Pushing the Boundaries: Advocating Space and Place in Innovation Studies

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Abstract

Heuristic models within Innovation Studies have been critiqued for lacking theoretical clarity vis-à-vis socio-spatial processes underpinning sustainability transitions. System boundaries and the multiple scales at which dynamic processes are thought to operate have not always been clearly delineated. The local context of individual case studies can make it hard to generalise and, in some approaches, time is privileged over space. As a reaction to these deficits, economic geographers have pushed for a spatial turn in Innovation Studies since the mid-2000s. The exponents of this turn, whether working in evolutionary or relational economic geography, have sought to place greater emphasis on the spatial outcomes of the social processes which reinforce the uneven distribution of innovative opportunities across economic space like path dependency. This work suggests that more overtly geographical, relational and multi-scalar insights into territory, space and place also need to be emphasised in case study analyses in innovation studies in order to offer improved understandings of the dynamics of transition processes within and between nations, regions and sectors. We examine the spatial turn in Innovation Studies via a critique of the hydrogen and fuel cell (H&FC) literature. We then assess the initial first cut of emerging findings from a detailed comparative case study of the Technology Innovation Systems (TISs) for hydrogen and fuel cells (H&FCs) in Germany and the UK in terms of the spatial deficits identified in the critiques being made by economic geographers. We incorporate into our analysis of hydrogen and fuel cells (H&FC) innovative activity ideas from evolutionary and relational economic geography concerning the spatial distribution of socio-economic and socio-technical processes. Finally, we reflect upon the implications of our analysis by advancing theoretical and conceptual understandings of the role of space and place in the dynamics of innovation systems and sustainability transitions.

key words: sustainability transitions, theory, place, space, scale, hydrogen

1.0 Introduction

In this paper, we examine research into sustainability transitions in the innovation studies literature, specifically those where case studies on hydrogen and fuel cells (H&FCs) have been used. Here, investigators have pursued heuristic models in Innovation Systems (ISs), Systems Innovation (SI) and in the Sociology of Expectations (SOE) (e.g. Park, 2009; McDowall and Eames, 2004, 2006; Bakker et al, 2010, 2012). However, there are significant theoretical shortcomings to these approaches in terms of their conceptions of space, place, scale and territory (Morgan, 2004, 2012; Coenen et al, 2012). These deficits include more overt recognition of the social construction of boundaries and scale, more local context, avoiding the privileging of time over space, and a better understanding of the socio-spatial processes which reinforce the uneven distribution of innovative opportunities across economic space. A spatial turn in innovation studies was identified in the mid-2000s (Morgan, 2004) and a re-evaluation of space, place, scale and territory is still being worked through in terms of the theoretical approaches to innovation studies that we highlight here (Coenen et al, 2012; Truffer and Coenen, 2012). In this context, we examine the preliminary results of a comparative case study on innovative activity in hydrogen and fuel cells (H&FCs) in the UK and Germany. From this, we explore how to best improve the understanding of the territorial and multi-scalar dynamics witnessed in terms of economic activity with H&FCs. Ultimately, we conclude that while theoretical improvements to heuristic models in Innovation Studies are still tentatively moving forward along a number of lines, insights from both evolutionary and relational economic geography have much to offer such developments.

2.0 Heuristic Approaches Within Innovation Studies

In Innovation Studies, there are a number of approaches to the role of innovation and sustainability transitions. Table 1 shows how we have employed a tripartite division between Innovation Systems (IS) approaches, Systems Innovation (SI) approaches and models based on the Sociology of Expectations (SOE). Since the 1980s, Innovation Systems (IS) approaches have evolved into related but distinct heuristics: National Systems of Innovation (NSIs), Regional Systems (RSIs), Sectoral Systems of Innovation (SSIs) and Technological Innovation Systems (TISs)[1]. In the early 1990s, Systems Innovation (SI) and sociology of expectations (SE) approaches to innovation emerged. These imported micro-economic insights about learning, actor-networks, and power from Science, Technology and Society (STS) researchers (cf. Latour and

[1] These approaches were also originally referred to in the literature as ‘National Innovation Systems’ (NSIs), ‘Regional Innovation Systems’ (RISs), and ‘Sectoral Innovation Systems’ (SISs). The TIS approach when linked to the ‘functions of innovation systems’ approach is also referred to as ‘Technologically Specific Innovation Systems’ (TSISs).

Table 1: Innovation Approaches, Models and Hydrogen and Fuel Cell (H&FC) Literature

Innovation Approach	Innovation Model	Hydrogen and Fuel Cell (H&FC)Studies
Innovation Systems (ISs)	Innovation Systems (general)	Bleischwitz and Bader (2010), Bleischwitz et al (2010)
	National Systems of Innovation (NSIs)	Foxon et al (2005), Mans et al (2008), Park (2009)
	Regional Systems of Innovation (RSIs)	Bleischwitz et al (2008), Madsen and Andersen (2010)
	Sectoral Systems of Innovation (SSIs)	Choi et al (2011)
	Technological Innovation Systems (TISs)	Bleischwitz et al (2008), Brown et al (2007), Godoe and Nygaard (2004), Madsen and Andersen (2010), Markand and Truffer (2008), Musiolik and Markard (2011), Suurs et al (2009)
Systems Innovation (SI)	Strategic Niche Management (SNM)	Agnolucci and Ekins (2007), Park (2011), Ehret (2004), Ehret and Dignum (2012)
	Transition Management (TM) / Multi-level Perspective (MLP)	van den Bosch et al (2005), Eames and McDowall (2010), Farla et al (2011), Hisschemöller et al (2006), Kohler et al (2010), McDowall (2010, 2012)
Sociology of Expectations (SOE)	Visions / Roadmaps / Arenas of Expectation	Alkemade and Suurs (2012), Bakker (2010a, 2010b, 2011), Bakker et al (2010, 2012), Eames et al (2006), McDowall and Eames (2004, 2006), Ruef and Markand (2010), Wüstenhagen et al (2009)

Woolgar, 1979; Callon, 1980, 1986; Pinch and Bijker, 1984; Hughes, 1986). The right-hand side of Table 1 shows how this tripartite division of approaches and models relates to specific H&FC literature.

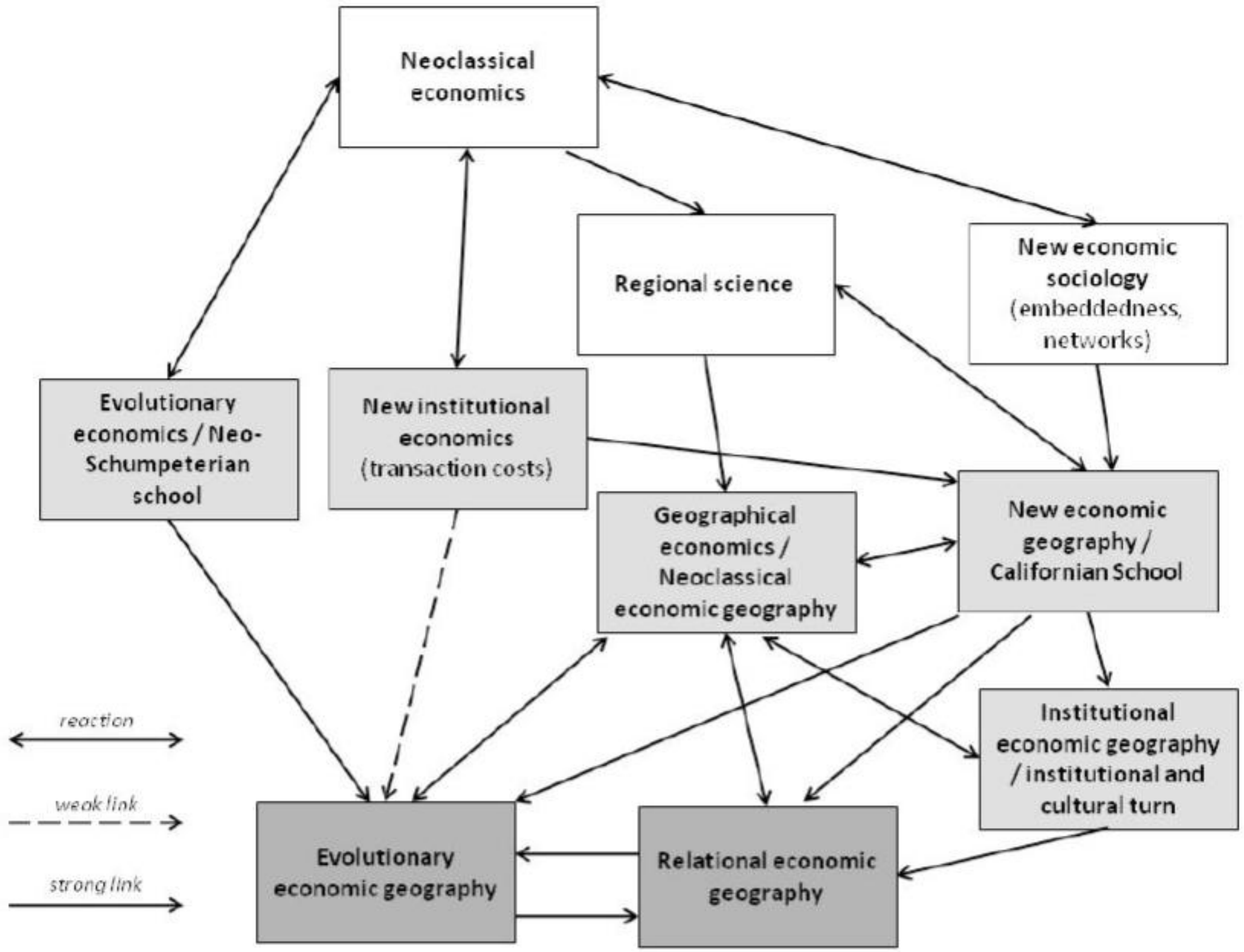
3.0 The Spatial Turn in Innovation Studies

The Innovation Systems (IS), Systems Innovation (SI) approaches have been critiqued by economic geographers for the lack of explicit recognition of the social construction of boundaries, territory and scale, the lack of local context, the privileging of time over space, and the need to improve understandings of the socio-spatial processes that reinforce uneven development, amongst other things (Coenen et al, 2012; Truffer and Coenen, 2012). Sociology of Expectations (SOE) approaches have faced less scrutiny and some work there has incorporated a spatial approach (cf. Eames et al, 2006). A spatial turn has taken place in Innovation Studies as the discipline "discovered that geography matters" (Morgan, 2010). This turn came two decades on from early theorizing about the rise of globally- rather than locally-distributed value chains (Dicken and Lloyd, 1976; Dicken, 1986). The process of globalization, which grew rapidly from the 1970s, broke what were formerly direct links between product life cycles and local spaces (Simmie, 2005). The rise of transnational corporations (TNCs), showed how some institutions can exert power and influence across numerous regional and national boundaries, often without having a physical presence in the destination territory. Thus, in terms of Innovation Studies' institutional approach to innovation, the spatial turn suggests that two things are required: i) a better understanding of the socio-spatial processes that reinforce uneven development chiefly the "extent to which path dependence is a place-dependent process" (Morgan, 2012, forthcoming), and ii) a better understanding of the strategic behaviour of TNCs and national and regional governments within that uneven economic space (Dicken, 1986; Dicken et al, 2001).

3.1 Schools of Thought Within Economic Geography

Institutional analyses of the 'geography of the firm' have been pursued by economic geographers seeking explanations for comparative national/regional/sectoral advantage since the early 1990s (Bathelt, 2006). Insights into the spatial deficits identified in Innovation Studies approaches have since come from two broadly competing schools of thought in economic geography: evolutionary economic geography (EEG) and relational economic geography (both of these are shown in Figure 1 in relation to other schools of economic and geographical thought). Despite the potential for these two approaches to be in competition in certain aspects of their analysis (cf. Hassink and Klaerding, 2009), advocates of both agree that a region should not be studied independently of the economic and social relations of the actor-networks operating

Figure 1: The position of evolutionary and relational economic geography in the pedigree of theories of economic geography and related disciplines



(Hassink and Klaerding, 2009, 21)

there (Pike et al, 2009; Morgan, 2012). In terms of analysis, this suggests that relational proximity as much as spatial proximity is what enables the kind of close actor/institutional interaction that underpins the key social processes behind regional and/or national comparative advantage (Bathelt, 2006).

Advances in post-structural human geography (Massey, 1979; Paasi, 1991; Sayer, 1989, 1991; Allen and Thompson 1997; Murdoch, 1998) led to a relational turn in economic geography in the early 2000s (Boggs and Rantisi, 2003; Yeung, 2005; Sunley, 2008; Fløysand and Jakobson, 2011). This has involved relational perspectives on globalisation (Amin, 2002), global production networks (Dicken et al, 2001; Coe et al, 2008) and cities and regions (Amin, 2004). The focus of this research has been on the "creation of knowledge and competences of firms, temporary work organisations (projects) as well as a socio-cultural embeddedness of firms" (Ibert, 2008, pages unknown, cited in Hassink and Klaerding, 2009, 4). Studies have examined the intra- and inter-firm relations through which competitive advantage is achieved (Boggs and Rantisi, 2003).

At the same time, there an evolutionary turn in economic geography emerged which incorporates ideas from both neo-Schumpeterian economics and complexity science (Boschma and Lambooy, 1999; Boschma and Frenken, 2006; Boschma and Martin, 2010). Evolutionary economic geography (EEG) involves examining "the processes by which the economic landscape - the spatial organization of economic production, distribution and consumption - is transformed over time" (Boschma and Martin, 2007, 539).

Both these strands of thinking within economic geography recognise the firm's social relations and its historical developmental paths (Bathelt and Glückler, 2003; Boschma and Frenken, 2006). Space is therefore regarded as socially constructed and initially neutral. Both approaches also regard spatial structures as being created by social processes operating over space, both share a critical stance towards a fixed territoriality of institutions (Bathelt and Glückler, 2003: Boschma and Frenken, 2006; Hassink and Klaerding, 2009), learning is equally important to both approaches in terms of stimulating regional growth and both agree on knowledge-creation as a major driving force for market competition (Hassink and Klaerding, 2009). There is also recognition by both schools of thought in economic geography that no spatial scale should be privileged over another in terms of analysing the evolution of the economic landscape (cf. Dicken et al, 2001; Essletzbichler, 2012). This has prompted a search for multiscalar, local-global refinements to Innovation Studies' heuristics (e.g. Geels and Deuten, 2006). Achieving this, however, suggests that existing notions of scale and territory may need to be radically rethought (Allen et al 1998; Shepherd, 2002; Allen, 2011). Allen (2011, 11), for example, suggests that:

> "[Institutions], it would appear, connect more or less directly with others elsewhere without the need to 'jump' scale or 'move up and down' from the local to the global."

A truly multiscalar approach for Innovation Studies heuristics would therefore would need to overcome the micro-macro problem, the long-standing recognition that, in epistemological terms, micro- and macro-perspectives like those seen in the Systems Innovation (SI) and Innovation Systems (IS) approaches rarely, if ever, fit together (Giddens, 1979; Callon and Latour, 1981; Wiley, 1988). However, the micro-macro problem might be avoided with a relational approach to space because similar social processes are regarded as taking place at a variety of scales (cf. Boyle, 2002; Davis, 2005).

4.0 Review of Hydrogen and Fuel Cell (H&FC) Literature

For all of the reasons outlined above, insights from both economic and relational economic geography will inform our review of the hydrogen and fuel cell (H&FC) literature below.

4.1 Social Construction of Boundaries and Scale

In terms of boundaries and territory, a key concern for models in Innovation Studies is that the socially-constructed spatial delineations of these territories are too loosely defined and typically do not fit well with the activities of the institutions involved within them (cf. Carlsson and Stankiewicz, 1991, Cooke et al, 1997; Edquist, 1997, 2005; Morgan, 2004; Park, 2009). The manifest ability of institutions based outside of a country, a region or a sector's stated physical borders to influence innovative activity within it, is not readily explained. In the case of National Systems of Innovation (NSIs) and the hydrogen and fuels cells (H&FCs) literature, shown in Table 1, for example, Foxon et al (2005, 2131) note in their study of H&FCs (and three renewables) in the UK, that: "most technology for demonstration [is] being sourced from overseas ... [and hopes for future market activity come] mainly as a result of significant collaboration and strong international knowledge networks within the sector."

In terms of scale – which is also socially constructed - the three main Innovation Studies approaches theorise matters largely in terms of hierarchical linkages between different scales of activity (Coenen et al, 2012). However, case studies typically reveal heterogeneous institutions in actor-networks making links with each other between and/or across scales (Hodson et al, 2010). With the two detailed articles on hydrogen and fuel cell (H&FC) policy shown in the first Innovation Systems (IS) category in Table 1 (Bleischwitz and Bader, 2010; Bleischwitz et al, 2010), there is implicit recognition of different scales in the European policy space, for example, but how such a multiscalar approach is meant to be operationalized by policymakers is not made clear (cf. Archibugi et al, 1999; Bunnell and Coe, 2001). As Bunnell and Coe (2001, 583) point out: "The system or scale as 'container' effectively means the relative neglect of broader networks that support innovation in particular locales". Thus, by examining these networks with less concern for the socio-spatial construction of boundaries and scales, the use of Innovation Studies heuristics can de-emphasize the importance of power struggles of actors and institutions seeking to achieve their strategic ends the outcomes of which are seen in socio-spatial terms (cf. Callon, 1986; Latour, 1987; Murdoch, 1998, 2006; Park, 2009; Choi et al, 2011; Coenen et al, 2012).

4.2 Lack of Local Context

For the Systems Innovation (SI) approaches of Strategic Niche Management (SNM) and Transition Management (TM) / Multi-level Perspective (MLP), Simmie (2012, 730) points out that, in terms of local context:

> "technological regimes and economic landscapes play out differently and have different characteristics in different regions. From this perspective it is important to analyse the regional and local geographies of energy transitions."

Some of the strategic niche management (SNM), transition management (TM) and multi-level perspective (MLP) literature in Table 1 draws on context-specific case study material (e.g. van den Bosch et al, 2005; Agnolucci and Ekins, 2007; McDowall; 2010; Park, 2011; Farla et al, 2011). Other research, meanwhile, offers generic theorising and/or policy suggestions.

4.3 Privileging Time Over Space

Coenen et al (2012) suggest that both Technological Innovation Systems (TISs) and the Multi-level Perspective (MLP) tend to privilege time over space. Researchers using time as an independent variable invite an implicit causality between events which can be unwarranted. As Coenen et al (2012, 975) suggest:

> "Introducing space to these analyses helps contribute to creating better explanations of the timings and sequences of transitions, reducing the problem of the 'causality of time', making more explicit why particular transitions have succeeded or failed."

The TIS and MLP literature cited in Table 1 use relatively detailed case studies. However, articles like Musiolik and Markand's (2011) study of the stationary fuel cell TIS in Germany and van den Bosch et al's (2005) examination of the potential for a fuel cell transport system in Rotterdam – both potential transitions - characterize the historical context to these case studies in broadly functional terms with little or no overt reference to space.

4.4 The Socio-spatial Processes Which Reinforce Uneven Development

In terms of the causes of uneven development, and in particular the reasons for less-favoured regions being unable to innovate as others do, Morgan (2012) makes clear that a systemic form of regional lock-in can occur which will result in a place-dependent form of path dependence. Citing Grabher's (1993) different levels of lock-in – functional, cognitive and political – Morgan (2012, forthcoming) stresses that:

> "the state must take the initiative for *unlocking* the process, either by orchestrating the restructuring of traditional industries or by attracting new enterprise … the state actually shapes the structure of the space economy in multiple ways – by what it does *and* by what it chooses not to do." [italics in original]

In the literature in Table 1, Bleischwitz et al's (2008) policy study encourages the healthy growth of European hydrogen and fuel cell (H&FC) 'clusters' and advises national and regional authorities to boost functional activities such as knowledge transfer and coordination in pre-existing, likely self-declared, clusters. Similarly, Madsen and Andersen (2010, 5380) report that: "geography and cluster aspects seem to matter". However, which systemic processes are linked to clustering are not made clear.

In terms of regional/local clustering taking place within an NSI analytical framework, the study by Mans et al (2008, 1384) is an analysis of self-declared H&FC clusters in the Netherlands. Here, spatial aspects of innovative activity are both explicit and implicit. The geographical boundary in which the NSI fits is made explicit is in geographical terms. However, the social processes underpinning key systemic and functional aspects of innovation taking place in these Dutch clusters, such as learning and the maintenance of trust, are only implicit, despite the clear involvement of a distance decay function (cf. Howells, 1999). By contrast, in Park's (2009) study of the NSIs in Iceland, the UK and Korea, the context-specific nature of each national case study is made explicit in terms of how various socio-economic and socio-technical processes operate in both economic and networked space.

The hydrogen and fuel cell (H&FC) literature for Sectoral Systems of Innovation (SSI), highlighted in Table 1, includes Choi et al's (2011) study of the South Korean H&FC SSI. Echoing Morgan's (2012) suggestion above, but from the point of view of a highly successful economy, Choi et al (2011) see a dual role for government in terms of being an investor in R&D and a facilitator/organiser of knowledge networks.

5.0 Case Study Methodology

We present the emerging findings of comparative German and UK case studies. These two countries are known to be at different stages of developing their technological innovation system (TIS) for hydrogen and fuel cells (H&FCs). Two regionally-based case studies were then chosen from within each country: North Rhine-Westphalia and Baden Württemberg in Germany and London and the South-East region and the Outer Hebrides in the Scottish Highlands and Islands. This case study selection allows for intra- and inter-regional comparisons.

5.1 Research Questions

A mixed-methods approach helps us to draw conclusions about two key research questions: i) the relative 'health' of the technological innovation systems (TISs) for hydrogen and fuel cells (H&FCs) in Germany and the UK, and ii) the utility of the TIS modelling approach itself in terms of the spatial and relational aspects of the social processes thought to be taking place in these territories.

5.2 Institutional Approach

Institutional maps for each of the four case studies were created and quantitative market data on H&FC activity was gathered. On one level, one can think of each institutional map as revealing a hierarchy of institutions. These range from supranational (European) institutions on the top, national ones in the middle and finally regional institutions at the bottom. However, this tends to privilege the analysis from the viewpoint of the supranational level. Also, direct links between the various institutions at different levels begin to reveal a variety of actor-networks have been left off each institutional map because such linkages cross, overlap and go directly from one hierarchical level to another. This is particularly the case with the activities of the transnational corporations (TNCs) which, while active at all levels, can, in particular, bypass national institutions in their search for regional/local resources.

Table 2 shows the quantitative indicators broken down into the 'Functions of Innovation Systems' approach of Hekkert et al (2007). On the left-hand side of Table 2, the seven functions of a technologically specific innovation system (TSIS) are listed. Quantitative indicators for each of these suggested by Hekkert et al (2007) are given in the next column to the right and finally, to the right of this, quantitative data known to be available is given.

Table 2 also indicates that qualitative data is available for all of Hekkert et al's (2007) functions. Forty-seven in-depth interviews with actors from key institutions were undertaken using a topic guide. In interview, participants indicated what they considered to be the enablers and barriers to 'healthy' H&FC activity amongst a range of relevant subjects touched on for all functions by the topic guide questions. Different actors were expected to have competing logics and rationalities for their activities in the same operational space so the interview data was analysed for its emergent themes according to an analytical inductive approach (cf. Silverman, 2006).

6.0 Expectations for Both German and UK Technological Innovation Systems (TISs)

The history of hydrogen and fuel cell (H&FC) developments in both countries can be thought of in terms of the shared expectations of all those with a stake in H&FC technologies: producers and consumers (cf. van Lente, 1993; van Lente and Rip, 1998). As such, distinct hype cycles in the media have emerged in Germany and the UK including several key phases: i) rediscovery (given fuel cells were first developed in the early 19th Century), ii) hype, and iii) disillusionment, before the cycle begins again (cf. Ruef and Markand, 2010).

6.1 Dynamics of the German H&FC Technological Innovation System (TIS)

The German hydrogen and fuel (H&FC) technological innovation system (TIS) has world-class research and development (R&D) being undertaken. This is backed up by a significant government commitment in translating home-grown knowledge in H&FCs into a broader industry. There is coordinated support for growing a variety of domestic and export markets. Previously, significant federal government funds for H&FC research and development (R&D) began with 'rediscovery' in 1990. From this period, H&FC R&D relied on close institutional links between academic researchers and industry going back two decades (Ehret, 2004; Blau, 2010), as well as ever-increasing coordination between the German automotive and energy sectors over H&FCs (Ehret and Dignum, 2012). The latter led to a policy forum known as the Transport Energy Strategy (TES) which aimed to identify the 'fuel of the future'. Members, including DaimlerChrysler, BMW, MAN, Volkswagen, Aral, RWE and Shell, believed that a transition to more

Table 2: Quantitative Indicators for Functions of Innovation Systems Analysis for Germany and UK

Function	Indicators (cf. Hekkert et al, 2007)	Quantitative Data Available (Qualitative data available for all functions)
1) entrepreneurial activities	1a) map the number of new entrants 1b) map diversification activities of incumbent actors 1c) map number of experiments with new technology 1d) numbers of companies	1a) PEM fuel cell developers: Entrants and exits (global, 1995-2010) 1b) considered too time-consuming 1c) H2FC demonstration projects / Registration of interest for communities undertaking large- scale H2FC projects and innovative applications 1d) publicly-listed fuel cell companies, 2002-2011
2) knowledge development	2a) map R&D projects 2b) map patents 2c) map investments in R&D 2d) map the increase in technological with learning curves 2e) academic papers	2b-i) relative patent advantages in hydrogen fuel cells by country 2000-2010 (inc. UK/Germany) 2b-ii) PCT patents globally, 1986-2010 (inc. UK/Germany) 2b-iii) share of global PCT patents 1995-2010 (inc. UK/Germany) 2c) public R&D spending (not including regional funding) 2d) Literature (cf. Zangwill and Kantor, 1998, 2000) considered too time-consuming 2e-i) English & German-language academic papers (2010) 2e-ii) Annual English-language H& FC publications since 1975 (to 2010) [also publications 1960-2011] 2f) citations, 1961-2011
3) knowledge diffusion through networks	3a) map workshops and conferences 3b) map network size & intensity over time 3c) map the number of trade fairs	3a) workshops and conference held in Germany and UK, 3b) total member organisations of H2FC associations (global, 2003-11) [no breakdown] 3c) numbers of trade fairs
4) guidance of the search	4a) map government or industry targets for H&FCs 4b) map articles in professional journals raising expectations 4c) count negative articles	4a) UK – none; Germany – various 4b) International Journal of Hydrogen Energy (IJHE) – Scopus positive review 4c) International Journal of Hydrogen Energy (IJHE) – Scopus negative review
5) market formation	5) none offered in Hekkert et al (2007) 5a-g) size of the market (cf. Madsen & Andersen, 2010)	5a) Shipments by application 2007-2011 (global, portable/stationary/transport) 5b) MW by application 2007-2011 (global, portable/stationary/transport) 5c) Shipments by region 2007-2011 (Europe/N America/Asia/RoW) 5d) MW by region 2007-2011 (Europe/N America/Asia/RoW) 5e) Shipments by fuel cell type 2010 (PEMFC/DMFC/PAFC/SOFC/MCFC/AFC) 5f) Shipments by fuel cell type 2010 (PEMFC/DMFC/PAFC/SOFC/MCFC/AFC) 5g) Unit shipments 2007-2011 (by application/region/fuel cell type) 5h) MW shipments 2007-2011 (by application/region/fuel cell type) 5g) Hydrogen fuelling stations
6) resources mobilization	6) detect, by means of interviews, whether or not inner core actors perceive access to sufficient resources as problematic	6) qualitative interviews
7) creation of legitimacy/counteract resistance to change	7) no indicators suggested	7a) newspaper articles mentioning H&FCs

sustainable transport was inevitable and hydrogen was selected as the most-promising fuel (Ehret and Dignum, 2012). Expectations for hydrogen and fuel cell (H&FC) technologies then peaked in 2001 (Ruef and Markand, 2010).

Public expectations for hydrogen and fuel cells (H&FCs) dipped significantly after 2001, but from 2005 onwards, things have steadily picked up again especially in terms of those working in private finance. Despite the peak in media hype, significant public and private investment has continued in the sector with the sustained involvement of a number of transnational automotive and energy majors based both inside and outside of Germany. This has led to the creation of a federal-level roadmap for hydrogen implementation, a National Innovation Plan (NIP), in 2006, and the establishment in 2008 of the National Organization for Hydrogen and Fuel Cells (NOW), a public-private agency with a budget of 1.4 billion Euros between 2007 to 2016 (Williamson, 2010). Then, in September 2009, a Memorandum of Understanding (MOU) was signed between the German government and these transnational corporations (TNCs) to invest in hydrogen and fuel cell infrastructure and, separately in the 'H2Mobility' programme, to roll out mass-produced H&FC vehicles by 2015 (Daimler, 2009; Ehret and Dignum, 2012). It was also agreed at this time that part of the National Economic Stimulus Package ('Konjunkturpaket II') programme, which had started in January 2009, would be used to help kickstart private investment in hydrogen refuelling infrastructure (Daimler, 2012). In combination, the H_2 Mobility and Konjunkturpaket II policies appear likely to help Germany to meet Europe's low carbon targets for 2050 whilst simultaneously boosting Germany's domestic economy via foreign sales and economic regeneration of regions like the Ruhr. Simultaneously, the sixteen fully devolved regional states – the Länder - have been able to top up the funding of these local, national and supranational H&FC research, development and demonstration (RD&D) projects (*Scientific American*, 25.8.11).

This activity within the emerging hydrogen and fuel cell (H&FC) technological innovation system (TIS) in Germany shows the importance that the federal government places on a collectively agreed public-private vision for the future development of the sector. The recognition that this vision needed to be medium- to long-term has partly de-risked private-sector investment in infrastructure (Garche et al, 2009). As one study participant stated: "It's really about innovation and innovation is more than just about novelty. It's about bringing novelty to the market. [This is when] you need a stronger input by industry." It is not all plain sailing. There are nevertheless concerns in Germany about barriers to growth of its emerging H&FC TIS, chief among these is an emerging skills shortage as young people increasingly opt out of science and engineering careers (Cremer, 2011). Also, what happens when federal government funding for H&FC infrastructure stops in 2016? Will it have been enough, and will the German economy be in good enough shape, to maintain the momentum building up in this TIS?

6.1.1 Regional Case Study 1: North Rhine-Westphalia

The Rhine-Ruhr area to the west of the North Rhine-Westphalia länder was identified by Maisonnier et al (2007) as an important part of the major European industrial belt stretching from the Midlands in the UK through Belgium and Germany and on to northern Italy. As such, a number of areas along this axis, including the Rhine-Ruhr area, are known to have relatively dense networks of hydrogen pipelines, thanks to heavy industry, which could help with supplying substantial quantities of hydrogen chiefly for mobility (Pastowski and Grube, 2010). National and regional government activity has therefore been focussed for some time on encouraging the growth of hydrogen and fuel cell (H&FC) activity and a true 'cluster' is now felt to exist there centred on the Rhine-Ruhr area (*Fuel Cell Today*, 2012).

Appendix 1 is the institutional map for hydrogen and fuel cell (H&FC) activity in the North Rhine-Westphalia region as it currently stands. Public institutions are shown in yellow, private institutions are in purple, public-private ones are in blue, leaving academic institutions in orange. In governance terms, the activities of the four regional government ministries which potentially impact upon the hydrogen and fuel cell (H&FC) technological innovation system (TIS), are constrained by the activities of similar bodies at the national and supranational levels. The H&FC cluster centres on the activities of the North Rhine Westphalia Fuel Cells and Hydrogen Network (NBW-NRW) based in Düsseldorf which has over 330 members in a variety of industries linked to H&FCs. When examined in more detail, there are a large number of locally-owned, small-and-medium enterprises (SMEs) (each under 250 employees), fewer large enterprises (LEs) (over 250 employees), a significant number of SMEs and LEs owned by companies in Germany, but outside of North Rhine-Westphalia, and then a certain number of foreign-owned SMEs and LEs. Appendix 1 also shows that higher education is strongly represented in the region with, amongst others, sixteen university departments and twenty research institutes involved in H&FCs. Interestingly, there is also a degree of linkage between higher education institutions working in H&FCs in North Rhine-Westphalia and some elsewhere in Germany or overseas.

The qualitative interviews undertaken revealed some significant things about the spatial and functional nature of the hydrogen and fuel cell (H&FC) networks embedded in Germany. One interviewee working for a transnational corporation (TNC)-owned research and development (R&D) operation based in North Rhine-Westphalia, G-TNC1 said that significant ideas come via the dense, yet open network of H&FC institutions linked via the North Rhine Westphalia (NRW) Fuel Cells and Hydrogen Network:

> "[W]e have a network, working together with the institutes, the universities with private companies, so little and medium ones, and also with the big OEMs … in other industry sectors, and … there might

be also some very interesting ideas which you can also maybe collect, yes copy and paste onto your … technology." (G-TNC1)

However, some of these TNCs are also choosing not to be actively engaged, or particularly well embedded, in the local region and lack close geographical or relational links to other embedded institutions via locally-based actor-networks. Instead, some are simply choosing to benefit from access to spatially delimited resources, chiefly regional government grants and the skilled work force, and are much more closely tied relationally to their overseas parent than to other institutions in North Rhine-Westphalia.

6.1.2 Regional Case Study 2: Baden-Württemburg

Baden-Württemburg in the south-west of Germany is the leading federal state in terms of research and development (R&D) spend and performance (Grupp et al, 2009). At the same time, the bulk of the German automotive industry has historically been centred on the state capital, Stuttgart (Cooke, 1994, 1997). Today, both Daimler and Porsche have their R&D and manufacturing operations located in and around the city. Automotive R&D into hydrogen and fuel cells (H&FCs), which Daimler has taken a national and international lead in, drives much of the H&FC activity in the Baden-Württemburg region at least in volume terms.

Appendix 2 shows the institutional map for H&FC activity in the region at the moment. A somewhat more tentative H&FC cluster than that in the Rhine-Ruhr can be said to be centred on Stuttgart where the Fuel Cell and Battery Alliance Baden-Württemberg (BBA-BW) is based. It has around 65 members in various industries linked to H&FCs and, like in North Rhine-Westphalia, the majority are locally-owned SMEs and LEs, while the remainder are owned by companies outside the state border or outside the national border, i.e. in the latter case, they are owned by transnational corporations (TNCs). The state of Baden-Württemberg has the highest total number of higher education institutions in the country and these, with their links to industry, help to contribute to significantly high rates of patenting in the region. In governance terms, the situation is similar to that in North Rhine-Westphalia in that a dependent hierarchy of institutions going up from the regional to the national and supranational could be said to exist. However, multiscalar global-local links have long been established here by supranational institutions, including European funding bodies and the TNCs as well as overseas higher education institutes.

One interviewee from a foreign-owned TNC based in Baden-Württemburg characterised the cluster as one where public and private interests are aligned:

> "Stuttgart is ... one of the hydrogen regions in Germany ... [W]e will have two public stations in a couple of weeks, and the entire industry here is very, very car-oriented because of Porsche being here, because of Bosch being here, Siemens, and … Daimler ... there's a lot of support for new technologies in general, and then on top of that we just got a new local Govt, which is run by a green party, so that adds to that green momentum as well." (G-TNC4)

6.2 Dynamics of the UK Technological Innovation System (TIS)

Like Germany, the UK has world-class hydrogen and fuel cell (H&FC) research and development (R&D) being undertaken at certain universities and in certain private companies with strengths in H_2 production and storage. It has had and continues to have a number of regionally-based hydrogen demonstration projects. There are also private-sector actors (investors) with interests in hydrogen technology. As in Germany, but delayed slightly, expectations for H&FC technologies rose steadily from 1993 to 2003 (Ananthaswamy, 2003). After the peak in the hype cycle, expectations have again been rising steadily since the mid- to late 2000s. One interviewee from an overseas-based transnational corporation (TNC) said in interview: "In the UK, we have moved beyond the demonstration stage. We're ready for the market."

Government funding for hydrogen and fuel cell (H&FC) research and development (R&D) in the UK formally started in 1992, but the amount invested was at a lower level than in Germany. From this period, institutional links between academic researchers and industry began to develop, including major UK-based transnational corporations (TNCs) like Rolls Royce and Johnson Matthey. After the 2003 peak in the H&FC hype cycle in the UK, significant investment has still continued in the sector albeit with claims for establishing a future 'hydrogen economy' now largely in the background. Since 2003, a number of TNCs in energy and transportation as well as locally-owned SMEs have continued to move things forward from the R&D phase of evolution of the technological innovation system (TIS) to a hoped-for market phase.

Despite certain top-down policy initiatives from central government - in early 2012 a review for a proposed 'UK H_2 Mobility programme' was announced - there is little evidence of coordinated support for growing a variety of domestic and export hydrogen and fuel cell (H&FC) markets. This suggests conflicting policy priorities between the Department for Business, Innovation and Skills (BIS), the Department of Energy and Climate Change (DECC) and the Treasury, who, since 2008, have been operating in austere times. In terms of UK innovation and energy policy, for example, the marketplace is now largely expected to solve many future energy concerns in terms of sustainability and security of supply.

Key structural and policy-related issues for the H&FC TIS in the UK are;

- the lack of a top-down, politically-sanctioned medium- to long-term vision,
- the short-term trading emphasis of Britain's capital markets,
- persistent under-resourcing and under-valuation of education and training,
- less effective institutional links between universities doing hydrogen research, development and demonstration (RD&D) and (former) regional development agencies (RDAs), local planning authorities (LPAs) and private enterprise,
- the lack of home-grown R&D in the automotive sector may be a significant factor in terms of lack of government political priority and strategic support leading to poor funding allocation, and
- national policy makers have largely focussed on electric vehicle prospects.

6.2.1 Regional Case Study 3: London and the South-East of England

Appendix 3 is the institutional map for this city-region. It shows that hydrogen and fuel cell (H&FC) activity in London and the South-East city-region centres on the London Hydrogen Partnership (LHP), a public-private body set up by the Greater London Authority (GLA) in 2002 just before the last peak in the UK hype cycle for H&FCs. The LHP currently has nineteen members who come from a cross-section of industrial, academic and regional governmental institutions. National-level policymakers based in Whitehall in London, like those from DECC, are also involved. Beyond the national tier of governmental institutions, the supranational bodies are the same as for the two case studies in Germany. In terms of the companies in the region which are linked to the LHP, most are small and medium-sized enterprises (SMEs) but they are not based in the region or even in the country. Those that are in the region, like Surrey-based AFC Energy for example, have not necessarily chosen to network closely with the LHP.

Like Berlin, London has a number of advantages for transnational corporations (TNCs) involved in hydrogen and fuel cells (H&FCs). Beyond the skilled work force, research universities (in this case University College London and Imperial College), and the potential to meet financiers of renewable projects in the City of London, London has always been a leading demonstration site for H&FCs because of the international exposure that such a world city can offer (Hodson and Marvin, 2007). The CUTE and HYFLEET CUTE bus programmes, for example, operated demonstration vehicles in London between 2003 and 2006. This activity was organised by an actor-network consisting of DaimlerChrysler, BP, the GLA and the European Commission (EC) (Hodson and Marvin, 2010). There is currently a hydrogen-powered demonstration bus service, the R71, in operation thanks to the following actors working together: the GLA, Transport for London (TfL), London Bus Services (LBS) Ltd, Wrightbus, Ballard, ISE Corp and Air Products Ltd, the last four of which are foreign-owned TNCs. National H&FC companies, ITM Power and Intelligent Energy, have run vehicle trials for black cabs and scooters respectively and there is still a fuel-cell- (FC) powered back up power supply in the former London Development Agency's (LDA)'s Palestra office in Southwark. All these activities make a clear link between the ability for zero-carbon vehicles to begin tackling poor urban air quality and suggest that London will remain a significant showcase for H&FC demonstrations where the public in greater numbers are beginning to experience H&FC buses, taxis and scooters, for example. However, industrial H&FC activity in the UK is largely taking place in regions outside of London and the South East.

6.2.2 Regional Case Study 4: The Outer Hebrides

Appendix 4 is the institutional map for the Outer Hebrides which is part of the Scottish Highlands and Islands region. Designated as economically fragile, the local council, Na h-Eileanan Siar, has pursued sustainable development policies on its fifteen inhabited islands. In terms of energy policy, the costs of fossil fuels are automatically high on the Outer Hebrides as they must be shipped from the mainland. Also, access to the natural gas grid is poor and the electricity supply can be unreliable and hugely inefficient. This has meant that for some time the high cost of centralized energy production has been considered a key potential driver to assist in the introduction of hydrogen and fuel cell (H&FC) technologies in the Highlands and Islands. Rural communities, and in particular island communities like those on the Outer Hebrides, have therefore be used to demonstrate in a bounded model how a future, small-scale hydrogen economy might function (Hodson et al, 2008).

Appendix 4 shows the same supranational institutions as the other case studies, but here, unlike London and the south-east, the council in the Outer Hebrides, Na h-Eileanan Siar, made connections with the European Commission's energy funding body because of the relatively deprived, rural nature of the area. Unlike the other regions above, there is no professional networking body for hydrogen and fuel cells (H&FCs). Instead, Na h-Eileanan Siar has held together a vision for low- or zero-carbon industrial development and regeneration with its Energy Innovation Zone policy (2001), Structure Plan (2003) and Local Plan (2008). These have been instrumental in creating the Hebridean Hydrogen Park (2006) which has largely focused on the regeneration of Stornoway, long in decline due to reduced activity in the North Sea oil and gas sector. Building a new skills base in hydrogen has been managed by Lews Castle College on the Isle of Lewis, while the EC-funded £2.5M towards an 'H2 SEED' project which covered an exploration of the whole value chain of hydrogen technologies by looking at hydrogen production from biogas, hydrogen storage, a hydrogen filling station and hydrogen use in both stationary and transport applications. There was a hydrogen road trial in 2010 with a fuelling station supported by the French-owned transnational corporation (TNC), Air Products. Lastly, a Hebridean Hydrogen Growth ('H2growth') project has long been planned to market the outcomes of H2 SEED and the council again approached the EC in early 2012 to fund a hydrogen highway across the islands entitled HIGH2WAY (Na h-Eileanan Siar, 2012).

7.0 Results - Technological Innovation System (TIS) Performance

Our results on how the German and UK hydrogen and fuel cell (H&FC) technological innovation systems (TISs) score on many of the quantitative economic indicators suggested by Hekkert et al (2007) are still in a preliminary form.

7.1 Results – German Technological Innovation System (TIS) Performance

In general terms, the German TIS cannot be said to be at a fully industrial, market-led stage yet. As one contributor, 'G-TNC4' based in Baden-Württemburg, said to us, Germany is currently at stage two of three, with stage one being R&D, stage two "pre-commercial" and stage three "industrialisation or commercialisation".

7.2 Results - UK Technological Innovation System (TIS) Performance

Some fairly significant differences between the UK and Germany are anticipated in terms of the quantitative indicators sought in Table 2. While the UK is similarly at a pre-commercial stage, its technological innovation system (TIS) lags further behind Germany in terms of its evolution, i.e. its preparedness to launch certain H&FC products (English, 2012). The key reason for this is that, with little central government commitment that might translate the learning and expertise being generated in public and private R&D in the UK into broader industrial advantage, the hydrogen and fuel cell (H&FC) TIS is likely to remain internationally disadvantaged in market terms compared to Germany and other nations like the United States and Japan.

In terms of the UK's potential for the commercial development of certain H&FC products, the inherent difficulties in bringing such items to market are well known (cf. Ricci et al, 2008, 2010; Ekins and Hughes, 2007; Roche et al, 2010; Sherry-Brennan et al, 2010). These include existing technological lock-in with fossil fuels, the high costs of R&D, the inability of institutions to coordinate activity without a guiding vision, poor access to funding, the cost of infrastructure and the continuing lack of generation of end user awareness (and hence market demand). Such barriers are not unique to the UK and appear to be relatively uniform in developed nations pursuing H&FCs around the globe (Anscombe, 2010). However, a politically-agreed top-down guiding vision or framework for the H&FC industry, as is the case in Germany, has been suggested by soon to be the best way to motivate bottom-up public-private activities that can begin breaking down such barriers (Williamson, 2010).

7.3 Results - Intra- and Inter-regional Comparisons

In terms of intra- and inter-regional comparisons, institutions that are helping to strengthen Germany and the UK's hydrogen and fuel cell (H&FC) TISs via positive feedback are not doing so in uniform ways across (and between) national economic space. The technological innovation systems (TIS) and 'functions of innovation' approaches, however, do not account for such spatial variation in terms of future economic opportunities.

Regional and national policymakers in Germany, for example, have been keen to regenerate certain city regions since the 1970s, like the Rhine-Ruhr area, and have also attempted to encourage green technologies in existing manufacturing centres like Stuttgart. Hydrogen and Fuel Cell (H&FC) activity has therefore evolved in, and been drawn to, some very distinct territories all with key attributes like regional government subsidies and a skilled workforce. Presently, while German H&FC activity appears largely embedded in two key R&D-rich Länder, North Rhine-Westphalia and Baden-Württemburg, significant numbers of H&FC companies also exist in the states of Bremen, Hessen and Bayern and many of these are making institutional links to those companies in North Rhine-Westphalia and Baden-Württemburg and thes need to be accounted for in any analysis.

Similar spatially-focused policy approaches have been attempted in the UK where, for example, the regeneration of the South Wales (cf. Morgan, 2012) and the West Midlands regions have been attempted in part via the revitalization of the automotive sector there. One element of this has been through encouraging hydrogen and fuel cell (H&FC) research, development and demonstration (RD&D) activity via academic research grants and the designation of instruments like the Low-Carbon Economic Area (LCEA) in South Wales in 2009.

What we are also seeing in and around potential H&FC clusters in spatial and functional terms is a number of major transnational corporations (TNCs) either acquiring R&D firms, locating branch manufacturing plants, and/or maintaining an interest in demonstration activities. These TNCs have significant resources and therefore can be expected to exercise greater levels of political power and financial leverage in both the German and UK national and regional economic space as compared to small and medium-sized enterprise (SMEs).

Overall, the case studies resonate with Hodson and Marvin's (2007, 2010) geographically-based typology of hydrogen and fuel cell (H&FC) activities. We see here H&FC 'city-regions' and 'islands'. They are also similar to other regional case studies of H&FC clusters (e.g. McDowall, 2010) where the relational and geographical links between public and private institutions are shown to be complex, heterogeneous, path-dependent and distinct to the resources embedded in a particular territory (cf. Morgan, 2012).

8.0 Analysis - Place Matters

Our preliminary data so far suggests that place matters for the German and UK hydrogen and fuel cell (H&FC) technological innovation systems (TISs). The Hekkert et al (2007) model of the functions of a technology-specific innovation system (TSIS) is useful in offering a differential 'health check' for H&FC activity in each country at the national level, but lacks an overt recognition that space and place matter to the dynamic social processes that underpin innovation at the regional and local levels. Ultimately, both countries are on similar, but quite different, development paths for hydrogen and fuel cells (H&FCs) and that is due in large part to unevenly distributed resources and institutional arrangements.

The functions of innovation systems approach regards entrepreneurial activity as effectively aspatial. Yet the case studies suggest the importance of local context. German and UK H&FC innovative activity is taking place in very particular places. In our case study examples, this is shown to be in city-regions and islands where public and private institutions are either well aligned, as in Germany, or could be better aligned, as in the UK, in terms of regional, national and supranational institutional governance. Looking closer at "the regional and local geographies of energy transitions" as (Simmie, 2012, 730) suggests, it is clear that, at the local level, resources, funding and incentives are important. Thus, having examined the quantitative and qualitative data on indicators, Germany and the UK are moving at quite different speeds towards marketing H&FC technologies.

The case studies presented here suggest that regional and national boundaries, like scale, can only ever be considered to be socially-constructed. Institutional linkages in actor-networks clearly cut across scale (Hodson et al, 2010; Allen, 2011) and in Germany and the UK key institutions based outside of a country's national and/or regional space have agency and can influence what goes on inside that space. In fact, the institutional approach of all the heuristics used in Innovation Studies immediately present concerns about how best to analyse and display graphically the actor-networks involved in innovation (cf. Conway and

Steward, 1998). As Allen (2011) indicates, any two-dimensional ordering that an investigator might wish to impose on a page, in terms of knowing which institutions should be included in a study of an innovation system, soon breaks down given the complex picture of regional, national and supranational institutions. Each has complex relational and geographical links. Because of this, multiscalar approaches to global-local links, in particular, have since been sought (cf. Geels and Deuten, 2006) and insights into topologies from relational economic geography appear potentially useful here given the spatial turn in Innovation Studies (cf. Dicken et al, 2001; Jones, 2009; Allen, 2011).

In the case studies, we have so far attempted to avoid privileging time as an independent variable over space (cf. Coenen et al, 2012). Both Germany and the UK are still at the very early stages of what may or may not turn out to be a transition to greater use of hydrogen and fuel cells in the national energy economies. We have therefore introduced space into our analysis in part to ensure the reasons for the success or failure of these transitions are not lost in a frame of retrospective historical determinism.

The clustering of hydrogen and fuel cell (H&FC) activity, seen most distinctly by the large numbers of companies in the Rhine-Ruhr area of North Rhine-Westphalia, appears to be built in part on a distance decay function in terms of face-to-face communication which supports the building of trust (cf. Howells, 1999; Simmie, 2005). Interviewees have described the importance of such networking opportunities and we suspect such socio-spatial processes to help further characterise the nature of the uneven distribution of future innovative opportunities in the national economic space of both countries.

Finally, in terms of improving the outcomes of the social processes that lie behind the uneven distribution of future innovative opportunities, we note that Coenen et al (2012) suggest that institutional embeddedness can be boosted by institutions that enable and/or constrain innovation in spatially differentiated ways. They argue that purposive action, i.e. agency, when regarded relationally emerges from interdependencies between actors and institutions bound by social relations in actor-networks. This is a useful insight because aspatial approach of Innovation Studies heuristics typically miss much of the impact of power relations on innovation. From the qualitative data revealed so far in our cases studies, there is a need to better understand the impact of the power relations between actors in a hydrogen and fuel cell (H&FC) cluster appears crucial to understanding the uneven distribution across economic space of future innovative opportunities. Foreign-owned TNCs and locally-owned SMEs struggle for funding, but have markedly different levels of financial and political leverage regarding key funding institutions.

9.0 Modelling Refinement

The results of our data are only in a preliminary stage of analysis. However, at this early stage, it is possible to suggest that insights from both evolutionary economic geography and relational economic geography have much to offer. For a more complete understanding of the socio-spatial processes underpinning innovation, the feedback loops of the functions of innovation systems approach could do well to incorporate the distance decay function seen with cluster activity (Howells, 1999). Similarly, further development of the relational nature of links between institutions in actor-networks with alternative topologies might avoid the need to 'jump' scale (Allen, 2011).

10.0 Conclusions

The case study material from the UK and Germany strongly suggests that, in terms of agency and structure for hydrogen and fuel cell (H&FC) innovation, place matters. The nationally-based H&FC actor-networks in both countries have functional links centred distinct territories, whether these are city regions or islands, as in our case studies. For our analysis, in the UK we found that the lack of home-grown R&D activities in the automotive sector in formerly active regions like the West Midlands and South Wales appears to be a significant factor in terms of central government not making economic regeneration via H&FCs a political priority (cf. Morgan, 2012). Strategic spoken support for hoped-for H&FC clusters exists on paper in both of these locations, but little else concrete has emerged beyond some regional funding (now lost) and funds for R&D via academic funding bodies which is now declining. Local government in the Outer Hebrides, by contrast, is seeking a more radical approach to energy and regeneration policies through a bottom-up approach that has so far largely avoiding the need to go to UK central government for funding. As an 'island' demonstration for H&FC technologies, the local authority has gathered a mix of public and private institutions with a strategic vision involving training and hoped-for sales and marketing of trialled technologies. It is noticeable that at present the activities of UK H&FC actor-networks appear much more constrained than their German counterparts – UK-based TNCs linked to H&FCs have generally been choosing to invest more in Germany since the creation of the public-private H&FC funding agency, NOW, in 2008.

Our case study material suggests that the German government's commitment to the H2Mobility programme from 2009 was complimented by its new institutional arrangements with the public-private funding body, NOW, and corporate and academic institutional links centred on the Rhine-Ruhr area as well as on Stuttgart in Baden-Württemburg. Our case studies suggest that the locational advantages being offered up by these actor-networks centre on the "institutional embeddedness of socio-technical development processes" (Coenen et al, 2012, 968) within the territorial spaces in question, in this case regional (hoped-for) 'clusters' (cf. Saxenian, 1994). As such, institutional embeddedness is a measure of the effectiveness of institutional links between existing private enterprises, existing public and private sources of capital (including central and regional government-backed R&D funding bodies), universities doing hydrogen RD&D, regional development agencies (RDAs), local planning authorities (LPAs) and other relevant institutions. Our institutional approach has examined which H&FC-linked organisations in the actor-network enable and/or constrain innovation and whether they do so in spatially differentiated ways. This approach therefore suggests that purposive action - agency - is *interdependent* amongst institutions (actors) within the global H&FC TIS and is bound by social relations (cf. Granovetter, 1985; Asheim and Coenen, 2006; Martin, 2000; Maskell and Malmberg; 1999; Storper, 1997). From this, evolutionary explanations of comparative national or regional advantage in terms of innovation emerge from other variables in the evolutionary economic geography and regional systems of innovation literature (which are also linked to institutional embeddedness).

In terms of agency, these hydrogen and fuel cell (H&FC) actor-networks could be said to behave like 'enactors' (cf. Garud and Ahlstrom, 1997; Bakker, 2011) offering up certain locational advantages to national or supranational 'selectors'. While the comparative advantages of certain places matters, in particular to the transnational corporations (TNCs) like the automotive OEMs and energy majors who may decide to invest in a region, a private financing institution, by contrast, has said it is less concerned with place and more interested in its return horizons.

In sum, the hydrogen and fuel cell (H&FC) case study material from the UK and Germany so far suggests that places may, in time, acquire the agency to effect an energy transition. However, the pre-existing and uneven spatial distribution of resources - and the social processes linked to accessing them - means that maintaining enough agency to change things can be difficult and extraordinarily time-consuming especially when positive feedback turns negative. We have seen that when theorizing about the functions of innovation, the twin approaches of relational and evolutionary economic geography have now staked their respective claims in ensuring that space and place are better incorporated into Innovation Studies heuristics and contributes to an improved understanding of the uneven distribution of innovative opportunities across economic space. As Coenen et al (2012) point out, the institutional power needed to achieve things is actively constructed - or lost - through the activities of actor-networks. From this, we are seeing how the 'global-local' relational links that underpin clustering activities run in two directions. While transnational corporations (TNCs) have the power to choose to locate somewhere, certain places nevertheless exercise significant economic power on the global stage thanks to their comparative regional advantage and their institutions also have considerable power in helping to determine *where* innovation is likely to take place – the often missing element in Innovation Studies approaches.

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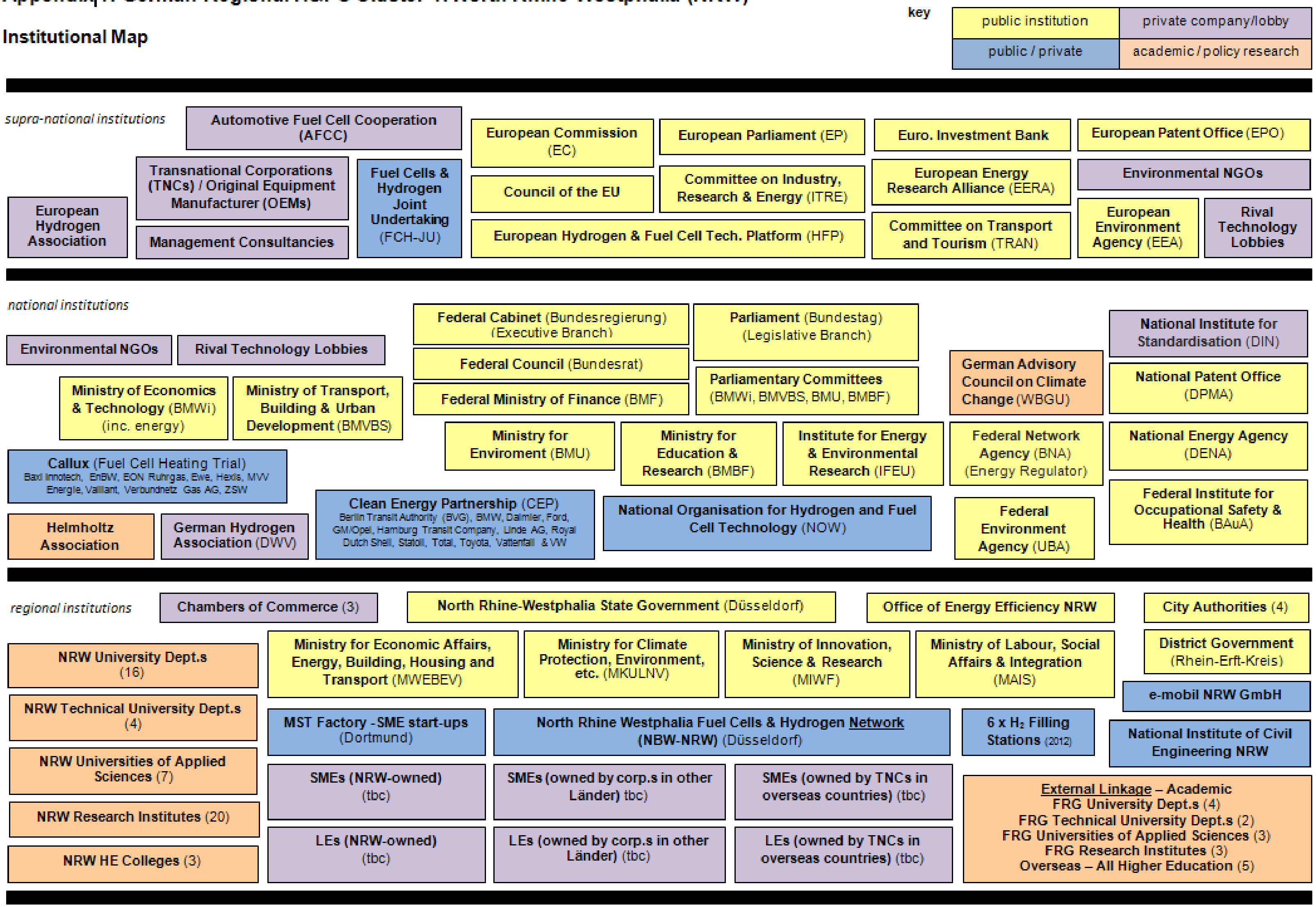
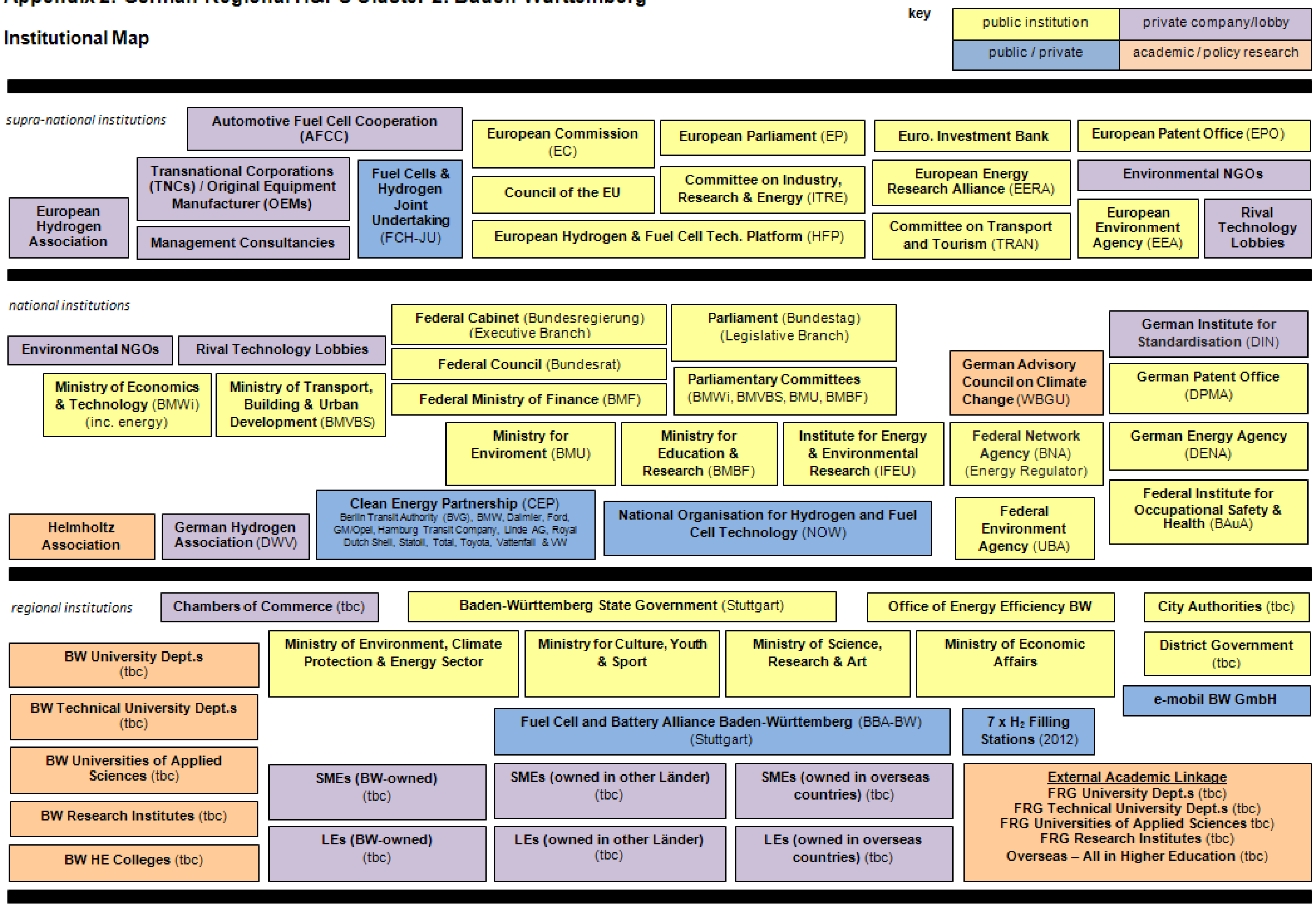
Appendix 1: German Regional H&FC Cluster 1: North Rhine-Westphalia (NRW)

Institutional Map



Appendix 2: German Regional H&FC Cluster 2: Baden-Württemberg

Institutional Map

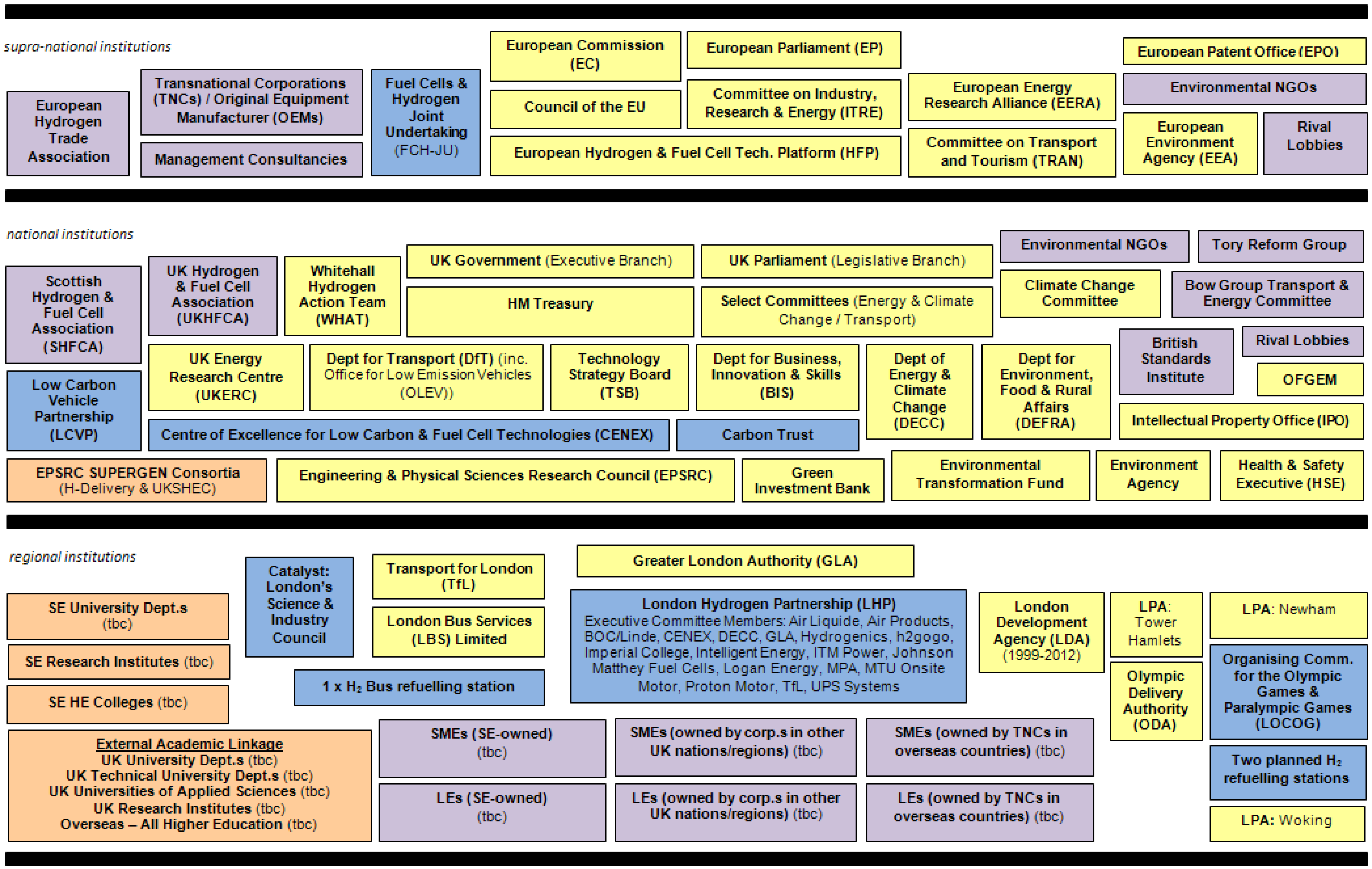


Appendix 3: UK Regional Hydrogen Cluster 1: London and the South East (SE)

Institutional Map

key

public institution	private company/lobby
public / private	academic / policy research



Appendix 4: UK Regional Hydrogen Cluster 2: Outer Hebrides

Institutional Map

key: public institution | private company/lobby | public / private | academic / policy research