related post-graduate training, which meet the needs of users and beneficiaries and contribute to the economic competitiveness of the UK and the quality of life; and
- to provide advice, disseminate knowledge, and promote public understanding.

Research Councils UK (RCUK) was established as a partnership between the UK Research Councils in 2002 to optimise the ways that the Research Councils work together to deliver their goals and enhance the overall impact of UK research, training and knowledge transfer. The cross-council RCUK Energy Programme (RCEP) was established in 2004 with the aim of positioning the UK to be able to meet its energy, environmental and policy goals through world-class research and training. Between 2004 and 2011 RCEP committed a total of £839 million to energy research, with the majority of this

being committed by EPSRC who lead the programme. Neither RCEP nor RCUK are constituted as legal entities. They do not supersede the accountabilities of individual Research Councils who conduct their own energy-relevant activities within the framework of their own Strategic Plans.

5.1.2 Key Functions

Whilst research support and postgraduate training are the primary responsibility of the Research Councils, they also undertake a range of other activities that support energy innovation in the UK. RCUK intermediary functions are briefly outlined, before those performed via RCEP investments and those that are supported outside of this programme by individual Research Councils, focusing specifically on EPSRC.

5.1.2.1 RCUK

As the umbrella organisation, RCUK brings the various Research Councils together to discuss how they might be able to better coordinate their activities to maximize their impact. However, given its limited powers RCUK performs only a handful of other intermediary functions. One important function it performs is international network building through its UK Research Office (UKRO), which is the UK's leading information and advice service on EU funding for research and higher education, facilitating the involvement of UK researchers in EU research programmes. It also has teams in China, the USA, and India, working to facilitate collaboration between researchers in these countries and those in the UK. These teams also work closely with other organisations such as the Science and Innovation Network (SIN), UK Trade and Investment (UKTI) and the British Council to align activities and present a joined up picture of UK research resources and expertise.

RCUK is currently developing an initiative called *Gateway to Research*[5], designed to give the public better access to information about what the research that is supported, who has received the funds and the outputs generated. Businesses and other interested parties can identify potential university partners to develop and commercialise knowledge, and maximise the impact of publicly funded research.

5.1.2.2 RCUK Energy Programme

EPSRC and the other Research Councils channel many of their energy-specific intermediary functions through RCEP funded initiatives, notably the UK Energy Research Centre (UKERC).[6, 7] UKERC was funded through RCEP in 2004 with the principal aims of identifying and catalysing new research activities; providing support to help train a new generation of researchers in interdisciplinary energy research; and acting as a focal point for the UK's participation in international research efforts. UKERC is active in developing a strong energy research network in the UK via a number of tools, including the *National Energy Research Network (NERN)*[8], which is open to energy professionals from all sectors, including both knowledge producers and users, providing them with regular updates on news, jobs, events, opportunities and developments across the energy field in the form of a weekly newsletter. NERN is also active in building international energy research networks[9], for

[5] http://www.rcuk.ac.uk/research/gtr/
[6] http://www.ukerc.ac.uk/support/tiki-index.php
[7] UKERC is currently going through the bidding process for Phase 3, which would run from 2014. The details of which activities will be covered are still being finalised and it is possible some of its intermediary functions will be revised.
[8] http://www.ukerc.ac.uk/support/NERN
[9] http://www.ukerc.ac.uk/support/International%20Activities#list-eur

instance through the European Energy Research Alliance (EERA). UKERC acts on behalf of the UK research community to co-ordinate the UK's contribution to EERA's Joint-Programmes building on activities within the Energy Programme. UKERC also runs its *Meeting Place*[10] initiative, which allows researchers to bid for funding to run events that bring together people with expertise and knowledge from different backgrounds, sectors, disciplines and perspectives.

UKERC also plays an important role in knowledge brokering, demand articulation and innovation process management through its *Research Atlas*[11], which helps policy makers and researchers to review the current status of UK energy R&D and identify the key research challenges. The Atlas has four components[12]: 1) an online searchable database of energy related projects; 2) a set of landscape documents that review the UK's research activities and capabilities; 3) a set of roadmaps that highlights priority energy research challenges and the sequence in which these should be tackled; and 4) an online, searchable data base of publicly available energy and related data.

Since 2003, the RCEP has funded 14 Supergen consortia in different research areas bringing together researchers from both academia and industry. The most recent Supergens have been established as 'hubs', which are designed to encourage the core consortium partners to reach out and engage with academia, industry, NGOs and government both nationally and internationally. The hubs perform a range of networking activities such as holding annual assemblies where a combination of academic and industry experts, undertaking stakeholder 'outreach' programmes and facilitating knowledge exchange.

RCEP supports capacity building through 13 Centres for Doctoral Training (CDTs), which aim to provide students with a 'whole systems' understanding of the energy system. The CDTs place a strong emphasis on gaining experience of working in industry, offering opportunities for industrial placements. Some of these are industrial doctorate centres that require students to spend about 75% of their time working directly with a company. This arrangement builds valuable links between academia and industry. Whilst most of the Research Councils' energy-related capacity building activities are now performed through the RCEP supported CDTs, they continue to allocate PhD studentships to individual universities on the basis of their research grant income. Furthermore, whilst being phased out by some of the Research Councils (e.g. EPSRC), project-based studentships also exist, which attach PhD funding to a wider research project.

To complement these capacity building functions, RCEP supports a number of other initiatives. The annual UKERC *International Summer School*[13] gives a mixture of both domestic and international PhD students an opportunity to develop a wider understanding of the energy system and also network with international energy students. The UKERC's *Sparks*[14] network for early-career energy researchers runs seminars and social events to support interdisciplinary collaboration and knowledge exchange. UKERC has also offered interdisciplinary energy PhD studentships[15] in the past, which span scientific, engineering and socio-economic boundaries. In a similar vein an *Energy CDT*

[10] http://www.ukerc.ac.uk/support/TheMeetingPlace
[11] http://ukerc.rl.ac.uk/index.html
[12] It should be noted that some of these functions have not been as comprehensive as first envisaged. For example, the roadmaps are incomplete and many of them are out of date.
[13] http://www.ukerc.ac.uk/support/UKERC+Summer+School+New&structure=Education+Overview
[14] http://www.ukerc.ac.uk/support/Sparks+Overview
[15] http://www.ukerc.ac.uk/support/tiki-index.php?page=Studentships&structure=Education+Overview

Network[16] was established in 2011 to draw together the energy CDTs to facilitate coordination of energy training programmes; collaboration between PhD students; and knowledge exchange.

Finally, the RCEP has recently supported its own demand articulation function by funding the Energy Strategy Fellowship[17], which produced a Prospectus[18] for RCEP and the Research Councils articulating priority energy research and training needs in the UK.

5.1.2.3 Individual Research Councils

The individual Research Councils also perform a range of other intermediary functions that are independent of the RCEP's activities. This section focuses on EPSRC.

Alongside support for PhD training, EPSRC is active in network building between researchers, particularly at the international level. It fosters long-term research collaborations with international peers through funding for overseas travel and bilateral research workshops[19]. At the domestic level, EPSRC also seeks to build connections between academia and industry, for instance through its strategic partnerships with other public, private and third sector organisations[20]. Here, the various parties exchange information, work together to develop strategies that support each other's objectives and address important gaps in research and training. One of the key aims of this initiative is to cultivate routes for research outputs to be taken forward by actors further down the innovation chain. This function is also complemented by EPSRC's *Pathways to Impact*[21] requirements, which requires researchers to outline how their outputs will benefit wider society and to devise a strategy for disseminating these outputs to the relevant parties.

EPSRC does not curate data generated through its research. Data curation is an important part of knowledge brokering. As does BBSRC, they devolve responsibility to researchers rather than performing this function themselves. However, ESRC, STFC and NERC all impose 'strong' data collection sharing requirements on those they fund (or in the case of STFC on those whose research they facilitate). These Research Councils support data providers and/or management centres to curate and share the research outputs, thus facilitating future activities. For example, ESRC funds the *UK Data Archive*[22] which curates the largest collection of digital data in the social sciences and humanities in the UK. Data is freely available to researchers, students and teachers who are able to register with the UK Data Service.

5.2 Technology Strategy Board

5.2.1 Overview

The Technology Strategy Board (TSB) was established in 2004 as an advisory board to inform the UK government's Technology Strategy, specifically on priorities for business and technology RD&D and how to support these activities (TSB, 2013d). It was given executive status in 2007, and now

[16] http://www.ukerc.ac.uk/support/CDT+overview
[17] The Fellowship team is comprised of the authors of this report.
[18] https://workspace.imperial.ac.uk/rcukenergystrategy/Public/reports/Final%20Reports/RCUK%20Brighter%20energy.pdf
[19] http://www.epsrc.ac.uk/funding/routes/int/Pages/EPSRCfunding.aspx
[20] http://www.epsrc.ac.uk/about/partner/Pages/strategic.aspx
[21] http://www.epsrc.ac.uk/innovation/publicengagement/pathwaystoimpact/Pages/default.aspx
[22] http://www.data-archive.ac.uk/about/archive

operates as a Non-Departmental Public Body (NDPB with executive powers rather than advisory. It is currently funded by the Department for Business Innovation and Skills (BIS), and its core aim is to boost economic growth and employment.

In 2012-13 TSB spent £375m on RD&D support, which includes funding for both RD&D projects and intermediary activities (TSB, 2013a). Of this, it committed £18m to energy supply, £23m to transport and £15m to 'built environment' projects, with a number of other themes having relevance to the energy sector, such as electrical science, sustainability etc. Alongside this direct RD&D funding, TSB has also committed support for intermediary activities, including £37m for knowledge exchange, some of it focused on energy innovation. Spending is expected to increase for 2013-14 to approximately £440 million (TSB, 2013c).

5.2.2 Key Functions

TSB's intermediary functions are split between those that are either: a) specifically intermediary in nature *or* b) are direct energy RD&D funding mechanisms that have some intermediary aspects.

In the first category, TSB operates a number of *Knowledge Transfer Networks*[23] (KTNs), which 'link up' the UK's innovation community by facilitating knowledge brokering and network building. Of most relevance to energy RD&D is the *Energy Generation and Supply Knowledge Transfer Network*[24], which aims 'to simplify the UK Energy Innovation landscape by providing a clear and focused vehicle for the rapid transfer of high-quality information on technologies, markets, funding and partnering opportunities' (TSB, 2014b). However, various other KTNs also touch upon the UK's energy innovation landscape, such as the *Modern Built Environment* and *Transport* networks (TSB, 2014c). Through the KTNs, TSB performs various activities, including networking events, disseminating energy 'factsheets' and managing a platform for online discussions through its connect business networking and open innovation portal. It is also home to the Low Carbon Funding Landscape Navigator[25], which guides innovators through the low carbon energy funding landscape, helping them to identify funding opportunities. TSB also manages a number of *Knowledge Transfer Partnerships*[26] (KTPs) that offer businesses the opportunity to work in partnership with academic institutions to gain access to new knowledge, technology and skills.

TSB's annual *Innovate UK*[27] conference provides the opportunity for members of business, government and academia to meet with one another, showcase their work, develop their ideas and build professional networks. These mechanisms focus on bringing innovation actors closer together by encouraging them to share skills and experiences relating to the energy sector.

TSB also promotes linkages between domestic and international energy innovators[28], for instance through its entrepreneur *Missions*[29] programme that enables UK companies to travel to countries with a strong innovation track-record to make new connections and meet potential investors,

[23] https://www.innovateuk.org/-/knowledge-transfer-networks
[24] https://connect.innovateuk.org/web/energyktn
[25] http://www.lowcarbonfunding.org.uk/
[26] https://www.innovateuk.org/-/knowledge-transfer-partnerships
[27] https://www.innovateuk.org/-/innovate-uk
[28] These efforts are complemented by the UK's *Science and Innovation Network* (SIN), which is also supported by TSB's primary funder BIS.
[29] https://www.innovateuk.org/-/missions

suppliers and customers. This scheme is complemented by TSB's *International Programmes*[30] that help UK organisations build important relationships with European partners in order to access European energy RD&D support. For instance, it manages the National Contact Points (NCPs) on behalf of the UK, which provide guidance, practical information and assistance on all aspects of Horizon 2020; the most recent European research framework programme.

With respect to demand articulation, TSB also regularly issues its *Delivery Plan*[31]. Whilst this mainly outlines how the TSB will spend its funds over the forthcoming year, it also constitutes something of a 'scanning and scoping' exercise that articulates the demand for innovation is specific energy RD&D in specific areas.

In the second category TSB of funding mechanisms that have some intermediary aspects, TSB has established a series of new *Catapult Centres*[32] described as 'physical centre[s] where the very best of the UK's businesses, scientists and engineers work side by side on late-stage research and development - transforming "high potential" ideas into new products and services to generate economic growth'(TSB, 2014a). In the energy domain, TSB has so far established Catapults for *offshore renewable energy, future cities, transport systems* and *connected digital economy*, with one currently planned for *energy systems*. By providing a space to bring together experts from different sectors these centres encourage network building, innovation process management (especially through aligning agendas and learning) and knowledge brokering, all of which is leveraged through the inter-Catapult network that is being developed. Most notably the centres bring together both private and public sector innovators through the funding model they employ, which relies upon a mix of competitively won private, public and private-public RD&D funding (Figure 3).

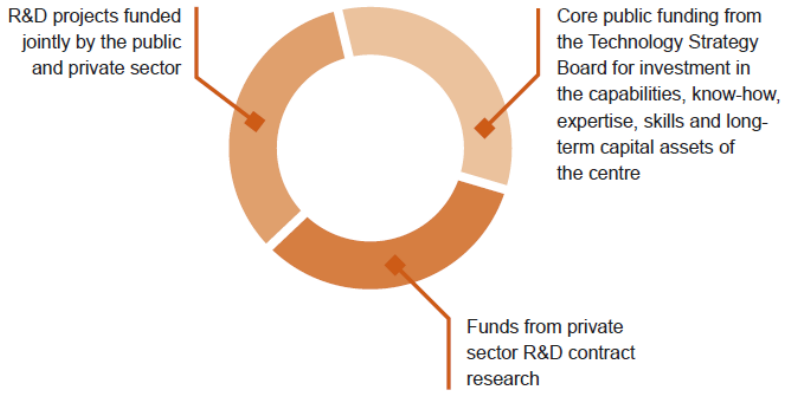

Figure 3: Catapult funding model (TSB, 2013b)

TSB promotes network building between knowledge producers in other ways. For instance, through its *collaborative RD&D*[33] programme, it provides funds to businesses and researchers to work together on innovative projects in strategically important areas of science, engineering and technology. These include offshore energy, nuclear, alternative energy vectors and community

[30] https://www.innovateuk.org/-/international-programmes
[31] https://www.innovateuk.org/documents/1524978/2138994/Delivery+Plan+-+Financial+year+2013-14/c435471d-222c-4e63-8269-d0f4b2b61c2f
[32] https://www.innovateuk.org/-/catapult-centres
[33] https://www.innovateuk.org/-/collaborative-r-d

energy systems. It also runs a number of joint funding calls with EPSRC and DECC to support energy research projects that bring together universities and industry. It also builds relationships between knowledge producers *and* users. For instance, it runs the *Innovation Vouchers*[34] scheme that provides grants of up to £5,000 for knowledge users to engage with knowledge suppliers who currently operate outside their current actor network. It also runs a *Small Business Research Initiative*[35] that aims to bring together private sector knowledge producers with public sector knowledge users to solve specific problems.

To support the better integration of the different stages of innovation, TSB has recently launched a *Catalyst*[36] programme, which it jointly runs with the Research Councils. Catalysts are designed to progress projects from the basic research stage as far towards commercialisation as possible. The programme aims to better integrate the various stages of the innovation chain from beginning to end, thus constituting a form of interface management (see Table 1). TSB is in the process of establishing an Energy Catalyst to support energy research topics spanning across the energy supply chain, with relevance to the UK's energy trilemma (Gray, 2014).

5.3 Low Carbon Innovation Coordination Group

5.3.1 Overview

In 2008 TSB, the Carbon Trust and the Energy Technologies Institute (ETI) established the Low Carbon Innovation Group (LCIG) (LCICG, 2014b). In 2009 LCIG was expanded to include the Department of Energy and Climate Change (DECC), the Department for Business, Innovation and Skills (BIS), and EPSRC (representing RCUK). LCIG was re-launched as the Low Carbon Innovation Coordination Group (LCICG) in 2011. Today LCICG comprises eight *core* organisational members and nine *associate* members[37]including government departments and non-departmental public bodies. Its c*ore* members include organisations, such as DECC, TSB, EPSRC, BIS etc., who together are expected to spend over £1 billion of public-sector funding on low carbon innovation in the period up to April 2015[38].

The initial motivation for establishing LCICG was to help the constituent bodies avoid duplication of effort. However, LCICG has evolved into an explicitly intermediary entity whose core aim is to 'enhance the focus, coordination and delivery of government-backed support for innovation in low carbon technologies, in order to maximise the economic benefits to the UK' (LCICG, 2014a). The premise is, that by bringing these bodies closer together, LCICG will increase the collective impact of these organisations' programmes, primarily by helping them to leverage each other's resources and avoid duplication of efforts through more active coordination. In turn these efforts are expected to help these organisations to provide a more comprehensive range of support than would otherwise have been possible without LCICG.

5.3.2 Key Functions

At the broadest level LCICG brings the main UK energy innovation bodies closer together in order to better align their activities through communication and coordination. Many of its members perform

[34] https://www.innovateuk.org/-/innovation-vouchers
[35] https://www.innovateuk.org/-/sbri
[36] https://www.innovateuk.org/-/catalysts
[37] Full list of members available in Annex A
[38] http://www.lowcarboninnovation.co.uk/working_together/

intermediary functions already, such as TSB and EPSRC (see Sections 5.1.2 and 5.2.2). However, LCICG operates at a higher system-level than these other entities, intermediating between the intermediaries, thus constituting a 'super-intermediary' (Section 7.3).

LCICG also serves as a forum for discussion between the main UK energy innovation bodies, providing an opportunity for senior members of these organisations to exchange ideas with one another. Since 2012, LCICG has produced a set of *Technology Innovation Needs Assessments (TINAs)*[39], which identify the key innovation needs and value the benefits of specific low carbon technology families in order to inform the prioritisation of public sector support. The TINAs were compiled with significant input from industry and academia and represent a shared evidence base that highlights priority RD&D areas (LCICG, 2014a). They help the UK to plan its energy innovation activities, helping to articulate demand for priority innovation areas and how these might be addressed.

Following LCICG's TINA work, it produced a *Strategic Framework*[40], which performs two main functions. The first is to articulate what the group's shared objectives and how it intends to meet these via coordination and collaboration. Building on the TINAs, the framework also sets out what the group believes to be the key innovation across the energy innovation landscape over the remainder of the decade, also assessing the scale and type of support required. In this sense both the TINAs and the Strategic Framework provide some institutional support for certain types of energy innovation by building consensus amongst key innovation stakeholders around key priorities for energy RD&D.

5.4 Summary of Intermediary Functions

The three case studies indicate that system-level innovation intermediaries enhance the effectiveness of the UK's energy innovation system in several ways. The activities of the Research Councils, TSB and LCICG are plotted alongside the innovation intermediary functions outlined in Section 2.2 in Table 2.

[39] http://www.lowcarboninnovation.co.uk/working_together/technology_focus_areas/overview/
[40] http://www.lowcarboninnovation.co.uk/document.php?o=23

Table 2: A summary of the functions performed by three of the UK's system-level energy innovation intermediaries

Function	Research Councils	TSB	LCICG
Demand articulation	• Energy Strategy Fellowship's energy and research training needs Prospectus • Research Atlas roadmaps (UKERC)	• TSB's Delivery Plan	• Technology Innovation Needs Assessments (TINAs) • Strategic Framework
Network building	**Domestic** • Energy CDT Network (UKERC) [1] • Sparks network (UKERC) [1] • Strategic partnerships with other innovation actors [2] • Meeting Place (UKERC) [3] • National Energy Research Network (UKERC) [3] • Supergen consortia [3]	**Domestic** • Collaborative RD&D projects [1] • Innovation Vouchers [2] • Small Business Research Initiative [2] • Catapult Centres [3] • Innovate UK annual conference [3]	**Domestic** • Brings together 8 core and 9 associate key energy innovation actors, who meet regularly
	International • International summer school (UKERC) [1] • Overseas travel and bilateral research workshops (EPSRC) [1] • UK Research Office [3] • Overseas offices in India, China and USA [3] • European Energy Research Alliance membership (UKERC/EPSRC) [3]	**International** • International Programmes [1] • Entrepreneur Missions programme [3]	
Capacity building	• PhD training • International summer school (UKERC)		
Innovation process management	• Strategic partnerships with other innovation actors • Cross-council funding calls • Joint-funding calls with other innovation bodies e.g. TSB	• Joint-funding calls with other innovation bodies e.g. EPSRC • Catapult Centres • Catalysts	• Strategic Framework
Knowledge brokering	• Gateway to Research (RCUK) • Pathways to Impact (EPSRC) • Research Atlas (UKERC) • Meeting Place (UKERC) • National Energy Research Network (UKERC) • Data repositories	• Knowledge Transfer Networks • Knowledge Transfer Partnerships • Catapult Centres • Innovate UK annual conference	
Institutional support			• Technology Innovation Needs Assessments (TINAs) • Strategic Framework

[1] Producer-to-producer; [2] Producer-to-user; [3] Producer-to-producer *and* producer-to-user

6 Recommendations to improve the effectiveness of the UK's energy innovation intermediaries

This section sets out a number of recommendations to improve the effectiveness of the UK's systemic energy innovation intermediaries and in turn, the wider energy innovation system.

6.1 Demand articulation

The UK is relatively well catered for in terms of energy innovation demand articulation, notably through LCICG's work on the *TINAs* and its *Strategic Framework* and the Research Councils' commissioning of the energy research and training needs Prospectus. However, these works need to be regularly revisited to ensure that they remain up-to-date and reflect the UK's changing innovation needs.

6.2 Network building

The work of three case study intermediaries has played a critical role in bringing the UK's innovation actors closer together, not least LCICG which operates as a 'super-intermediary', building networks between the Research Councils and TSB who work at a lower system level. However, the landscape still remains quite fragmented and would benefit from further network building. One way of addressing this would be to develop more joint-funding calls between different innovation funders, thus encouraging these actors to communicate and collaborate. This could be between funders operating in the same area of the innovation chain, such as the Research Councils, or funders operating in different areas, such as a research council and TSB. The latter could play a particularly important role in facilitating knowledge brokering between latter stage and early stage innovation actors (see Section 6.5).

6.3 Capacity building

Both the Research Councils and TSB support undertake valuable individual and organisational capacity building, however this paper makes some recommendations to improve this. With regards to the PhD funding models employed by the Research Councils there has been a move away from project-based PhD research funding models to CDT funding (Section 5.1.2.2), each of which have their strengths and weaknesses. For instance, the former model can sometimes isolate students, unlike the CDT model where students operate as part of a cohort. Conversely, the project-based model provides students with valuable experience of developing and delivering a research project, which is often a criticism of the CDT model. Consequently, a balance between these would be appropriate. The findings also support the need for PhD funding models, such as CASE studentships and Engineering Doctorates, where students are part-funded by industry and are also required to spend time working in these companies. This helps to develop a wide-portfolio of skills relevant to both academia and industry, also building important links between these domains.

6.4 Innovation process management

The LCICG is playing an essential role in the energy innovation space, where coordination was badly needed. The LCICG membership is wide and contributing organisations have diverse missions relating to low-carbon, energy and economic growth. There is only so much that a high-level umbrella group can do. However, this could be addressed to some extent by the formation of working sub-groups could help focus intermediary efforts to address weaknesses in the UK's energy

innovation system. It is also evident that some of LCICG associate members, such as Ofgem, are key players in the UK energy innovation landscape and should qualify for full membership given their influence on the innovation landscape.

Looking internationally, there remain concerns around the extent to which the UK is directing, influencing and coordinating research at an international level, for instance the development of funding calls under Horizon 2020. The establishment of focused LCICG sub-groups to address this issue could help coordinate the UK's efforts. It is recommended that the UK operates a 'best with best' international collaboration principle, working with leading countries on a topic-by-topic basis. This is instead of the current practice of prioritising collaboration with a handful of countries across all areas of energy innovation due to their prominence in terms of both the global energy system and economy.

6.5 Knowledge brokering

As explained in Section 2.1, innovation is not a linear process whereby discoveries emerge serendipitously from the laboratory and are taken up by entrepreneurs. Pilot projects and early demonstrations often identify problems that need to be solved through the application of basic science and engineering. This implies a need for collaboration between the Research Councils and bodies such as TSB and ETI, so that important findings during the later stage innovation processes can be fed back into early stage processes to inform the design of basic research projects. Therefore, recent collaborations between the Research Councils and TSB in the low carbon sphere are to be welcomed. However, work needs to be done to identify ways to incentivise private sector innovation actors to feed back their findings into earlier stage, publicly funded research.

Knowledge brokering could also be supported via the establishment of data repositories, where energy research data is curated and shared and can provide the basis for further innovation. Neither EPSRC nor BBSRC have strong data sharing policies and such policies should be put in place. Furthermore, there is a significant amount of data that has manifest 'common good' characteristics but which is not publicly available due to confidentiality and intellectual property concerns. Easier access to this data for intermediaries, without contravening commercial and personal data sensitivities, would facilitate knowledge brokering and in turn present more opportunities for future innovation projects that rely on this data. Another key issue is agreeing which bodies are responsible for funding and managing such a programme of data curation and sharing given that such activities are typically very resource intensive.

6.6 Institutional support

Kilelu et al. (2011) note that 'intermediaries play a role in institutional innovation as boundary actors, particularly in the interface between science and practice and also in the policy and regulatory arena in innovation processes' (p.29). The findings support this view, indicating that innovation intermediaries can play an important role in cultivating an institutional environment that is generally supportive of innovation. For instance, they facilitate communication between innovators and policymakers, informing the latter of the value of innovation when dictating any regulatory change that might impact upon the innovation capacity of a given sector or country. Going one step further, intermediaries can help to underline the value of specific innovations, providing valuable institutional support to help accelerate their development. However, advocacy could soon stray into the arena of lobbying and the remit of organisations like trade associations.

Furthermore, it undermines the principal that intermediaries should strive towards impartiality wherever possible to build trust and credibility (Section 2.2.2).

7 The characteristics and functionality of systemic innovation intermediaries

This section reflects on the findings from the empirical investigation and discusses how these contribute to our understanding of systemic innovation intermediaries, not just in the energy sector.

7.1 Emergence

Whilst innovation intermediaries can be established specifically to perform such a role, the findings indicate that direct RD&D funders often begin performing intermediary functions in a more *ad hoc* manner, in order to complement their funding activities and maximise their impact. This challenges Winch and Courtney's (2007) view that 'innovation brokers in our definition are organizations that are founded especially to undertake an intermediary role, rather than performing that role as a by-product of their principal activities' (p.747). In contrast, it supports Kivimaa's (in press) and Howells (2006) suggestion that intermediaries typically perform a wide range of activities, many of which are not explicitly intermediary in nature.

7.2 Constitution

The research finds that both 'hard' and 'soft' intermediaries exist. 'Hard' intermediaries are defined as legally constituted organisations that have executive powers to perform intermediary functions, with both the Research Councils and TSB meeting these criteria. 'Soft' intermediaries on the other hand are not legally constituted and do not possess executive powers. Instead they constitute a type of actor group or network that brings together legally constituted organisations, many of whom are often intermediaries. RCUK, RCEP and LCICG can be placed in this category.

7.3 Operational scale

Whilst the case study intermediaries all work at a higher level of aggregation than the firm and all have a nation-wide presence, they do not all work at the same 'system-level'. This is most evident with LCICG, which along with a number of other key innovation actors, serves to bring the Research Councils and TSB closer together, both of which are systemic intermediaries in their own right. In this regard LCICG represents a 'super-intermediary', i.e. a network or group of multiple systemic intermediaries, which aims to both facilitate and coordinate the activities of these entities despite their different remits and objectives. It works to ensure that the efforts of numerous systemic intermediaries are aligned to the extent that they avoid duplication of effort or that these efforts negate each other. Additionally, LCICG serves as a forum for intermediaries to pool their resources and experiences. Super-intermediaries are a manifestation of the desire between multiple systemic intermediaries to collaborate with one another in order to enhance their effectiveness and in turn the effectiveness of the wider innovation system.

The UK's systemic innovation intermediaries operate within an international as well as national system of innovation. The case studies illustrate that both TSB and the Research Councils are active in this regard and sensitive to the lessons that can be learnt from energy innovation overseas.

7.4 Bias

Impartiality has been highlighted as a desirable characteristic for innovation intermediaries to have (Kilelu et al., 2011, Klerkx and Gildemacher, 2012), because it can help these entities gain the trust of innovators and help them to access their networks. However, the findings support Kivimaa's (in press) observation that in practice intermediaries are not entirely impartial, instead exhibiting some degree of bias. For instance, TSB aims to support energy innovation capable of stimulating economic growth, whilst LCICG aims to address the UK's energy trilemma, helping to illustrate the different agendas of these intermediaries. This paper warns that without a combination of communication and collaboration, different intermediaries could perform functions with the aim of fulfilling competing objectives, resulting in the misallocation of public funds.

7.5 Audience

An intermediary's activities may be focused on different audiences. These can broadly be split between focusing exclusively on knowledge supplier communities *or* both knowledge supplier and user communities. For example, the Research Councils are active in promoting knowledge exchange and collaboration between researchers (i.e. knowledge producers) who have not previously worked together, in order to improve the quantity and/or quantity of their outputs. In contrast, they also work at building relationships between researchers (i.e. knowledge producers) and knowledge users, such as applied RD&D companies or policymakers, in order to maximize the impact of the research projects it funds. Therefore, some intermediary activities focus on enhancing the production of knowledge, whilst others facilitate the movement of knowledge along the innovation chain.

The activities performed by intermediaries can fulfil multiple functions. For instance, the establishment of research networks or networking events constitutes a form of network building but is also likely to lead to knowledge brokering as the newly networked actors communicate with one another. A more integrated innovation community is also likely to make demand articulation easier, especially identifying knowledge gaps and opportunities to address these.

8 Conclusions

Research, development and demonstration (RD&D) can play a critical role in reducing the carbon emissions, costs and security concerns associated with the UK's energy supply, alongside supporting economic growth. However, the effectiveness of the UK's energy innovation system has been questioned and a number of entities have taken on system-level intermediary roles to help address these weaknesses. These entities operate at the interface between innovation actors, working to facilitate and coordinate innovation activities at the system-level.

This paper examines how three such entities have served to foster energy innovation in the UK, namely the *Research Councils*, the *Technology Strategy Board* and the *Low Carbon Innovation and Coordination Group.* Whilst there is some degree of overlap between these intermediaries' functions, they each perform their own valuable role in facilitating and coordinating energy innovation in the UK. These entities have played an important role in driving forward energy innovation in a direction that will help to address the challenges facing the UK energy system.

Despite their relative strengths, there are a number of ways in which the functionality of these intermediaries could be enhanced. These include: 1) frequently updating demand articulation

activities; 2) more joint-intermediary initiatives; 3) greater international engagement; 4) a blend of complementary capacity building approaches; 5) expanding membership of super-intermediaries (e.g. LCICG) to include all key innovation actors; 6) encouraging feedback from knowledge users to producers; 7) establishing systems for data curation and sharing; and 8) encouraging institutional support for promising innovations whilst avoiding 'out and out' advocacy or lobbying. These recommendations could as easily be taken forward by other systemic innovation intermediaries operating in different sectors or countries.

Finally, on the basis of the empirical investigation, the paper makes a number of theoretical contributions to the systemic innovation intermediary literature. These are split these between intermediary *emergence, constitution, operational scale, bias* and *audience*. Most notably, the paper highlights that it is frequently direct RD&D funders who perform intermediary functions, stepping into complementary intermediary roles to maximize the impact of publicly funded RD&D projects. It also finds that intermediaries tend to emerge in response to manifest needs and weaknesses rather than be purposively established and that both 'hard' and 'soft' intermediaries exist, referring to whether they are legally constituted or not. Finally, it highlights that not all systemic innovation intermediaries work at the same *operational level* and that systemic intermediaries can be integrated and coordinated by 'super-intermediaries' that work at a higher system-level.

In order to develop the literature further this paper reinforces the call from other scholars (Klerkx and Leeuwis, 2009, Dalziel, 2010) to not only undertake additional empirical work on systemic innovation intermediaries but to also develop and apply innovation indicators capable of quantitatively assessing the impact of systemic innovation intermediaries on the effectiveness of innovation systems.

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Annex A – LCICG Members

Core Members	▪ Carbon Trust ▪ Department for Business, Innovation & Skills (BIS) ▪ Department of Energy & Climate Change (DECC) ▪ Energy Technologies Institute (ETI) ▪ Engineering and Physical Sciences Research Council (EPSRC) ▪ Scottish Enterprise ▪ Scottish Government ▪ Technology Strategy Board
Associate Members	▪ The Crown Estate ▪ Department for Communities and Local Government ▪ Department for Environment, Food and Rural Affairs (Defra) ▪ Department for Transport ▪ Ministry of Defence (MoD) ▪ Department of Enterprise, Trade and Investment ▪ Office of the Gas and Electricity Markets (Ofgem) ▪ Welsh Government ▪ UK Trade & Investment (UKTI)