Hargreaves, Tom; Burgess, Jacquelin

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by

Tom Hargreaves and Jacquelin Burgess

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Tom Hargreaves and Jacquelin Burgess
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Correspondence:
Dr Tom Hargreaves
School of Environmental Sciences
University of East Anglia
Norwich, UK
NR4 7TJ
Tel: +44 (0)1603 593116
Fax: +44 (0)1603 593739
Email: tom.hargreaves@uea.ac.uk

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1. Introduction: Overview of the Transition Pathways Project

Questions about the future of the energy system in the UK have, in recent years become deeply entangled with a number of previously discrete intellectual, commercial and policy domains. Not least, the emergence of what Hulme (2009) refers to as 'upper-case Climate Change' to distinguish this discourse from the routine dynamics of weather and climate systems, with its imperative massively to reduce global production of greenhouse gases within the next 50-60 years, has added a sense of urgency and a different rationale to underpin future strategies for managing the energy sector than has previously been the case. Each IPCC assessment report has provided stronger justification for the need for action; many governments in the developed world have responded by seizing opportunities to review, redirect and /or renew their energy policies and provide a framework for future investment by the private sector (see, for example, DTI 2003, 2006, 2007) whilst seizing opportunities to benefit from the rapid deployment of technological innovations to support the growth of 'clean energy' systems.

In response to these drivers and a long period of relatively little investment, the Research Councils Energy Programme was established in 2004, co-ordinated by the Engineering and Physical Sciences Research Council (EPSRC). So far, some £24M has been invested to:

- provide scientific evidence in support of energy policy
- contribute to processes of adaptation to climate change
- build capacity through partnerships with stakeholders and energy-related businesses
- increase the international profile of UK energy research
- expand UK university energy related research capacity (see www.epsrc.ac.uk/ResearchFunding/Programmes/Energy/).

As part of the Energy initiative, in 2006 EPSRC signed an agreement with the power and gas company E.On UK to support a funding partnership worth £10M to further research on future low carbon energy solutions. This initiative provided an excellent opportunity to promote the RCUK's goal of supporting more interdisciplinary research on energy questions. The first call for interdisciplinary proposals under the EPSRC/E.On fund was initiated through an EPSRC-facilitated '*Sandpit*', hosted by E.On at its Ratcliffe-on-Soar power station in April 2007. The multi-university, multi-disciplinary consortium undertaking its 4-year programme analysing 'Transition Pathways to a Low Carbon Economy'[1] emerged through this process. The Transition Pathways (TP) consortium aims to design and assess a set of socially, economically, politically and technically plausible pathways to a low carbon energy economy. To do this, the consortium draws together 24 researchers from 8 UK Universities (Imperial College, Kings College London, Bath University, Leeds University, the University of East Anglia, Strathclyde University, Loughborough University and the University of Surrey) with diverse disciplinary backgrounds and research interests, including electrical engineering, mechanical engineering, cultural geography, energy economics, and innovation theory.

[1] Project website at: http://www.lowcarbonpathways.org.uk/ (last accessed on 22.10.09)

The TP consortium is thus an example of researchers from very different disciplines bringing their expertises to bear on the difficult issues associated with energy futures specifically, but it is also an empirical example of a growing trend across academia more generally (e.g. Nowotny *et al* 2001, Barry *et al* 2008), that mono-disciplinary approaches are unsuitable for addressing complex, 'wicked problems' (Turnpenny *et al* 2009; Rittel and Webber 1973) that cross conventional divides between academic disciplines and between academia and society. Accordingly, a range of new interdisciplinary research strategies are being pursued, and it is worth establishing some common definitions before proceeding. Conventionally, *multidisciplinary* approaches involve several disciplines working alongside each other on a common problem, but each using their standard disciplinary framings and approaches. In contrast, *interdisciplinary* approaches involve some attempt to integrate or synthesise the different perspectives and approaches that disciplines bring to the same problem. Finally, *transdisciplinary* approaches attempt to cross disciplinary boundaries, norms and procedures in order to address real-world problems, overcome the divide between 'expert' and 'lay' knowledges, and/or reduce the distance between research and policy or other societal decision makers (Barry *et al* 2008, 27; see also Petts *et al* 2008; Wickson *et al* 2006; Lawrence and Després 2004; Thompson Klein 2004; Lowe and Phillipson 2006; Horlick-Jones and Sime 2004). Following Petts *et al* (2008) and Barry *et al* (2008), and to avoid confusion, we suggest that these multiple definitions point towards a spectrum of interdisciplinarity that spans from the simple coordination of disciplines at one end, and moves towards a more radical approach with the potential to fundamentally re-imagine disciplines at the other. Accordingly, we adopt the term 'interdisciplinarity' throughout to refer to this broad spectrum, but draw on these distinct definitions where they appear helpful.

Given this general move towards interdisciplinary research, and specifically within the area of energy, this report takes the TP project as a case study and seeks to explore the nature and challenges of undertaking interdisciplinary research experienced on the project. In the original research proposal (see project website), the Consortium expressed its desire to be reflexive in its methods of working. This Report, based on empirical research conducted between January and May 2009, provides a detailed analysis of progress over the first 18-months of the project. Based on multiple social scientific methods (semi-structured interviews, participant observation, Q methodology and social network analysis), we explore current working practices on the TP project to identify areas of convergence and divergence between researchers from different disciplines about how interdisciplinary energy research should be conducted. Our aim is not to criticise but, as promised in the original submission, to conduct a *formative evaluation* of progress so far in order to stimulate discussion among the TP consortium, and to provide a basis for further work later in the life of the project to assess whether experiences of interdisciplinary working have led to any changes in individual academics' knowledge, values, attitudes and practices. Accordingly, the conclusions to this report are not presented as final outcomes, but as questions to the consortium that deserve further attention.

The next section of this report highlights some of the key issues in the literature on interdisciplinary research. Subsequently, section 3 introduces the TP project as a case study in more detail, concentrating on its formation through a '*Sandpit*' process. In addition, section 3 introduces the multiple methodologies used for this report in more detail. Sections 4, 5, and 6 then present the empirical data. Section 4 focuses on

consortium members understandings of interdisciplinarity and the challenges it poses. Section 5 considers the conceptual basis of the TP project, highlighting the different ways in which consortium members understand the terms 'transition' and 'pathway'. Section 6 then explores the current social and working relationships within the TP consortium by using exploratory social network analysis to represent project interactions to date, and also considering the various ways in which consortium members conceptualised interdisciplinary working on the project. Finally, section 7 concludes the report with a series of questions to the consortium that we feel merit further discussion.

2. The Challenges of Interdisciplinary Research: Key issues from the literature

As noted above, calls for interdisciplinary collaboration have grown substantially in recent years (e.g. Petts *et al* 2008; Barry *et al* 2008; Strathern 2004; Lowe and Phillipson 2006). For some, this growth is indicative of a qualitative shift in the nature of relationships between science and society. Prominently, Nowotny *et al* (2001) suggest this has involved a move away from what they call 'Mode-1 science' and towards 'Mode-2 knowledge production'. Where Mode 1 science is seen to involve autonomous disciplinary research producing knowledge within the confines of the academy, Mode 2 knowledge production, they suggest, involves transdisciplinary research produced across many sites, by many (academic and non-academic) stakeholders and demands new means of assessment and quality control that displace a culture of autonomy in favour a culture of accountability (Nowotny *et al* 2001). Following these ideas, numerous commentaries have reflected on the relative merits and challenges interdisciplinary working leading Barry *et al* suggest:

> "The present situation can be understood as a problematization: the question of whether a given knowledge practice is too disciplinary, or interdisciplinary, or not disciplinary enough has become an issue and an object of enquiry for governments, funding agencies and researchers themselves." (Barry *et al* 2008, 21)

Within this problematization, arguments suggest that whilst disciplinary research preserves scientific autonomy, it may be unhelpful for seeking innovative solutions to complex problems that are characterised by high levels of uncertainty, and may be unaccountable to the many stakeholders beyond the academy that are implicated in these problems. In contrast, others argue that interdisciplinary collaboration to address pressing policy problems represents a dangerous erosion of the autonomy of science, particularly given that disciplines have endured precisely because they serve many valuable functions (*cf.* Petts *et al* 2008).

Based on extensive empirical research (reported in Weszkanlys 2006), Barry *et al* (2008) provide an excellent critical review of these debates by suggesting that interdisciplinary research is driven by three distinct 'logics'. The first is a *'logic of accountability'*. This is the basic premise that by addressing real world problems and involving stakeholders beyond the academy, interdisciplinary work is more accountable to society than disciplinary work that remains within the confines of academic ivory towers. The second is a *'logic of innovation'*, suggesting that combining distinct disciplinary approaches to problems will lead to improved and more innovative solutions. In this respect interdisciplinarity is also seen as a means of

channelling academic research towards the needs of the knowledge economy (*cf.* Lowe and Phillipson 2006). Whilst these two logics dominate, Barry *et al* also discern a third *'logic of ontology'* (*cf.* Lawrence and Després 2004), wherein interdisciplinary research is seen not only in these instrumental terms but is also 'intended to effect qualitative transformations, experimenting with and establishing new forms of practice…that may destabilize, existing disciplines and practices' (Barry *et al* 2008, 30).

Cutting across these three logics of interdisciplinarity, based on 10 case studies of interdisciplinary initiatives and institutions, Barry *et al* (2008) identify three distinct 'modes' according to which, they suggest, disciplinary collaboration tends to occur. The first, *integrative-synthesis* mode, sees interdisciplinarity as occurring through 'the integration of two or more 'antecedent disciplines' in relatively symmetrical form' (Barry *et al* 2008, 28). This mode, they argue, dominates contemporary discourse on interdisciplinarity, presenting it as a consensual process of integrating insights from multiple disciplines in order to solve a common problem. Nonetheless, Barry *et al* observe that it ultimately leaves the antecedent disciplines unchallenged and unchaged. The second, *subordination-service* mode sees one or more 'service discipline(s)…making up for or filling in for an absence or lack in the other, (master) discipline(s).' (*Ibid.*, 29). They suggest that this is a common way in which the relationship between engineering or natural science disciplines and the social sciences is conceived. For example, once the 'correct' natural science or engineering definition of the research problem has been accepted, the social sciences are seen as a means of engaging with 'social factors' for instance by helping to promote public engagement or acceptance of proposed solutions (see Shove 1998; Owens *et al* 2006). Again, in this mode the antecedent disciplines are left intact. The third, *agonistic-antagonistic* mode sees 'interdisciplinary research…neither as a synthesis nor in terms of a disciplinary division of labour, but as driven by an agonistic or antagonistic relation to existing forms of disciplinary knowledge and practice' (Barry *et al* 2008, 29). This appears to be the least common mode, although the one that Barry *et al* seem most favourably disposed towards, not least because of the ontological disputes and developments it seems most likely to promote which have the potential to fundamentally change the nature of the antecedent disciplines involved.

Delving inside these broad conceptual distinctions, others have looked at the 'boundary problems' (Horlick-Jones and Sime 2004) involved in interdisciplinary projects. These 'border troubles' (Petts *et al* 2008) include both practical and conceptual challenges. Practical challenges include issues surrounding communication between disciplines and establishing a common language (e.g. Bracken and Oughton 2006), the division of labour between disciplines (particularly between social and natural/engineering sciences – e.g. Barry *et al* 2008) and problems relating to the institutional 'hard-wiring' of mono-disciplinary approaches e.g. in peer review procedures and the Research Assessment Exercise (e.g. Lowe and Phillipson 2006).

More challenging, however, are the conceptual troubles relating to, for example, the delicate negotiations of academic identity involved in novel interdisciplinary exchanges (e.g. Lingard *et al* 2007), questions over the applied or conceptual nature of interdisciplinary research, and perhaps most importantly issues relating to the epistemological structure and culture of distinct disciplines. Here, Petts *et al* (2008)

highlight the issue of problem framing, arguing that "what is designated a 'problem' can itself constitute a critical difference between disciplinary cultures, and can cause real communication problems." (Petts *et al* 2008, 598). This issue would appear to be particularly acute when collaborations are between incognate disciplines (e.g. across research domains such as the natural, engineering and social sciences) that do not necessarily share assumptions about ontology (what exists) and epistemology (what we can know). For example, in the context of energy research, Shove (1998) highlights the 'conceptual chasms' between approaches which distinguish between 'the social' and 'the technical' and which seek to understand how one affects the other (often how the social can be made to accept the technical), and approaches which instead seek to understand socio-technical configurations in which no straightforward distinctions can be drawn between social and technical domains. Petts *et al* suggest that "if frames are imposed rather than negotiated, this will lead at best to mis-understanding, and at worse to antagonism from disciplines that are marginalised as a result" (Petts *et al* 2008, 598). Accordingly, they imply that problem frames should be carefully and reflexively negotiated on a project-specific basis to encourage meaningful exchange between equal disciplinary partners.

This brief review of some of the key issues relating to interdisciplinary research serves not only to provide some conceptual background to these issues, but also to highlight that debates about interdisciplinarity have been firmly driven from within the social sciences. By contrast, such issues appear to have received little sustained attention from the natural and engineering sciences which, arguably, possess stronger and more established disciplinary cultures. As such, it would appear both necessary and timely to consider how engineers and natural scientists perceive these issues, particularly if they are increasingly being expected to engage in collaborative projects. At the same time, whilst many studies have reflected on the challenges of conducting interdisciplinary research, most of these accounts appear *ex post facto*. Action research which reflects on these issues *in situ*, asking how interdisciplinary exchanges unfold in practice, how these challenges are interpreted and addressed by researchers, and which seeks to develop pragmatic solutions to these issues would thus appear to be useful. In this respect, the TP project serves as an ideal case study as it represents an attempt at interdisciplinary collaboration involving researchers from a wide-range of institutions, disciplinary backgrounds and career stages. The next section will therefore introduce the TP project as a case study in much greater detail, focussing particularly on its formation through a *Sandpit* process. It will also highlight the multiple methods used to investigate interdisciplinary working on the project.

3. The Transitions Project

Given the institutional dominance of academic disciplines, reinforced by successive rounds of Research Assessment, interdisciplinary collaboration in research projects is unlikely to occur spontaneously. As such, over the last decade, the Research Councils UK (RCUK) has embarked on a process of incentivising academics to work across traditional disciplinary boundaries, as well as embracing the interests of stakeholders more passionately than hitherto. Mechanisms range from setting aside funding specifically for outreach and knowledge exchange to extensive consultation on the design of research calls that require strong evidence of interdisciplinary intent. Notable examples include the multi-site, multi-disciplinary Tyndall Centre for Climate Change established in 2000 (www.tyndall.ac.uk), the UK-Energy Research

Centre (UKERC – www.ukerc.ac.uk) , and the Rural Economy and Land Use (RELU) programme which has broken new ground in developing processes to promote effective interdisciplinary research and practice (www.relu.ac.uk, and see Lowe and Phillipson 2006).

Research Councils are developing a range of strategies to encourage more interdisciplinarity. Perhaps as befits the Engineering and Physical Sciences Research Council, EPSRC has developed a social engineering approach through its 'IDEAS Factory' and 'Sandpits'. Sandpits are residential meetings with up to 30 participants who are facilitated through a number of consensual and competitive activities, small group work, visits, role play and brainstorming activities, designed "to drive lateral thinking and radical approaches to addressing particular research challenges" (www.epsrc.ac.uk/ResearchFunding/Opportunities/Networking/IDEASFactory/WhatIsASandpit.htm). Attendance at a *Sandpit* is by invitation only, based on one-page expressions of interest submitted to EPSRC who, through consultation between its officers, the Director of the Sandpit, and the clients, design the disciplinary mix of the meeting. One aim is to bring individual academics together who would not, under normal circumstances, be likely to meet and share ideas. Residential *Sandpit*s usually last for 5 days. The E.On / EPSRC *Sandpit* lasted for just two and a half days which meant that the steps in encouraging the development of innovation were tightly constrained. Team formation was especially pressured, given proposals had to be developed and then presented to a 'Dragons Den' panel of E.On, representatives of other power sector interests and EPSRC officers to win permission to develop a full proposal within this truncated period.

The TP consortium emerged from the Sandpit, with engineers, economists and social scientists finding common cause in understanding the dynamics of transition pathways to a low carbon economy, with an electricity focus. Leading members of the Consortium with expertise on the engineering aspects of developments in electricity supply, distribution and use, had a track record of research collaborations through programmes such as EPSRC SUPERGEN 3 Future Network Technologies and Highly Distributed Power Systems; Platform Grant on Distributed Generation; PLUS project; DTI Centre for Distributed Generation and Sustainable Electrical Energy; DTI Dynamic Demand, and research with industry, including E.On UK. The economists and social scientists brought different expertise to the Consortium, including analysis and modelling of past and prospective energy system transitions, innovation and social/behavioural change, and a record of successful interdisciplinary teamwork and of engagement in four UKERC themes/functions.

Everyone attending the Sandpit contributed to its agreed Mission Statement: '*To undertake socially and scientifically engaged research into innovative technologies, policies and practices leading towards a low carbon energy system*'. Specifically, the TP consortium proposed to undertake historically-informed and forward-looking analysis of energy system transitions, bringing together quantitative and qualitative research methods in a novel and exciting collaboration. Three research challenges were articulated:

1. To learn from past transitions to help explore future transitions and what might enable or avoid them;
2. To design and evaluate transition pathways towards alternative socio-technical energy systems and infrastructures for a low carbon future; and

3. To understand and where appropriate model the changing roles, influences and opportunities of large and small 'actors' in the dynamics of energy transitions.

After a very high level proposal was put to the Dragons Den panel, approval was given for preparation of a full research bid, in direct competition with one other consortium to emerge at the Sandpit, for funding worth up to £2M. Subsequently, the TP consortium bid was assembled over three months through discussion among the PIs and Co-Is, a scoping workshop, bi-lateral meetings, and teleconferences and feedback from E.On-UK representatives.

In summary, the proposal finally approved through EPSRC's normal peer-review process, was to adopt Transitions Theory (discussed further in Section 5 below) as the conceptual basis on which to develop the next steps in moving to a low carbon energy system in the UK. The goal is to build on work by UKERC for DTI, using the MARKAL model, and on that undertaken by the Supergen Futurenet project (by members of this consortium) which explored plausible least-cost scenarios for achieving the UK's 60% reduction target by 2050, to develop and explore the dynamics of more detailed transition pathways towards alternative future energy systems, and to assess their technical and social feasibility and acceptability. This requires detailed technical analysis of potential changes in electricity supply and demand systems and parallel social analysis of institutional and behavioural changes, focusing on the changing roles of both large actors such as multinational energy supply and distribution companies, national governments, major investors, and small actors such as households, innovators and entrepreneurs.

The TP consortium thus committed to *select, develop and analyse a set of potential transition pathways for the UK energy system to a low carbon future, and undertake integrated assessments of the technical and economic feasibility and social and environmental potential and acceptability of these pathways.* Rather than seeking to bring these assessments together in one over-arching, multi-criteria assessment, the aim is to assemble assessments through the detailed elucidation and interrogation of the transition pathways. This approach combines the story-telling approach used in exploratory scenarios, such as those developed by Shell, with detailed critical technical and social assessments of what would be required to bring them about. The detailed objective will be to identify and interrogate the dynamics of transition pathways to a low carbon economy (i.e. transitions that achieve at least a 60% emissions reduction by 2050), by:

- Developing a conceptual and analytical framework for exploring energy transition pathways, based on quantitative and qualitative methods, encompassing engineering, economic, environmental, policy and behavioural sciences.
- Applying and testing this framework by identifying and exploring a limited set of transition pathways to a UK low carbon energy system focussing on the role of electricity supply and demand;
- Undertaking detailed technical and social analysis of the feasibility and acceptability of these pathways, applying quantitative modelling and analysis of electricity systems and infrastructures, and qualitative assessment of the roles of industrial and consumer actors.

- Bringing these together in a whole systems analysis, employing a 'toolkit' of techniques to explore and evaluate specific implications of the selected pathways to a highly electric, low carbon economy.

In its successful proposal, the Consortium proposed three parallel *Themes* to develop this work. Theme 1 addresses transitions, scenarios and historical analysis; Theme 2 undertakes technical and social analysis of supply-side, demand-side and infrastructure networks; and Theme 3 applies whole systems assessment and integration. The contract was awarded to the TP Consortium, led by Profs Geoff Hammond (Bath University) and Peter Pearson (Imperial College), in summer 2007. Table 1 provides details of the full membership of the Consortium in January 2009 with all Post-Docs and PhD students in post, along with their disciplinary training and background.

3.1 Methodologies

This report sits within theme 3 of the TP project, a component of which seeks to promote interdisciplinary collaboration between consortium members through a range of formal and informal mechanisms. To achieve this, alongside facilitating workshops with key stakeholders from E.On, the UEA team has carried out research to reflect more explicitly on practices and processes of interdisciplinary working within the consortium. The research has several aims. Primarily, it seeks to conduct a formative evaluation of interdisciplinary working on the TP project as it unfolds in order to promote informed reflection and learning amongst the consortium regarding how interdisciplinarity might be better achieved as this project develops and on other future projects. In addition, and as noted above, rather than reflecting on challenges *ex post facto* as has occurred with most work in this area, the TP project serves as a valuable case study of the *processes* involved in interdisciplinary working *as it unfolds.* In this respect a key aim of this project is to generate some practical lessons for how the process of interdisciplinarity might be improved. These, it is hoped, will be useful not only for the TP project but also for a wide range of audiences involved in funding, managing, and conducting interdisciplinary research projects.

To help achieve these aims a broadly qualitative mixed-method approach was adopted as a means of stimulating discussion and learning amongst TP consortium members at the same time as gathering their perspectives on the TP project and interdisciplinarity. Specifically, this involved 3 formal methods: semi-structured interviews, Q methodology, and social network analysis. In addition, participant observation of key meetings, interactions and outputs from the project has also informed the analysis.

Semi-structured interviews were conducted with 23 (out of 24) of the consortium members between March and June 2009. These asked interviewees to discuss their disciplinary background, how they became involved in the TP project and what their current role on, involvement in and understanding of the project is, their understandings of interdisciplinarity in general and any previous experience they have had of interdisciplinary working and finally, how they perceive interdisciplinary working as it is occurring within the TP consortium. Interviews lasted from 45 to 120 minutes and were transcribed verbatim. Grounded theory analysis (e.g. Charmaz 2006; Strauss 1987) was then performed on the transcripts (by Hargreaves) to identify key themes that emerged across all interviewees.

Name	University	Department	Position on TP project	Disciplinary Training / Background
Prof Peter Pearson	Imperial, London	Mechanical Engineering	PI	Economics / History / Innovation Theory
Prof Goran Strbac	Imperial, London	Electrical Engineering	Co-I	Electrical Engineering
Dr Aidan Rhodes	Imperial, London	Electrical Engineering	RA	Chemistry
Mr Marko Aunedi	Imperial, London	Electrical Engineering	PhD	Electrical Engineering
Prof Geoff Hammond	Bath	Mechanical Engineering	PI	Mechanical Engineering / Environmental Engineering / Management Studies
Dr Craig Jones	Bath	Mechanical Engineering	RA	Mechanical Engineering
Prof David Infield	Strathclyde	Electrical Engineering	Co-I	Theoretical Physics / Electrical Engineering
Dr Graham Ault	Strathclyde	Electrical Engineering	Co-I	Electrical Engineering
Dr Stuart Galloway	Strathclyde	Electrical Engineering	Co-I	Mathematics
Dr Arturo Alarcon-Rodriguez	Strathclyde	Electrical Engineering	RA	Electrical Engineering
Ms Elizabeth Robertson	Strathclyde	Electrical Engineering	PhD	Physics
Mr Malcolm Barnacle	Strathclyde	Electrical Engineering	PhD	Electrical Engineering
Mr Sikai Huang	Strathclyde	Electrical Engineering	PhD	Electrical Engineering
Dr Murray Thomson	Loughborough	Electrical Engineering	Co-I	Electrical Engineering
Dr Simon Watson	Loughborough	Electrical Engineering	Co-I	Physics / Electrical Engineering
Dr Neil Strachan	Kings, London	Geography	Co-I	Energy Economics
Mr Nick Hughes	Kings, London	Geography	RA	Energy Economics / Music
Prof Matthew Leach	Surrey	Engineering	Co-I	Engineering / Multidisciplinary Technology Appraisal
Dr Mohammed Hassan-Sayed	Surrey	Engineering	RA	Mechanical Engineering / Chemical Engineering
Prof Jacquelin Burgess	East Anglia	Environmental Sciences	Co-I	Cultural Geography
Dr Tom Hargreaves	East Anglia	Environmental Sciences	RA	Cultural Geography
Dr Tim Foxon	Leeds	Earth and Environment	Co-I	Innovation Theory / Theoretical Physics
Mr Ronan Bolton	Leeds	Earth and Environment	PhD	Mechanical Engineering / Environmental Sustainability

Table 1: Membership of the Transition Pathways Consortium, January 2009

A *Q methodology* exercise was conducted with 21 of the consortium members to explore both their understandings of interdisciplinarity generally, and their personal experiences of it. Q methodology is a well established psychological technique designed to formally identify and distinguish between the different perspectives on any given complex topic – in this case interdisciplinarity (for more information on, and some applications of, Q methodology see for example Brown 1993, 1996; Stainton Rogers and Stainton Rogers 1990; Barry and Proops 1999; Eden *et al* 2005; Webler *et al* 2007; Watts and Stenner 2007). Q methodology operates by, first, creating a representative sample of the concourse (everything that gets said) about a particular complex issue. This is then converted into a series of short statements each representing a different perspective on the issue in question. Participants are then asked to sort these statements according to specific sorting instructions to demonstrate those statements that best describe their own views and those that least describe them. A range of statistical procedures can then be used to analyse these quantitative data. This typically involves some kind of factor analysis such as principal components. This analysis then reveals the key factors that sorters clustered around representing the commonly held perspectives on the particular issue in question.

For the TP project specifically, the Q exercise employed a concourse of 40 statements taken from a Rural Economy and Land Use (RELU – see Lowe and Phillipson 2006) project concerned with 'Understanding Environmental Knowledge Controversies' (http://knowledge-controversies.ouce.ox.ac.uk/project/). This concourse was identified through a review of policy documents and literature relating to interdisciplinarity, and through interviews with key experts on interdisciplinarity and the leaders of the RELU programme (Andrew Donaldson, *pers. comm.*), and the statements were deemed sufficiently generic that they could be readily applicable to the TP project. TP consortium members were then asked to sort these 40 statements from -5 (least describe) to +5 (best describe) according to two different sorting instructions: first, to represent what they consider to be the general view of interdisciplinarity (in policy documents, academic literature etc.) and second, to represent their own experience of interdisciplinarity to date. Once the data were collected, principal components analysis with varimax rotation was conducted to identify the key factors. These statistical results were then analysed in conjunction with the interview transcripts to produce the factor descriptions (see section 4.2 and appendix 1).

Finally, an exploratory *social network analysis* was conducted with 20 of the consortium members. Here, during the semi-structured interviews, interviewees were presented with cards that showed the name, institution and (where available) a photo of all the consortium members. Interviewees were then asked to describe the involvement of each other consortium member on the TP project and their own relationship with them. Finally, they were asked to create their 'ego network' (Hanneman and Riddle 2005) of the TP project which involved placing themselves (ego) in the middle and arranging the other cards (alters) around them to describe in what ways and how closely they relate to others. These ego networks were then photographed and the photos and relevant sections of the interview transcripts were converted into network data (edgelist1.dl format) and analysed using NetDraw Graph Visualization Software (Borgatti 2002 – see section 6.1) to produce network graphs that depict the current relationships between consortium members.

The next section will draw on the interview and Q methodology data to reflect on how consortium members understand interdisciplinarity in general. Section 5 will then draw on the interviews and participant observation to consider how different consortium members understand the TP project. Finally, section 6 explore the social network analysis and interview data to identify current challenges and tensions regarding interdisciplinary working on the TP project with a view to promoting informed discussion and improving collaborative working.

4. Understanding Interdisciplinarity

In order to understand how interdisciplinary working might be promoted on the TP project, it is first necessary to have a detailed understanding of how TP consortium members understand interdisciplinarity and what they see as its purpose. To achieve this, during interviews consortium members were asked to explain what they understood by interdisciplinarity, and to consider the challenges it may involve. In addition the Q method exercises explored understandings and experiences of interdisciplinarity more formally.

4.1 Interviews

The definitions of interdisciplinarity gathered in the interviews were strikingly similar. Typically, interviewees emphasised that interdisciplinarity involved a team of researchers coming from different disciplinary backgrounds working together to address a common problem. The following quotation is illustrative of this:

> "Interdisciplinarity is the idea of people from different disciplines getting together and using their relative strengths in order to solve a common problem in a different way." (Interviewee 07, p12 - Engineer)[2]

In addition, interviewees emphasised that interdisciplinarity was valuable because it offered a broader perspective that could help generate new understandings of problems where mono-disciplinary approaches had reached their limit. Beyond this common basis, however, there was an almost total divide between the engineers and social scientists/economists on the project with regards precisely what interdisciplinarity offers, what level of interaction and integration is required to achieve it, and what challenges it poses.

Generally, for those from engineering departments interdisciplinarity's key benefit was that it enabled research to see the 'bigger picture'. This view implies that mono-disciplinary research is somehow blind to the world beyond its boundaries and therefore that more disciplines are required to get a fuller and more rounded picture of a particular problem. Following this view, one interviewee suggested that different disciplines were like different pieces of a jigsaw, whereas another succinctly characterised this view as about seeing the whole elephant:

> "When you get several different people looking at an elephant, or from very close up, you don't get the rounded picture. You get somebody who is holding

[2] Although the interviews were transcribed verbatim, for the sake of clarity all quotations used have been cleaned to remove repetitions, hesitations and elisions for example. In addition, quotations have been labelled 'engineer' or 'social scientist/economist' to denote the broad disciplinary background of the interviewee.

> leg and saying ‘this is how it is’. Whereas once you get everyone around it, you eventually get the full picture that ‘this is an elephant’.” (Interviewee 14, p13 - Engineer)

Commonly, those who expressed this view saw the key challenges and difficulties of interdisciplinary working as being about establishing a common language and that, partly as a result, it took longer to do than mono-disciplinary research.

> “The main challenge I think is the common language barrier. If you get an engineer and a social scientist, they're not going to fully understand what each other is on about. I think that is the main barrier, and I think that’s why it takes longer.” (Interviewee 05, p16 - Engineer)

In general, this view appears closer to multidisciplinarity than interdisciplinarity as outlined in section 1. It implies that disciplines differ simply in the perspective they offer onto a common ‘real world’. Hence, one discipline sees the elephant’s leg, where another sees its trunk. The challenge of interdisciplinary working thus appears to be getting the right mix of disciplines working together in order to see the whole elephant, and simply spending sufficient time to ensure they all understand one another. What the pieces of a jigsaw metaphor expresses clearly, however, is that these disciplines have clear boundaries and whilst they need to work together, this view does not imply, necessarily, that they need to be mixed or integrated in order to get an accurate picture.

In contrast, those from social science/economics backgrounds tended to be less optimistic about the challenges involved in interdisciplinary working. Here, disciplines approach such ‘common problems’ in fundamentally different ways. For example, whilst different disciplines might both be approaching the common problem of climate change, they do not simply tackle different parts of it, but construct and interpret it differently as a technological, political or cultural problem. The challenge here is not simply to gather together enough disciplines, but to negotiate a route between and, where possible, integrate their different problem framings:

> “Faced with a hydro-electric dam the economist, the physicist, the ecologist, the political scientist all start with a different set of questions and would analyse the problem with a different set of tools.” (Interviewee 23, p4 – Social Scientist/Economist)

Within this view, the key benefit of interdisciplinarity was found in the way it challenged specific disciplinary assumptions about what a problem was, and how it should be understood and approached. Specifically, those who expressed this view suggested that interdisciplinarity was characterized by learning at the level of the individual, as s/he was forced to step out of his/her comfort zone by “reading things and talking in languages that they’re not familiar with” (Interviewee 12, p16 – Social Scientist/Economist). Further still, this view saw interdisciplinary research as an unpredictable process marked by unanticipated emergent properties of interactions between collaborators:

> “One of the things that characterizes interdisciplinary work for me is the emergent properties, the things that come out from left-field that you weren't

> anticipating, because of the kinds of folk who are working together and the things that they bring to the table." (Interviewee 20, p21 – Social Scientist/Economist)

Here, the challenge of conducting interdisciplinary work did involve establishing a common vocabulary, but this was only the first step. In addition, interdisciplinary collaboration involved overcoming individuals' educational backgrounds, worldviews and personalities. Although held predominantly by the social scientists/economists, this view was most clearly articulated by one of the engineers:

> "It's probably to do with how you're educated throughout your life. If you're an engineer, you probably instinctively try and approach the problem in analytical, systematic ways. You would like to see numbers, you would like to have some calculations. While I guess if you're a social scientist you would have a completely different approach, well I can't even imagine so I'm not even going to guess. So I think there's a different philosophy in how they actually approach the problem." (Interviewee 08, p11 - Engineer)

Following on from this, there was a much greater degree of doubt amongst the social scientist/economists with regards to whether or not useful interdisciplinary working was achievable in the context of a single research project involving so many researchers from such different backgrounds. Several argued, for example, that it could not be forced but must be allowed to occur (or not) organically.

This view thus appears closer to that of *inter*disciplinarity. Here, the challenge of interdisciplinary working is about integration and synthesis between different problem framings, however this may or may not be achievable. In summary, the interviews point towards a conceptual divide between engineers and social scientists/economists regarding what is involved in interdisciplinary research, how it should be sought, and how achievable it might be. Where engineers appeared to suggest the major challenge was learning to talk to one another and understanding each others contributions, social scientists/economists suggested that the problems ran significantly deeper than this and related to how different disciplines conceptualise and frame specific problems raising the possibility that some disciplinary differences may be insurmountable.

4.2 Q Methodology

Whilst the interviews reveal a distinction between how the engineers and social scientists/economists on the TP project talk about interdisciplinarity, the Q methodology results highlight some more subtle distinctions, but also large areas of common ground between consortium members that, crucially, do not map neatly onto disciplinary divides.

In all, two Q sorts were conducted by consortium members. The first asked them to arrange the 40 statements (see appendix 1 for a list of the statements) according to the 'general view' of interdisciplinarity that they see, that is as it is discussed in academic literature and in policy documents. The second asked them to arrange the statements according to their 'personal experience' of interdisciplinarity which, for some, would have comprised only their experiences on the TP project to date. This section will discuss the key findings and distinctions between the different factors each sort produced.

4.2.1 Sort 1: The General View of Interdisciplinarity

Using a scree test, 3 distinct factors were identified for sort 1 which explained 54% of the overall variance. Based on the analysis, each of these factors has been given an appropriate label:

- Factor 1: Horizon Expanders (explains 12% of the variance)
- Factor 2: Strict Disciplinarians (explains 21% of the variance)
- Factor 3: Interdisciplinary Appliers (explains 21% of the variance).

A positive correlation of 0.45 between factors 1 and 3 suggests there is some overlap between these views. In addition, a negative correlation of -0.44 between factors 1 and 2 suggests they may in fact be partial reflections of one another. Given that the first sort asked sorters to describe the 'general view' of interdisciplinarity that they see, it is important to remember that the results their sorts produce do not represent their personally held views, but instead illustrate what they perceive this 'general view' to be. This was stressed in interviews. In particular, those who loaded significantly on the 'strict disciplinarians factor' often emphasised that they were playing a particular role when completing the sort, with one describing this role as that of 'the pantomime villain.' Detailed descriptions of each of the factors are included as appendix 1.

Those who loaded strongly on factor 1 – *Horizon Expanders* – suggested that the general discourse surrounding interdisciplinary holds it to be a means of promoting innovation by challenging the ingrained assumptions of specific disciplines and thus broadening individual researchers' horizons. This factor suggested that general views of interdisciplinarity were supportive of it, and indeed that interdisciplinarity may even be seen as a measure of successful science. By contrast, those who loaded highly on factor 2 – *Strict Disciplinarians* – suggested a general view of interdisciplinarity that was far from supportive, but instead promoted and reinforced mono-disciplinary approaches. Here, disciplines were seen as at the cutting edge of research and should therefore be defended. Interdisciplinary approaches were described as posing a threat to this mono-disciplinary culture and offering little in the way of added accountability, innovation or broadening understandings in any case. Finally, those who loaded strongly on factor 3 – *Interdisciplinary Appliers* – again suggested that a generally positive view of interdisciplinarity existed. On this factor, however, this positivity did not stem from interdisciplinarity promoting innovation or expanding horizons (as on factor 1), but instead from the more applied nature of interdisciplinary research. Here, interdisciplinarity was seen as suitable for real world problems which do not respect disciplinary boundaries. Accordingly, this real world focus of interdisciplinarity helps to move research closer to the needs and concerns of citizens and consumers, and closer to application in policy and practice.

In summary, sort 1 presents a much more subtle reading of how consortium members relate to and understand interdisciplinarity than is provided by the interview transcripts alone. There is no clear disciplinary divide among these factors with both engineers and social scientists/economists loading strongly on all three factors. Crucially, therefore, this points towards areas of common ground which were obscured in the interviews. Importantly, however, this common ground appears to centre on positive values towards interdisciplinarity among consortium members, based around its real world focus and its ability to expand understandings of

problems, whereas the interviews suggest there may be some conceptual differences in understanding. Further, the results of the second sort, based on personal experiences of interdisciplinarity, appear to reinforce this view.

4.2.2 Sort 2: Personal Experiences of Interdisciplinarity

The second Q sort asked consortium members to arrange the statements so as to describe their own experience of interdisciplinarity. Using a scree test, 2 distinct factors were identified for sort 2 which explained 47% of the overall variance. Based on the analysis, each of these factors has been given an appropriate label:

- Factor 1: Applied Solution Seekers (explains 28% of the variance)
- Factor 2: Problem Explorers (explains 19% of the variance)

It is essential to note, however, that the two factors share a positive correlation of 0.54. They are therefore seen to overlap quite substantially. Indeed, there appears to be relatively little difference in terms of primary beliefs (+5, +4 and -5, -4 statements), although there are some notable differences in secondary beliefs (+3, +2 and -3, -2 statements). These differences also seem to align reasonably well with the distinction, found in sort 1, between interdisciplinarity as a way of expanding horizons or as a way of applying research. The following section summarises the key elements of these factors, whilst detailed descriptions of both of the factors are included as appendix 1.

Based on their previous experiences, those who loaded strongly on factor 1 – *Applied Solution Seekers* – appeared to suggest that interdisciplinary research is a form of applied research. Here, it is seen as a means of finding solutions to real world problems and, accordingly, as a way to bring research closer to the needs and concerns of society, and to application in policy and practice. In contrast, those who loaded strongly on factor 2 – *Problem Explorers* – seemed to suggest, based on their prior experience, that interdisciplinarity was primarily a means of improving research because it serves to challenge ingrained disciplinary assumptions and provides new perspectives and methodologies to employ. Notably, this sort also emphasised some of the practical challenges involved in interdisciplinary research, emphasising (as the interviews also had) that finding a common language, and working across different philosophies and personalities can be key issues.

In summary, both factors on sort 2 appear to be generally positive towards interdisciplinary research. Factor 1 emphasises its benefit for applied research, and factor 2 emphasises its role in expanding understandings of problems. As with sort 1, there was no clear disciplinary divide between those who loaded strongly on these factors, with both engineers and social scientists/economists stressing, on the basis of their prior experience, that interdisciplinary research can help in finding applied solutions to real world problems, or that it can help in expanding and exploring different problem framings. Vitally, both of these factors are generally favourable towards interdisciplinary research stressing its benefits much more prominently than the challenges involved or any disadvantages. As well as offering detailed understandings of how consortium members think about and relate to interdisciplinarity, this sort therefore suggests that despite the challenges involved, consortium members generally feel that interdisciplinary research is worth striving for.

4.3 Understanding Interdisciplinarity: Summary

This section has explored understandings of interdisciplinarity among consortium members using interview and Q methodology data. Vitally, where interviews reveal an apparent distinction in the ways the engineers and social scientists/economists on the consortium talk about interdisciplinary research, Q method reveals more subtle differences and commonalities between social scientists/economists and engineers in terms of how they think about interdisciplinary research when interpreting and arranging pre-prepared statements about interdisciplinarity. This reveals the significant benefit of adopting a mixed-method approach in order to tease out subtle differences. In this instance, it would appear that whilst engineers and social scientists/economists currently use different discourses to speak about interdisciplinary working, they may in fact share more common ground than interview transcripts alone reveal.

Relating these observations to the theoretical literature on interdisciplinarity discussed in section 2, the Q methodology study reveals some significant common ground among consortium members over the logic of accountability and the logic of innovation (*cf.* Barry *et al* 2008) involved in interdisciplinary research. This appears to generate generally positive attitudes towards interdisciplinary collaboration among consortium members and a desire to take part in innovative collaborative research such as the TP project. The interviews, however, reveal some significant distinctions among consortium members that appear to centre on the importance placed on a logic of ontology. In the interview transcripts, those from a broad engineering background tended to emphasise the practical challenges involved in collaborative working across disciplines stressing, for example, that it takes longer to do and involves various language difficulties. In contrast, the social scientists/economists on the project, tended to stress the more conceptual, ontological challenges involved in working across disciplines, particularly incognate disciplines, that adopt fundamentally different framings of problems.

To some extent, this might be a product of the Sandpit approach to funding. Such an approach, as outlined in section 3, seems able to get people together who are generally positive and favourable towards interdisciplinary and collaborative working, indeed this is one of its stated aims. By going through such an intense process so quickly, however, it appears as if there may be insufficient time to negotiate some of the more conceptual and ontological challenges that incognate interdisciplinary working poses. By contrast, more conventional funding mechanisms may allow more time for these issues to be explored, although, of course, the novel disciplinary collaborations and project ideas that Sandpits generate may never even be conceived. Given the rise in demands for interdisciplinary approaches, this is a significant issue and suggests that a great deal more thought, reflection and learning may be required regarding what interdisciplinary collaboration entails and how it might be achieved, before claims are made and proposals are written that seek to satisfy these demands. An approach to funding that finds a balance between these advantages and disadvantages of Sandpit and more conventional funding mechanisms would therefore appear to be a logical next step to promoting successful interdisciplinary collaboration.

With regards to the TP project more specifically, what these divides within the consortium suggest is a need to think carefully about the conceptual basis of the project, about what the different disciplines involved offer to each other, and about

how they can work together on this basis. Some potentially key elements of these discussions are discussed in subsequent sections. Specifically, what this analysis raises is a need to consider the extent to which enthusiasm for and willingness to work in interdisciplinary ways is sufficient to overcome complex and persistent conceptual challenges.

More positively, however, it would appear that elements of this conceptual discussion may have begun to occur through the process of conducting the research for this study. Amongst those interviewees who had completed their Q sorts prior to the interview occurring, it was noted on several occasions during interviews that they would speak about interdisciplinarity either using language drawn directly from the statements, or by using the Q statements to structure their responses to more general questions about interdisciplinarity. This suggests that understandings, on the one hand, that understandings and discourses of interdisciplinarity are not yet well-established amongst some researchers, whether engineers or social scientists/economists, and interviewees are still establishing a vocabulary with which to speak about these issues. Here, the Q methodology approach seems particularly valuable, not in order to put words into participants' mouths, but in order to allow them to express their views more clearly and subtly. On the other hand, this suggests that through the interview discussions and the Q methodology approach, TP consortium members were actively reflecting on and learning about what interdisciplinarity is and how to go about doing it. This suggests that explicit reflection on these issues is valuable not merely as an interesting aside, but as a core element in understanding how TP consortium members understand the aims and process of the TP project, how they relate to one another, and in deciding how interdisciplinary collaboration should occur.

Following on from this more general discussion of interdisciplinarity, the next section begins to develop these issues by grounding them in the key concepts and terms around which the TP project is based.

5. Understanding Transition Pathways

The term 'transition' is being used with increasing frequency within the academic literature (e.g. Geels 2005, UKERC 2009), policy documents (e.g. HM Government 2009) and even in civil society movements such as the emerging Transitions Towns network (http://www.transitiontowns.org/). Within the academic literature however, the term transition has a quite specific meaning based around Geels' Multi-Level Perspective. Here, and as summarised in box 1 and figure 1, transitions are radical shifts in socio-technical regimes that are brought about through interactions between the different levels of technological niches, socio-technical regimes and landscapes.

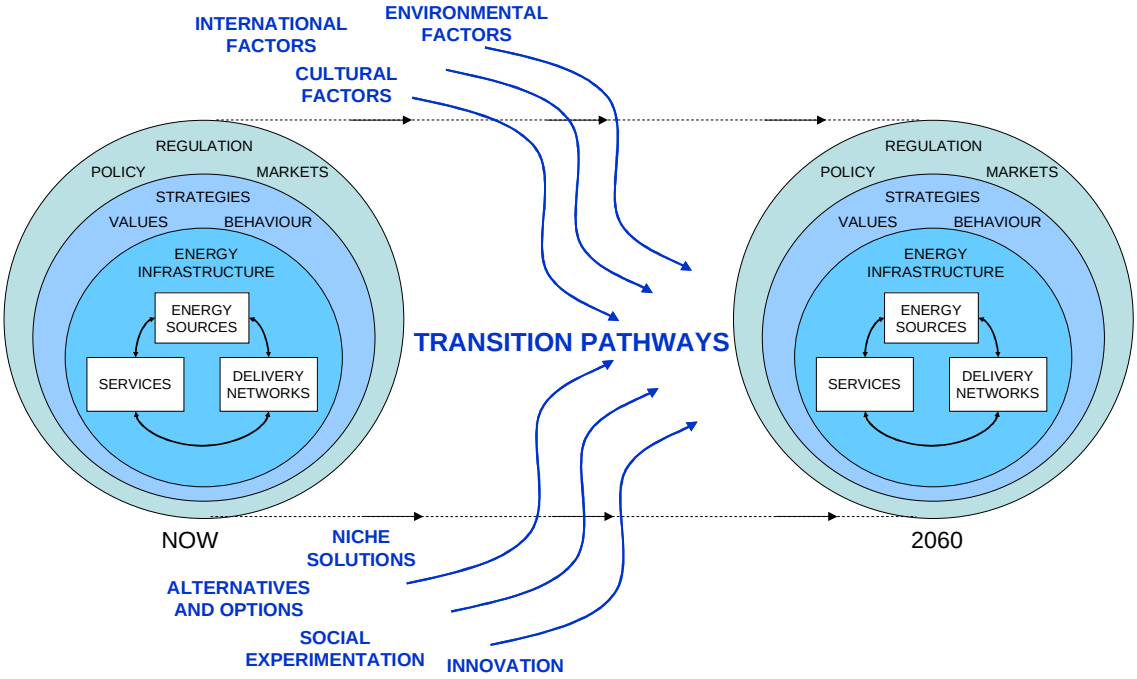

Figure 1: Possible Transition Pathways and the Factors that Influence them
(Source: www.lowcarbonpathways.org.uk)

Box 1: Research on Transitions in Socio-Technical Systems
(Source: www.lowcarbonpathways.org.uk)

Figure 1 is informed by an ongoing research programme on *transitions in socio-technical systems*, which has generated significant international attention (Elzen *et al*., 2004; Geels, 2005). This research combines technical, social and historical analysis of and insights into past and current transitions, using an analytical framework based on interactions between three 'levels': *technological niches*, *socio-technical regimes*, and *landscapes* (Kemp, 1994; Geels, 2002). The *landscape* represents the broader political, social and cultural values and institutions that form the deep structural relationships of a society and only change slowly. The *socio-technical regime* reflects the prevailing set of routines or practices used by actors, which that create and reinforce a particular technological system, including "engineering practices; production process technologies; product characteristics, skills and procedures […] all of them embedded in institutions and infrastructures" (Rip and Kemp, 1998). Whereas the existing regime generates incremental innovation, radical innovations are generated in *niches*, which are spaces that are at least partially insulated from 'normal' market selection in the regime, for example, specialised sectors or market locations. Niches provide places for learning processes to occur, and space to build up the social networks that support innovations, such as supply chains and user-producer relationships. Transition pathways arise through the dynamic interaction of technological and social factors at these different levels.

This analytical framework has influenced Dutch policy on promoting energy system transitions (Ministry of Economic Affairs, 2004), and stimulated historical case studies, including applications to the Dutch electricity system (Verbong and Geels, 2007). Further conceptual work has developed a more detailed typology of transition pathways (Geels and Schot, 2007), in response to critiques and insights in the academic literature (Smith *et al*., 2005). An initial theoretical analysis of past and possible future decarbonisation pathways for the UK (Shackley and Green, 2007) shows the potential for the application of the transitions approach to the UK and argued for more detailed work to be done. In order to address the three research challenges this Consortium proposes to carry out such work.

As box 1 illustrates, the TP project proposal, as well as the early outputs from the TP project (e.g. Foxon *et al* 2009; Nye *et al*, forthcoming), adopted the basic ideas and

terminology of transitions as its conceptual framework. A growing critique of these transitions concepts, particularly as they have been implied in Dutch energy policy, however, suggests that one of the key strengths of these ideas – that they are capable of unifying multiple perspectives into a coherent 'transitions' framework – also represents one of their biggest weaknesses in that the interpretive flexibility of the term transition can mask over critical differences of interpretation (e.g. Smith and Kern 2009). Given this critique, it seems prudent to explore how different consortium members differ in their interpretations of transitions, and how they understand their work in relation to it.

The other critical term within the TP project is 'pathway'. As Hughes (2009) shows, there is a well-established scenario building tradition within UK energy research and policy (e.g. RCEP 2000, Elders *et al* 2006; Strachan *et al* 2007; Hughes *et al* 2009), and indeed there is a great deal of scenario-building expertise and experience within the TP consortium. Critically, and as noted earlier, the TP project proposal suggests that *pathways*:

> "build on these scenarios to develop and explore the dynamics of more detailed transition pathways towards alternative future energy systems and to assess their technical and social feasibility and acceptability. This requires detailed technical analysis of potential changes in electricity supply and demand systems and parallel social analysis of institutional and behavioural changes….This approach combines the 'story-telling' approach used in exploratory scenarios…with detailed critical technical and social assessments of what would be required to bring them about."
> (www.lowcarbonpathways.org.uk)

As such, and as Hughes (2009) demonstrates, pathways seek to develop well-established technological and economic scenario-building techniques by actively exploring the co-evolution of actors and technological infrastructure in transition processes. In short, pathways seek not only to discover if different futures are technically and economically feasible, but also how such futures might plausibly be brought about by different social actors. Again, given the complexity of these ideas, and the prior experience of some consortium members, it seems wise to consider how the term pathway is understood and used within the TP project, and how different project members relate their work to it. The following two sub-sections will therefore focus on how consortium members used the terms 'transition' and 'pathway' in the interviews.

5.1 What is a pathway?

Despite frequent discussion in meetings and occasional jokes in the interviews about the distinction, semantic or otherwise, between a pathway and a scenario, there was in fact a high level of understanding and widespread agreement about precisely what a pathway entails. Interviewees noted that where scenarios can tend to provide snapshots and be based on inevitable end-points, pathways emphasise the *process* of achieving transitions and that "you wouldn't necessarily go in a straight line from here to there" (Interviewee 19, p11 - Engineer); that critical 'branching points' might be encountered along the way which can cause both lock-in and lock-out of different options, and that such processes are driven by the decisions of key actors. Others also added that pathways encouraged exploration of the different 'side-swipes' that may

occur to the system to knock it off course. These understandings come very close to those outlined by the Kings team on the basis of their extensive research into this area, and their argument that *good* scenarios *are* transition pathways (Hughes 2009).

The only real area of difference between interviewees regarding precisely what a pathway entails centred on whether or not pathways were normative. Some interviewees suggested that pathways sought to predict the 'best way' to achieve a low carbon energy system, and that the whole systems appraisal conducted under theme three of the project would somehow 'rank' the different options explored by the consortium. A more widespread feeling, however, was that the pathways should seek to identify a range of both technically and socially plausible ways of realising significant cuts in CO_2. In this view, their value was not in identifying a 'best way', but in identifying the many and various consequences of different types of decisions and actions for realising a low carbon system.

Another potentially significant area of difference about the pathways related to what the finished pathways will look like and be able to deliver. Several interviewees suggested that the pathways can only be considered finished once consensus and even 'buy-in' from all consortium members has been achieved. Such a view was seen to demand significant interaction between consortium members with the pathways acting as the key vehicle for the projects' interdisciplinary collaboration. Whilst none directly contradicted this view, others raised concerns over how 'robust' the pathways will be:

> "My worry is that the transition pathways are a bit too flowery. Now maybe that enables us to think more laterally, and that in itself will be good because the outputs we get will be broader, and the thinking will not be so restricted, but we need to say that in that case. We don't need to pretend that they are robust." (Interviewee 13, p13 - Engineer)

This view raises further questions about the relationship between the process of pathway creation in theme 1 of the project, and the various modelling approaches that will be applied to them in theme 2. In particular, some interviewees saw the pathways as merely 'inputs' to pre-existing models which would serve to make them more accurate, certain and robust; whereas others assumed that the pathways were the key 'value-added' that the project as a whole aimed to deliver and therefore that models should be adapted to fit the pathways rather than the other way around. This issue is discussed further in section 6.2 below. Crucially, despite the apparent areas of agreement noted above, there was relatively little certainty about what a finalised pathway should look like, summarised neatly in the following quotation:

> "To be honest no one has ever told me what a transition pathway is." (Interviewee 06, p4 - Engineer)

This is an area that appears to demand further discussion within the consortium.

5.2 What are transitions?

There was less consensus, however, regarding what was meant by the term 'transition'. In particular there was a divide between those who were familiar with Dutch transitions

theory and those who were not. Whilst this did largely correspond to division between the social science/economists and the engineers, this was not entirely the case as several of the engineers on the project were familiar with these theoretical concepts and in some cases (as noted below) had made a significant effort to relate them to their work. Nonetheless, those who were familiar with the transitions approach emphasised that this was the "guiding force behind the project" (Interviewee 16, p21 – social scientist/economist), and stressed, as is set out in the project proposal, that an approach broadly based on transitions theory was being used to produce the initial pathways. In contrast, for those unfamiliar with this body of work, transition referred simply to change:

> "Transition means changing from the current situation, to a better future for sustaining energy." (Interviewee 22, p5 - Engineer)

In general, however, there was a call for greater clarity on how the transitions approach is (or is not) being used to underpin work on the TP project.

This apparent lack of consensus over understandings of the term 'transition' may, of course, be unimportant. There is probably little to gain for some project members in becoming familiar with this often abstract body of theory. Where the lack of consensus does appear to matter, however, is in how consortium members understand relationships between the social and the technical and what this implies for how work on the TP project should proceed.

Specifically, there was a divide between those who conceived of transitions as a result of social *and* technical change, and those who refused to separate these domains and were instead concerned with *socio-technical* change (see Shove 1998). Whilst this may appear to be a semantic distinction, it has vital implications for interdisciplinary collaboration. Separating the domains points logically towards a programme of work in which detailed social and technical analyses are conducted in parallel before an attempt is made to combine them once they are completed. The process of combining the two themes would then centre on issues to do with how the social might influence the technical and vice-versa, and what might need to be done to shape these relationships in desirable, low-carbon directions. Following the distinctions made in section 1, this would appear to be a multidisciplinary approach using, at best, an integrative-synthesis mode of interdisciplinary working and, at worst, a subordination-service mode. It would, however, be more achievable within the time available and ensure that interdisciplinary elements of the TP project were based on strong disciplinary foundations.

In contrast, those who emphasised a socio-technical approach emphasised the complex and non-linear dynamics of co-evolution between the two domains. Here, it was seen as an error to draw a clear distinction between the two domains and instead, research should focus on the inter-relationships between them rather than the domains in and of themselves. This approach points towards a model of interdisciplinary working that demands constant discussion and interaction between the different research teams on the project and cautions against any retreat to mono-disciplinary ways of working. Again, drawing on Barry *et al*'s (2008) distinctions, this would appear to be an interdisciplinary model that would demand, at worst, an integrative-synthesis mode and, at best, an antagonistic-agonistic mode of working. Here, however, it was recognised that such an intensely interactive approach may be impractical:

> "I'm not starry eyed, in the sense that I don't think we're going to have a beautiful seamless kind of socio-technical thing out of this, but I do have real ambitions for the potential for people to learn to work together." (Interviewee 23, p26 – social scientist/economist)

And as this interviewee went on, it presents the danger that by failing to ground the research within any specific disciplinary framework, it poses a risk of a lowest common denominator approach, or what was described as "a kind of soggy hole in the middle" (Interviewee 23, p39 – social scientist/economist).

These issues thus appear fundamental to how research on the TP project should proceed and this is discussed further in section 6.3 below. As well as these distinctions around the concept of transitions, one other valuable interpretation of the transitions literature, from one of the engineers who had sought to relate their own work to it, was as a means of conceptualising how the TP project itself might have in role in bringing about the transition pathways it produces. This interviewee observed that whilst most of their research focuses on specific, 'niche' technologies, the TP project is seeking to have an influence at the broader regime or landscape level by shaping policies and large institutions:

> "The other projects [I work on] would go in at that technology level, so it would be in at the niche level. Whereas, I guess this project probably goes in at landscape because it will probably inform and change actors' views of what the pressures are at landscape level. So from that point of view it's a much more policy influence driven project than I think some of our other projects are." (Interviewee 21, p21 - Engineer)

Whilst this suggests a more reflexive understanding of the TP project that asks how the research is part of the systems it seeks to comment upon, it also adds a potentially valuable user-orientation to the project, suggesting that as well as considering how the different disciplines involved should work together, the project must also bear in mind how the different parts of the research will be used by different stakeholders such as E.On and UK policy makers. This user-orientation would appear to be close to a more transdisciplinary model of research, and although it does not provide any simple answers to how the disciplines involved should inter-relate, such a pragmatic output focus may be one means to bridge some of the divides noted above.

5.3 Summary

This section has considered how the conceptual basis of the TP project is understood by different consortium members. Whilst it observes a high degree of agreement over the term pathways, the term transition, and associated theoretical approaches, it also poses some larger issues that would appear to demand further discussion within the consortium.

Whilst section 4 focussed on general understandings of interdisciplinarity within the consortium, this section has shifted attention towards the conceptual basis of the TP project. Drawing on exploratory social network analysis and the interview data, section 6 will focus more specifically still on the practical challenges involved in interdisciplinary collaboration as they have arisen on the TP project to date.

6. The Transition Pathways Project: Processes and Tensions

Whilst the previous sections have focussed on interdisciplinarity in general, and the conceptual basis of the TP project, this section focuses in more detail on the practical processes and tensions involved in interdisciplinary collaboration as they have unfolded on the TP project to date. First, section 6.1 will discuss the results of an exploratory social network analysis exercise to help interpret how the TP consortium is collaborating at present. Second, section 6.2 will focus on a key tension within the project, as revealed by the social network analysis and in interviews, regarding the relationship the production of pathways and the use of well-established technical and economic models. Third, section 6.3 will offer an overview of the TP project as a whole and consider the different inter-relationships between the 3 project themes as they were invoked in the interviews.

6.1 Social Networks on the Transition Pathways Project

Towards the end of each interview, all except for three[3] members of the TP consortium were asked to sort a selection of cards containing the name, institution and (where available) a photo of all other consortium members. Specifically, they were asked to create an 'ego network' in which they place themselves (ego) at the centre and arrange other cards (alters) around them according to how closely they see themselves as related. Participants were asked to describe their relationship to each other consortium member as they went through this process and were also asked about their rationale for sorting the cards in a particular way. Once completed, a photograph was taken of the sorted cards (see figure 2 for an example)

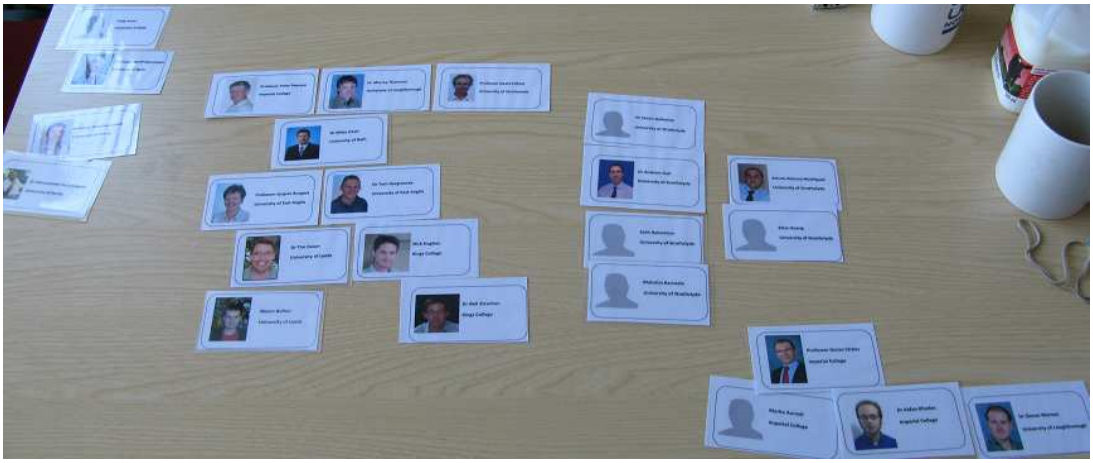

Figure 2: Hargreaves' Ego Network

Consortium members used many different approaches and rationales for sorting the cards. Amongst others these included:

- Collaboration on previous projects
- How well they knew others members' work
- How they are currently working together on the TP project
- How they envisage working together as the TP project develops

[3] This exercise was not completed with Craig Jones (CJ), Neil Strachan (NS) or Goran Strbac (GS) either because there was no time, or because no interview took place. It should therefore be borne in mind that due to the absence of outdegree data (i.e. who they consider themselves to be connected to) in these cases, these nodes are likely to occupy more peripheral positions than may actually be the case.

- Whether or not they are in the same theme of the TP project.
- What University people are from.
- What career stage (PhD, RA, Prof etc) they are at.

Typically, multiple rationales were used to produce each diagram. For example, people who had been collaborated with before would tend to be close to the ego, as would those who were in the same institution or part of the same theme on the TP project. Accordingly, the basis of the network varies slightly from ego to ego, but in general the sorters appeared happy that the final networks they produced represented the organisation of the TP project as they saw it at the time of the interview. To analyse the data, the photos along with the relevant section of the interview transcripts were used to assign each pair of participants a relationship ranging from 0 (no link) to 2 (strong link). Relationships were graded 2 if the ego commented that they worked closely with a particular alter either on the TP project or in general. Links were graded 1 if the ego had had some prior interaction with the alter. Links were graded 0 if the ego commented that they did not know the alter or did not see them as related on this project, or if the relationship was not reciprocated (i.e. where *x* knew *y*, but *y* did not know *x*). These data were then converted into the edgelist1.dl format for use with the Netdraw 2.089 visualization programme (Borgatti 2002). Figure 3 was then created using NetDraw's 'Spring Embedding' layout function. This uses an 'iterative fitting' approach to creating networks, in which it starts with a random layout of the nodes, measures the badness of fit between them, and progressively improves upon this in order to put those nodes with the shortest geodesic path lengths closest together. A geodesic path is calculated by the number of relations in the shortest possible route from one actor to another, and is thus a measure of how interconnected nodes within a network are to one another. In short, the spring embedding function arranges nodes according to their similarity. Thus, those with similar patterns of connections are closer together (Hanneman and Riddle 2005). For
ease of interpretation, figure 3 also uses NetDraw's 'node repulsion' and 'equal edge length' functions in order that nodes were not grouped too closely together.

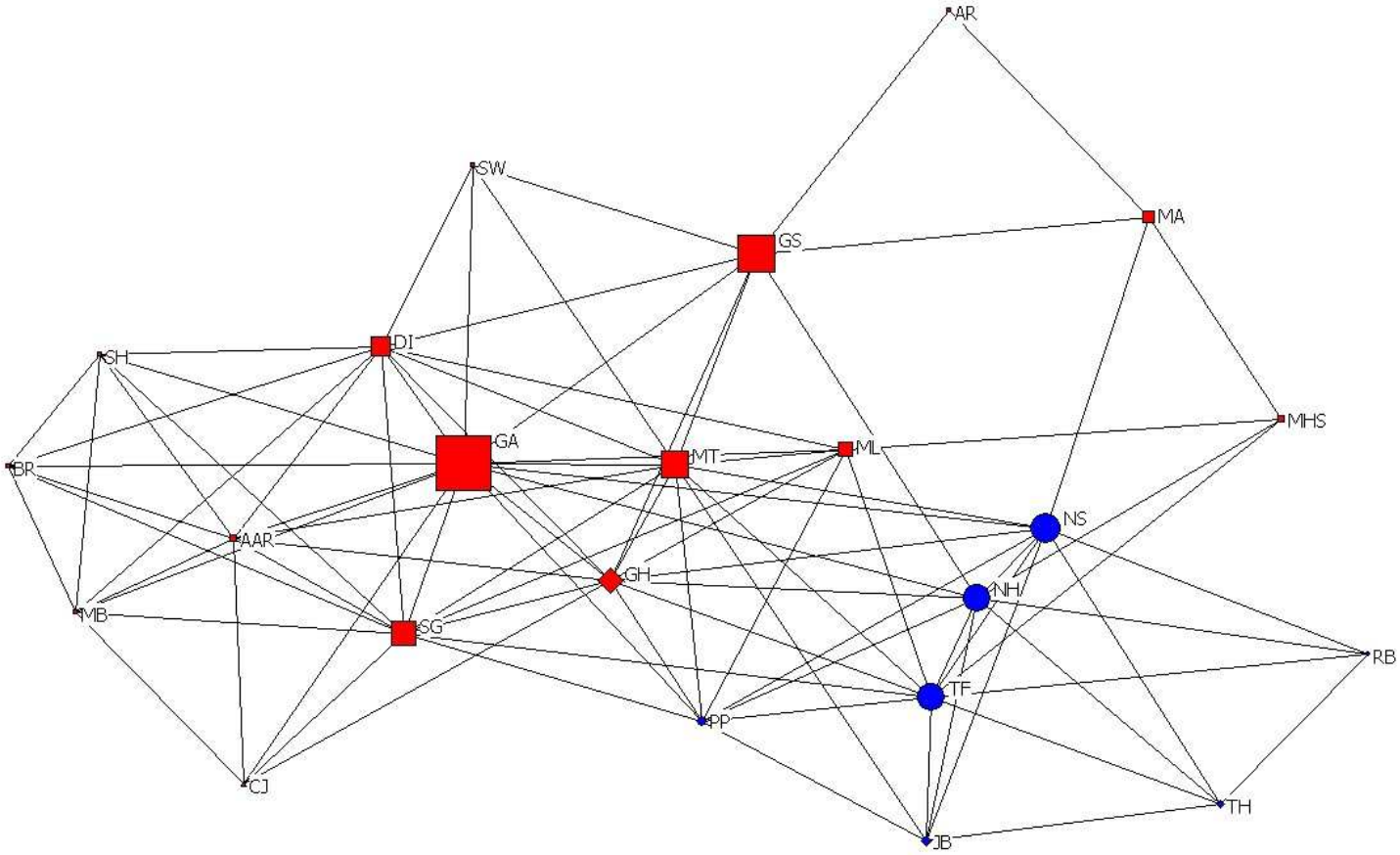

Figure 3: Graph of the Transition Pathways Project Social Network

Notes:
Node Colour: Red = engineering background. Blue = social science/economics background
Node Shape: Circle = theme 1. Square = theme 2. Triangle = theme 3. Diamond = more than one theme.
Node Size: Proportional to 'betweenness centrality'. This is a measure of the number of times a node appears on the shortest path between two other nodes and is used to identify crucial 'brokers' within social networks.

This network has an overall density of 0.35 (calculated by dividing the number of actual links between nodes, by the number of possible links). In short, this suggests that there is a relatively low level of interconnection between consortium members. Beyond this over-arching observation, a number of specific features stand out from the graph. First, it shows a very clear distinction between the engineers and social scientists/economists on the project. This division was also expressed on several occasions during interviews in which consortium members regularly commented that interaction and exchange across these broad disciplinary domains had been extremely limited:

> "Interviewer: So putting yourself in the middle, who do you see yourself as most closely related to and who's furthest away, those sorts of things? Respondent: Yeah. I wouldn't be surprised if those further away are all the social scientists." (Interviewee 02, p26 - Engineer)

This absence of strong relationships across the domains was also evidenced through confusion in the interviews about what role the different disciplines were playing on the TP project. Whilst there was some apparent agreement that those from an engineering background were likely to be doing some detailed modelling of the different pathways, there was less clarity about exactly what this would entail and how the models used would be related to the pathways (see section 6.2 below). In contrast, there was very little agreement about the role social scientists/economists are playing on the project with interviewees suggesting a number of different roles such as assessing public acceptability of new technologies, analysing the potential for cultural and institutional change within energy companies, understanding policy development and implementation processes. Such confusion was often blamed on a lack of clear roles being set out in the initial project proposal, although this was also welcomed by many as offering the flexibility needed for interdisciplinary working to occur. Nonetheless, such confusion over the roles different disciplines are playing on the project seems likely to hinder further interdisciplinary collaboration.

Another prominent feature of figure 3 is the clear distinction between the different themes on the project. Specifically, themes 1 (circles) and 2 (squares) are clearly distinct. Here, theme 1 appears to be relatively well connected internally, whereas theme 2 appears to be more scattered. In particular, there appear to be at least two institutional cliques (where all nodes know each other) apparent within theme 2. The Strathclyde team (bottom left of the graph) is internally well connected, and through Graham Ault (GA), Stuart Galloway (SG) and David Infield (DI) appears to have clear routes into the rest of the consortium. The Imperial team (Aidan Rhodes [AR], Marko Aunedi [MA] and Goran Strbac [GS] – top right of the graph) are also internally well connected, but here there are fewer links to the rest of the consortium, suggesting this team may be isolated from the rest of the consortium. Theme 3, however, remains the most scattered of all. Again, these divisions were borne out in the interview discussions:

> "If I was analysing this [ego network], I'd suggest that the problem is that the project is in 2 parts. There's theme 2, and then there's theme 1….I can see where it needs to interact. I'm worried I have no idea who these guys are." (Interviewee 03, p43-44 - Engineer)

This observation reinforces the apparent need for more interaction between the project teams, and for greater clarity over how each team is engaged in the pathway production process. The recently established Technical Elaboration Working Group would thus appear to be a positive step in this general direction.

A third prominent feature of figure 3, is the prominence of Tim Foxon (TF), Neil Strachan (NS), Nick Hughes (NH), Matthew Leach (ML), Geoff Hammond (GH), Peter Pearson (PP) and Murray Thomson (MT) as key brokers for linking the social science/economics nodes with the engineering nodes. This is a very positive observation as it suggests that vital links across the engineering and social science/economics domains, and between the different themes are already well-established. It also suggests that these individuals will play vitally important roles in developing these links further and increasing the networks overall density.

A fourth noticeable aspect of figure 3 is the peripheral role played by the PhDs and RAs on the project in comparison to the PIs and Co-Is. This is unsurprising especially given that many of the RAs and PhDs had had limited involvement with other consortium members when the interviews were conducted. Nonetheless, within interviews several of the PIs and Co-Is commented that the PhDs and RAs on the project were likely to be vital if meaningful interdisciplinary collaboration was to occur at all:

> "Ultimately the RAs and the PhD students are the engine room for the whole project, because none of the academics have any time to work on it properly" (Interviewee 03, p32 - Engineer)

The recent proposal by the RAs and PhDs to undertake a detailed characterisation of the existing energy system can thus be seen as a positive step towards closer interdisciplinary working. On a cautionary note, however, several more senior consortium members commented that interdisciplinarity can be a risky business for younger researchers as it may lead to a lack of sufficient disciplinary specialisation and publications. Whilst it is to be expected that the RAs and PhDs will take up more central positions in the consortium as the project continues and develops, this suggests that this process should be carefully planned and supervised by more senior consortium members.

Finally, based on the interview transcripts, two further features of this social network are conspicuous by their absence. First, there is a lack of any nodes from external stakeholders such as E.On. Several interviewees observed that having E.On as an external partner was incredibly valuable due to the industry expertise they possess and the access to data sets they may be able to provide. In general, however, there was a feeling among interviews that the consortium was not making the best use of E.On, and therefore that closer collaboration would be desirable. Second, several interviewees commented on the apparent lack of dedicated economists within the TP project:

> "I see no economists here. That's one area that's quite important to the project I think. If we are looking at transition pathways, then cost is an important issue, and we have no economist to actually sit down and do it." (Interviewee 22, p28 - Engineer)

This apparent lack of economists within the consortium is another issue that calls for further attention.

In summary, figure 3 offers several valuable insights into the current relationships and interactions on the TP project. Most worryingly, it suggests a relatively low level of interconnection to date, and the divides between disciplinary domains and between themes suggest that the project is currently working along mono-disciplinary lines and even, in some cases, in apparent isolation from other consortium activity. Figure 3 is static, however, and recent developments among the RAs/PhDs group and the Technical Elaboration Working Group suggest that future analyses may produce very different networks. It may therefore be valuable to repeat this exercise at different intervals in order to assess how interdisciplinary working practices have developed and ensure that critical relationships are established and worked upon if required.

6.2 Models and Pathways

Within the interviews, the distinction between theme 1 and theme 2 that figure 3 demonstrates appeared to focus on two key elements of the relationship between the pathways produced in theme 1, and the technological and economic models that would be used to develop the pathways under theme 2. First, in relation to how numerical and robust the pathways needed to be in order to allow modelling to occur, and how such numbers should be produced, and second, in relation to how models contained various built-in assumptions that needed to be considered in the process of developing the pathways.

The initial outline pathways were seen as insufficiently numerical by many of the modellers within theme 2 who required quite specific sets of numbers for their models to function adequately:

> "We need to receive fairly detailed ideas about how much wind energy they expect by 2020, how much nuclear energy they expect by 2020. Do they expect high quantities of microdistribution? Do they expect high quantities of large scale distribution? I know each pathway is different, but we need to have four or five scenarios with those ideas in there so we can say 'okay well we can model that like that', or 'we can model this like that'." (Interviewee 07, p8 - Engineer)

In addition, there was some reluctance among those within theme 2 to get involved in the production of the pathways, first because they perceived that a formal method, based on the Dutch transitions theory, had been adopted for their generation, and second because producing such numbers without such a formal method would represent mere 'guesswork':

> "There is a formal method that has been adopted for their generation, which is good because one of the problems with writing these scenarios is trying to ground it in something. Otherwise you're just sticking your finger in the air." (Interviewee 03, p20 - Engineer)

At the same time, members of theme 1 suggested a need for people on theme 2 to engage more directly in the production of the pathways and particularly adding numbers to them because, based on their technical expertise, they had a better 'feel' for what these numbers were today and thus how they might evolve. This apparent stand-off supports the call for greater 'off-model collaboration' in the production of the pathways made by the Kings College team in their statement on cross-disciplinary working on the TP project.

Whilst the issue of ensuring the pathways are sufficiently numerical to allow for modelling to occur is pressing, others perceived a more fundamental point to arise from the fact that the models themselves contain certain in-built assumptions about how the energy system functions. There was some concern that any models which are used needed to be included in the pathway production process from the outset and therefore act as a basis for structuring thinking across the whole project:

> "Anytime you use a modelling tool, then other parts of the project need to work with that modelling tool. That forces other people in the team to try and

> interact with this model which in some ways structures their thinking." (Interviewee 12, p5 – Social Scientist/Economist)

Structuring the project according to specific models, however, was recognised by others as failing to challenge the specific assumptions that are built into the models, and therefore as failing to get the most out of the interdisciplinary potential of the TP project. Indeed, were the TP project to be based around the models being used, this would approximate a multidisciplinary approach achieved via a subordination-service mode of working in which all parts of the project effectively serve the models. Instead, there was a perceived need amongst some interviewees to make the assumptions around which the models were constructed more explicit from the outset, in order that they may be challenged and changed if necessary. In particular, this issue arose with regards to how models characterise the behaviour of social actors:

> "I think a classic difficulty arises because one of the things the modellers would love to have is some way to put some numbers in their spreadsheets, which characterise the behaviours or the attitudes of the social actors. And there certainly can be a hope that the social science researchers will produce that number for you on a better basis than you could by plucking it out of the air. [However], many of the social scientists, I think, would push hard against that, because they're trying to bring a richer understanding. So I suspect we will hit some of those tensions further on down the line." (Interviewee 17, p20 - Engineer)

This example reveals that models invariably embody specific disciplinary approaches, which in turn raises very challenging questions about how they can be used within interdisciplinary projects. This suggests that in addition to a need for greater 'off-model collaboration', there may also be a need for some on-model, or perhaps in-model, collaboration in which these assumptions are made transparent and factored in to interdisciplinary collaborations. Such a suggestion places the initial onus of responsibility onto the social scientists/economists within the consortium to actively seek to understand how the engineering models function and how they account for social actors. At the same time, however, it would also call for the engineering modellers both to take the time to explain the models they use, and to be prepared to critique and be flexible about the assumptions they are based upon. In short, it would demand both patience and mutual understanding, and even with these in abundance it would not necessarily be guaranteed to produce successful outcomes. On the basis of this, and the discussion in section 5.1, however, it would appear that interdisciplinary collaboration is most vital, and perhaps holds most potential, in precisely the areas where mono-disciplinary approaches tend to hold sway and, as such, normally go unchallenged.

6.3 Models of interdisciplinary working

The relationship between the transition pathways and various energy system models is in many ways just a part of a larger issue raised in the interviews about how the different themes within the project should work together. Within the interviews several different conceptions of how the project should function were invoked, with the same interviewee often invoking more than one in the course of the same discussion.

Most participants suggested that an 'iterative' approach would form the ideal way for the project to work:

> "The way I thought it would work best is if there was iterations [between the themes]. You try something, and then it comes back, and it goes around." (Interviewee 16, p7 – Social Scientist/Economist)

In this iterative approach, the development of the pathways is led by theme 1 but in constant dialogue and collaboration with theme 2 which is seen to assess the pathways for their technical and social feasibility, and to add more detail to them which in turn enables those in theme 1 to constantly improve their overall plausibility. This is all seen to occur within the context of theme 3 which is engaged throughout this process, and once the pathways are agreed upon is then able to conduct whole systems appraisal of them. Even here, however, the whole systems appraisal process may generate a need for further iterations. This approach is summarized diagrammatically in figure 4 below.

As mentioned, this iterative approach was seen as ideal by most consortium members, however it was also seen as being extremely time consuming, particularly given the consortium's geographical spread, and as demanding that all consortium members remain flexible throughout the process in order that they can adapt their approaches, models and research according to how the pathways develop.

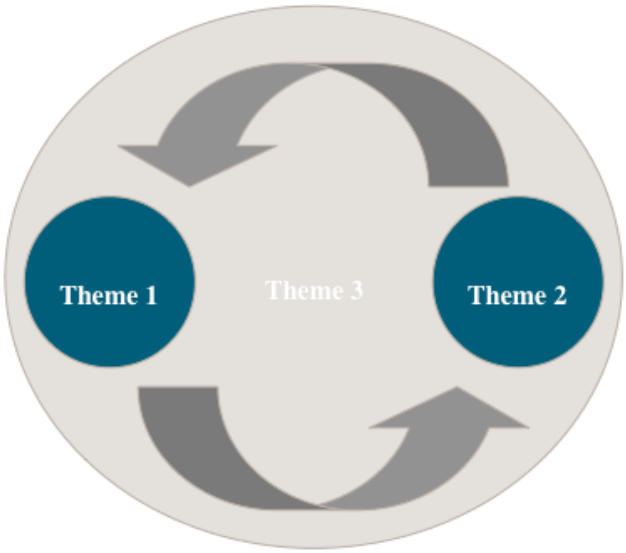

Figure 4: An Iterative Approach

The second most commonly invoked approach saw the different themes collaborating sequentially. Whilst the iterative approach had been presented as an ideal that may or may not be happening, this approach was often invoked indirectly as an example of how things were currently operating on the project. Here, and as summarized in figure 5, theme 1 is seen to produce the pathways before handing them over to theme 2 which is able to model, refine and add detail to them, before finally theme 3 appraises them according to certain properties:

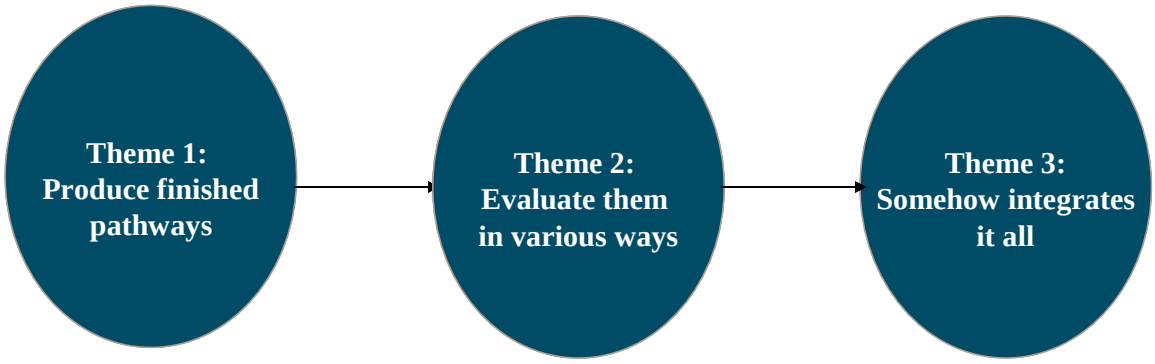

Figure 5: A Sequential Approach

> "We're waiting for theme one to sort out the pathways which they want us to model I think." (Interviewee 07, p8 - Engineer)

> "I think that in theme 3 we're at the end of it. So I think we collect the results of everybody else's work, and I don't see us directly working very, very closely with the other themes." (Interviewee 09, p36 - Engineer)

Whilst this approach was commonly invoked, it was also criticized by several interviewees. In particular, it was seen as avoiding any meaningful interdisciplinary collaboration and potentially enabling any assumptions made in theme 1 to go relatively unchallenged by the other themes. This approach may be seen as multidisciplinary at best, and mono-disciplinary at worst.

A third, 'staged' approach was also mentioned in which interdisciplinary collaboration occurs at particular stages of the project, in particular during the initial production of the pathways, but once this is completed the different themes then work in mono-disciplinary isolation:

> "Everything stems from the pathways. Once you've got them right, then you can go away and start detailed modelling with various specific aspects…I think the first half of this project is definitely interdisciplinary but I think towards the end, it will become, it will become more [disciplinary]." (Interviewee 05, p18 - Engineer)

Others suggested that this might also involve the themes coming together again towards the end of the project to integrate the work they have done:

> "Interviewer: So in some sense the social scientists have a role afterwards? They come later on in the project?
> Respondent: I would say so. That would be my gut feeling. Maybe they could have a role at the start, but there's seems to be little role in the middle." (Interviewee 07, p23 - Engineer)

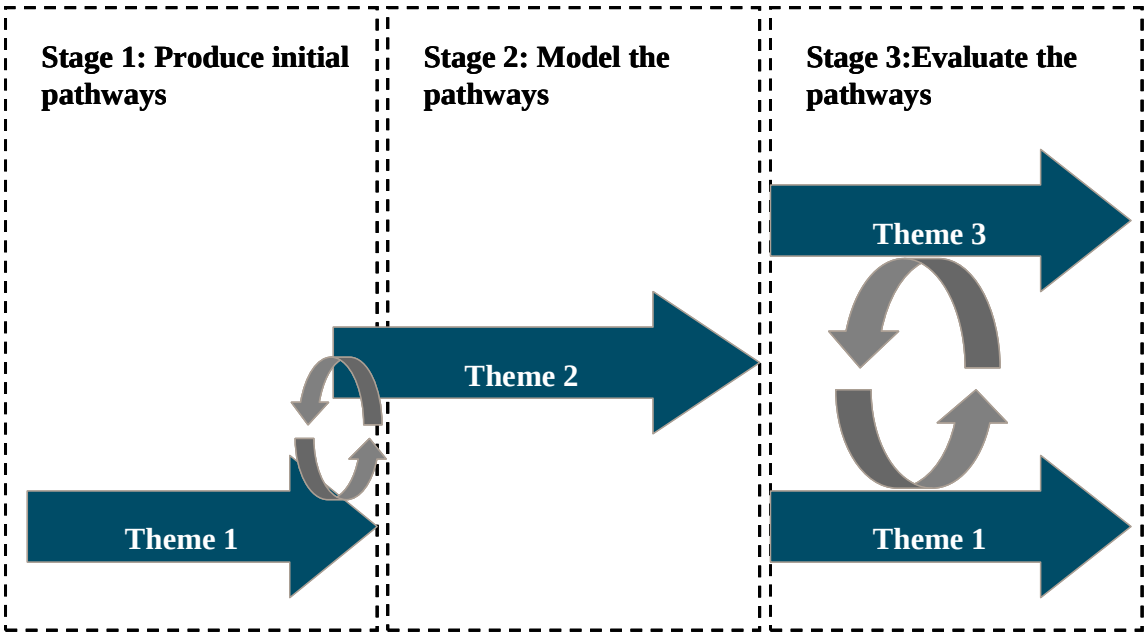

Figure 6: A Staged Approach

This approach is summarized in figure 6, and appears to be something of a compromise between the iterative and sequential model that enables a degree of interdisciplinary collaboration in the production of pathways and integration of results, but also overcomes the practical challenges of interdisciplinary research through periods of mono-disciplinary working. The key concerns with this approach however, are first that the opportunity for interdisciplinary collaboration may already have been missed, and second, that extended periods of lack of contact and interaction may mean that there are few opportunities to check that all partners are working towards the same aim. This approach also retains a sequential element meaning that assumptions made in one theme may go unchallenged throughout the project, or at least not be challenged until it is too late to make significant changes.

It is also worth noting that these quotations imply that theme 2 is the least interdisciplinary of all three themes on the project. In contrast, the previous sub-section illustrated that it is within theme 2, around issues of modelling the pathways, that the distinct ontological and epistemological assumptions of the different disciplinary approaches come into contact and therefore require the most careful interdisciplinary discussions. If such a staged, or a sequential, approach were allowed to come to pass, therefore, the TP project would run the risk of veering away from interdisciplinary collaboration at precisely the moment where it is most needed and could, potentially, offer most value.

A fourth and final ‘sliced’, or ‘gated’ approach (see figure 7) was not directly mentioned in any of the interviews but perhaps provides a further compromise, which retains the positive aspects of the other models but also avoids some of their pitfalls. In this model, the different themes are seen as operating in parallel throughout the duration of the project, but come together regularly to collaborate through meetings and sub-projects that produce joint outputs:

> "I think ideally we would have individual work packages that require people to be talking to each other, daily, weekly or whatever it might be...I think that should be firmly on the agenda, because otherwise the danger is that we come together every 3-6 months or so and then people go away and they do their own bit." (Interviewee 17, p25 - Engineer)

Whilst this approach is perhaps most accurately described as multidisciplinary, regular meetings could ensure consortium members question each others assumptions and work towards the same aims. Furthermore, through sub-projects, such as the RAs and PhDs recent 'Engine Room' meetings and the Technical Elaboration Working Group, this model is seen to be striving towards closer collaboration and even interdisciplinary collaboration throughout. Ultimately, this model accepts that multidisciplinary working may be the only realistic approach, but is seen as attempting to convert this into a deeper and more integrative form of interdisciplinarity as the project develops.

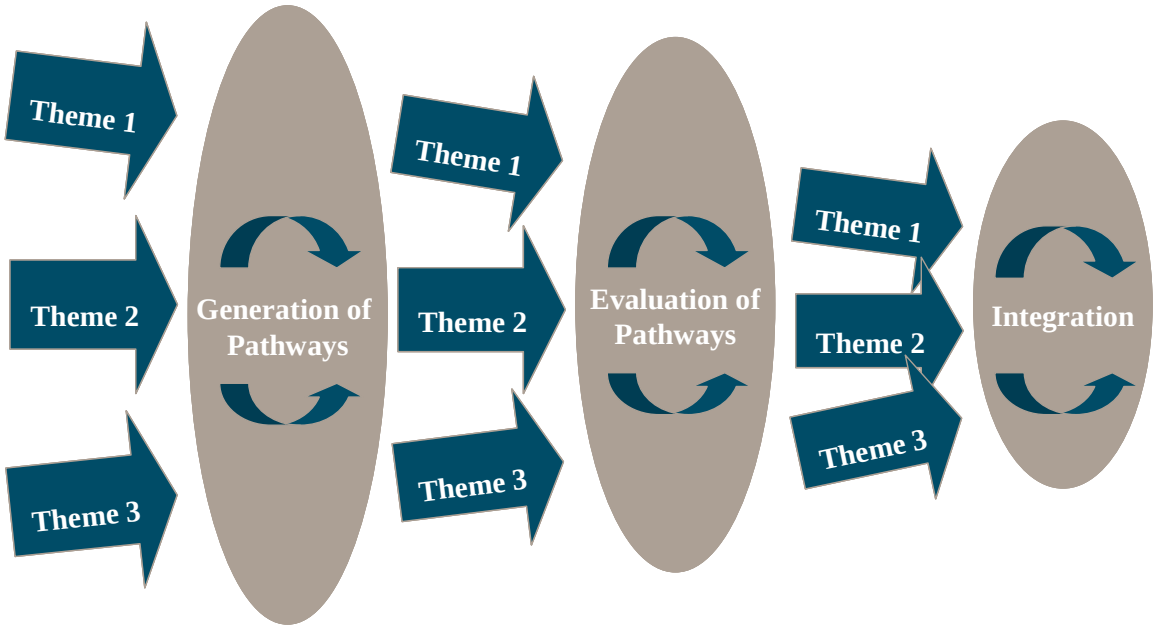

Figure 7: A Sliced or Gated Approach

All of these models have both strengths and weakness in terms of how practically achievable they may be, and with regards to how they approach interdisciplinary working. Currently, whilst most interviewees see an iterative approach as ideal, the social network analysis discussed in section 6.1, as well as several of the comments in the interviews, suggests that at present the project is closer to a staged or even sequential approach. The purpose of elaborating these different approaches, however, is to encourage the consortium to reflect explicitly on which approach is seen as most desirable in order that interventions can be made and successful interdisciplinary collaboration can be achieved.

7. Draft Conclusions

As noted at the outset, this report approaches the TP project as a case study of interdisciplinary energy research. Specifically, this report has sought to conduct a formative evaluation of the TP project, exploring current practices and processes of interdisciplinary working in order to lay the basis for further discussion and, hopefully, to improve our interdisciplinary collaboration in the future. We would like to thank everyone for co-operating so fully with us over the last few months in the production of this report, and hope that it will provide food for thought at the November Workshop. As the project is still in progress and has evolved rapidly since work on this report began, it would be inappropriate to present formal final conclusions based on this work at this stage. Instead, we present a series of draft conclusions drawn from this analysis in the form of questions and we welcome opportunities for further discussion.

Conclusions 1-5 are addressed to the TP Consortium for internal consideration whilst conclusions 6-7 are more outward facing.

1. In terms of social learning, there is evidence to show that taking part in this 'interdisciplinarity project' has been valuable in itself as it has enabled members to develop a vocabulary and common ways of understanding what interdisciplinarity entails. Those individuals who completed the Q sort ahead of the interview, for example, would often use statements from the concourse whereas others who undertook the Q sort after the interview sometimes struggled to express personal opinions on interdisciplinarity. For both groups, providing a 'formal' reason to reflect on what the TP consortium is committed to in terms of doing interdisciplinary research has been useful. Should further opportunities for reflection be built into future work?

2. The research is relevant to planning the next steps for TP project. The evidence shows that it takes time for specialists to learn more about each others theoretical/conceptual, methodological and empirical research. We have highlighted how, in the literature, discussions about interdisciplinary research between the physical and social sciences, tends towards a linear model of knowledge production with social scientists at the 'tail-end', undertaking the translation and policy-facing work associated with bringing research into practice. Physical scientists are urged to embrace social scientific concepts /frameworks in co-production models of research. But there is equally an onus on social scientists to engage more seriously with the epistemological and methodological bases of engineering research. To what extent is this level of reciprocity desirable or possible? The initiative being taken by the RAs and PhDs through their 'Engine Room' meetings suggests it might be.

3. The interviews have highlighted in a rigorous and systematic way, some of the on-going problems with Theme 2 which have already been discussed at previous Consortium meetings. Our analysis suggests that Theme 2 should become the most interdisciplinary aspect of the project whereas, at present, it is normally treated as the least. It is in Theme 2 where core concepts clash and where, therefore, most interdisciplinary value could be added or lost. The question for the November Workshop, and for the newly established Technical Elaboration Working group, is how best to do this.

4. Several interviewees expressed uncertainty as to what the final outputs of the TP project will be, and specifically, regarding what form the final pathways will take. Whilst a degree of flexibility in determining this was welcomed, particularly in the early stages of the project, it was generally felt that firmer guidelines regarding outputs should now be established. This raises several difficult questions: what will a finished pathway look like? To what extent, and how, will they integrate technical, social, quantitative and qualitative outputs?

5. A wide range of more practical recommendations were mentioned in the interviews, these included the following:
    - there should be more project meetings (or perhaps Skype calls), that should be better structured;
    - the whole consortium should make better use of the wiki;
    - there should be more focus on joint projects such as the RAs/PhDs work and the technical elaboration working group;
    - stronger leadership/vision of how the project should proceed and what its outputs will be would be helpful;
    - consortium members should agree on what level of interdisciplinary collaboration is realistic/achievable in this project. For example, we may have to accept multidisciplinarity in this project, but this could lay the ground for stronger interdisciplinarity in future projects;
    - the consortium as a whole should make better use of E.On's involvement in the project to develop its transdisciplinary aspects.

6. Looking outwards, we think there is evidence here to suggest that the EPSRC Sandpit process needs additional support in order to deliver its interdisciplinary goals. In particular, the speed with which the consortium was required to produce a full proposal meant that a number of important issues were not able to be fully dealt with ahead of the start of the full project. Getting to common understanding in interdisciplinary research takes time. It requires seedcorn funding to support 'proof-of-concept' ahead of implementation of the full research programme. The TP consortium is having to do this important work at the same time as undertaking its research programme.

7. Finally, we would agree with Strathern (2004) that interdisciplinarity has become hyper-formalised in contemporary research, but it is not always carefully thought through, nor is there a well-established vocabulary. The understanding of interdisciplinarity is at different stages of development in the social and engineering sciences. A major unresolved question is therefore, how far does willingness to do interdisciplinary work extend before real conceptual limits are reached?

Appendix 1: Detailed Factor Descriptions from the Q Methodology Study

Q Sort 1: The general view of interdisciplinarity

No.	Statement	Factor		
		1	2	3
1	Interdisciplinary research is a solution to real world problems	3	-1	4
2	The real world is not divided up by academic disciplines	3	-1	4
3	Interdisciplinarity is a measure of successful science	4	-5	-2
4	The success or failure of interdisciplinary research depends on project structures, procedures and requirements of those funding the research	-2	3	0
5	Interdisciplinarity is about working together to find things out	3	-1	1
6	Interdisciplinary research takes longer to do	1	4	-1
7	Interdisciplinarity is a problem to explore	2	0	-5
8	Real interdisciplinarity is a pipe-dream	0	4	-4
9	Interdisciplinary research opens up the framing of problems	2	-3	2
10	It's a way for politicians to control funding	-4	0	-5
11	Interdisciplinary research is less cutting edge than pure disciplinary research	-4	5	3
12	Interdisciplinary science is more accountable to society	-2	-4	-1
13	The problems of doing interdisciplinary research are about philosophies than disciplines	0	0	0
14	The problems of doing interdisciplinary research are more about individual personalities	0	1	-3
15	Interdisciplinarity is an end not a means	-5	3	-2
16	Finding a common language is the biggest problem in interdisciplinary working	1	1	2
17	Interdisciplinary brings science closer to the needs and concerns of citizens and consumers	2	-2	5
18	Disciplines are stifling	-1	-3	-4
19	Working with researchers from different disciplines is a way to improve my own research	1	-3	1
20	It is important to maintain the boundaries of disciplines	-1	5	-3
21	Research is about constructing disciplines	-3	1	-4
22	Some disciplines are better equipped than others for interdisciplinary collaboration	-2	3	0
23	The structure of project is more important than the disciplines involved	1	-1	0
24	Disciplines determine individual's research priorities	-1	2	0
25	Interdisciplinary research better serves the economy	2	-4	3
26	Problems are more important than disciplines	1	-2	0
27	Disciplines structure methodologies	-1	2	1
28	I don't care about disciplines	-2	-4	-1
29	Interdisciplinarity promotes innovation	5	-5	1
30	Interdisciplinary research promotes application of research in policy and practice	0	-2	5
31	The boundaries between social science disciplines are fuzzier than those in the natural sciences	-4	2	1
32	The promotion of interdisciplinarity is a threat to autonomous science	-5	4	-2
33	I don't privilege any particular way of framing a problem	-3	-2	-2
34	Working with other disciplines is about broadening my horizons	4	-1	2
35	Some disciplines are rife with internal divisions anyway	0	2	-1
36	Different disciplines offer more than just different perspectives	4	1	3
37	Interdisciplinarity is about synthesis and integration	-3	0	2
38	Some disciplines have a naturally subordinate position when working with others	-1	1	-1
39	Working with other disciplines helps challenge ingrained assumptions	5	0	4
40	Social sciences are more suited to a 'delivery' role	0	0	-3

Table 2: Sort 1 Factor Arrays

Table 2 summarises the 3 different factors produced by sort 1.

Sort 1 Factor 1: Horizon expanders

This factor explained 12% of the overall variance. Sorters who loaded highly on this view appear to suggest that the general view of interdisciplinarity is largely positive. A key benefit is that it promotes innovation (29 = +5[4]), and it appears it is able to do this because working with other disciplines helps to challenge ingrained assumptions (39 = +5) and in so doing opens up the framing of problems (9 = +2). In general, working with other disciplines is seen positively as a means of broadening horizons (34 = +4), and this is helped by the fact that different disciplines offer more than just different perspectives (36 = +4). Indeed, such is the degree of benefit that interdisciplinarity provides, it may even be seen as a measure of successful science (3 = +4).

Whilst the primary benefit of interdisciplinarity is its ability to challenge assumptions and expand horizons, a secondary benefit is that it can provide a solution to real world problems (1 = +3) which cannot be achieved by disciplinary research alone because the real world is not divided up by academic disciplines (2 = +3). Interdisciplinarity's real world focus, it seems, may also help to bring science closer to the needs and concerns of citizens and consumers (17 = +2) and is better able to serve the needs of the economy (25 = +2), although in interviews those who loaded highly on the sort expressed some doubt over whether or not this was specific to interdisciplinary research or could also be achieved through mono-disciplinary approaches.

Sorters agreeing with this view saw interdisciplinarity as a means rather than an end (15 = -5), and were quick to emphasise that it posed no threat to autonomous science (32 = -5), perhaps partly because is not a way for politicians to control funding (10 = -4). Indeed, sorters within this view would appear to suggest that it can happily co-exist with disciplinary research because although disciplines do not determine individuals' research priorities (24 = -1), structure methodologies (27 = -1) or necessarily produce research that is more cutting edge (11 = -4), they remain something that should be cared about (27 = -2) even if research should not be solely devoted to their construction (21 = -3).

Sort 1 Factor 2: Strict disciplinarians

This factor explains 21% of the overall variance. Sorters who load highly on this factor suggest that the general view of interdisciplinarity is in fact quite hostile towards interdisciplinary research. Here, disciplines should be cared about (28 = -4) and it is vitally important to maintain their boundaries (20 = +5) because they are the cutting edge of research (11 = +5). Interdisciplinarity is seen as a threat to such autonomous science (32 = +4) and, in any case, takes longer to do (6 = +4) and in many cases remains a pipe-dream (8 = +4). Indeed, disciplines themselves are seen as rife with internal divisions (35 = +2) therefore interdisciplinarity does not necessarily add new or alternative perspectives.

[4] These detailed factor descriptions represent an attempt to reconstruct the 'ideal type' sorts that emerged from the factor analysis. Accordingly, they stick closely to the language used within the sorted statements. Where a specific statement is referred to, its number and column position (from -5 to +5) is noted to ease interpretation.

Whilst this view sees interdisciplinarity as an end rather than a means (15 = +3), in interviews those who loaded highly on this sort stressed that it should not be seen as an end in itself. They were quick to point out that in some cases it might be useful, whereas in others a mono-disciplinary team is most useful. As such, interdisciplinarity is seen as a potential product of disciplines which structure methodologies (27 = +2) and determine individuals' research priorities (24 = +2). The success or failure of interdisciplinarity is thus crucially dependent on the structures, procedures and requirements of those funding the research (4 = +3) and how they arrange disciplines together into specific projects.

Disciplinary research is at the cutting edge of science and, as such, interdisciplinarity should certainly not be used as a measure of successful science (3 = -5). It does not necessarily promote innovation (29 = -5), it does not necessarily better serve the needs of the economy (25 = -4), it does not necessarily promote the application of research in policy and practice (30 = -2), it is not necessarily more accountable to society (12 = -4), and it does not necessarily bring science closer to the needs of citizens and consumers (17 = -2). At the same time, working with researchers from other disciplines does not necessarily improve an individuals' research (19 = -3), at least in part because it neither opens up the framing of problems (9 = -3) nor broadens horizons (34 = -1) any more so than pure disciplinary research.

Sort 1 Factor 3: Interdisciplinary appliers

This factor explained 21% of the total variance. Here, the general view of interdisciplinarity is that it is applied research. It can promote the application of research in policy and practice (30 = +5), and bring science closer to the needs and concerns of citizens and consumers (17 = +5). Although it is not a primary concern, such application also means that interdisciplinary research can better serve the needs of the economy (25 = +3). Such application does not, however, necessarily make it more accountable to society (12 = -1).

A key part of interdisciplinarity's applied nature is its real world focus. It is seen as a solution to real world problems (1 = +4) which are not divided up by academic disciplines (2 = +4). A key reason that it can help to address such real world problems is that by drawing multiple disciplines together, it helps open up the framing of problems (9 = +2) and can broaden individuals' horizons (34 = +2). The challenge of interdisciplinarity is then to bring about synthesis and integration (37 = +2) across these different disciplines. This demands collaborative working to help find things out (5= +1) and such working with others from different disciplines ma serve as a means of improving an individuals' own research (19 = +1), even if finding a common language can be a key challenge (16 = +2).

Despite its many benefits in terms of applying research to real world problems, this view also cautions that interdisciplinarity is less cutting edge than pure disciplinary research (11 = +3). Whilst research should not be about constructing disciplines (21 = -4) or necessarily striving to maintain their boundaries (20 = -3), this view stresses that disciplines are not stifling (18 = -4) and should therefore be retained in the attempt to get cutting edge solutions to real world problems. Interdisciplinarity is therefore not a threat to autonomous science (32 = -2) and is certainly not a way for politicians to control funding (10 = -5). It is a means rather than an end in itself (15 = -2) but achieving it is far from a pipe-dream (8 = -4). It does not necessarily take

longer than disciplinary research (6 = -1), but nor should time be wasted on exploring it as a problem in itself (7 = -5). In short, interdisciplinarity is not the be all and end all. It helps primarily as a means of applying cutting edge disciplinary research to help find solutions to real world problems.

Sort 2: Personal experiences of interdisciplinarity

Table 3 summarises the 2 different factors produced by sort 2.

Sort 2 Factor 1: Applied solution seekers

This factor explained 28% of the overall variance. In this view consortium members' prior experiences of interdisciplinarity lead them to suggest that it is about application. It serves to find solutions to real world problems (1 = +3) precisely because the real world is not divided up by academic disciplines (2 = +5). In turn, this real world focus helps promote the application of research in policy and practice (30 = +5) and also brings science closer to the needs and concerns of citizens and consumers (17 = +4). It should be noted, however, that such real world application does not necessarily make interdisciplinary research more accountable to society (12 = -1), and nor does it necessarily promote innovation (29 = +1) or better serve the needs of the economy (25 = +1).

A key means by which interdisciplinarity appears to be able to achieve its real world application is because working with other disciplines helps to challenge ingrained assumptions (39 = +3) which, in turn, helps individuals to broaden their horizons (34 = +4) and opens up the framing of problems (9 = +2). Through this, interdisciplinarity is seen as a means of improving an individuals' own research (19 = +3). At the same time however, working with other disciplines and the need for synthesis and integration (37 = +2) also poses the biggest challenge to interdisciplinary research, which is finding a common language (16 = +4). This also means it takes longer to do (6 = +1).

Importantly, interdisciplinarity is seen as a process, a means rather than an end (15 = -5) and as such is far from a pipe-dream (8 = -4). Experiences within the consortium also suggest that it poses no threat to autonomous science (32 = -5) and is certainly not a means for politicians to control funding (10 = -4). It can therefore be seen as happily co-existing alongside disciplinary research, but it is important to recognise that no research, whether inter or mono-disciplinary, should be purely about constructing disciplines (21 = -4) or maintaining their boundaries (20 = -3). Here, the applied nature of research appears paramount. Accordingly, interdisciplinary research can be just as cutting edge as disciplinary research (11 = -2) but still should not be taken as a measure of successful science (3 = -2). In this view, consortium members experiences of interdisciplinarity suggest that its primary value is its ability to help find solutions to real world problems, it is also recognised, however, that it is not always helpful and, in some cases, pure disciplinary research is better able to offer such solutions.

No.	Statement	Factor	
		1	2
1	Interdisciplinary research is a solution to real world problems	3	2
2	The real world is not divided up by academic disciplines	5	2
3	Interdisciplinarity is a measure of successful science	-2	-5
4	The success or failure of interdisciplinary research depends on project structures, procedures and requirements of those funding the research	-2	-1
5	Interdisciplinarity is about working together to find things out	2	4
6	Interdisciplinary research takes longer to do	1	3
7	Interdisciplinarity is a problem to explore	-2	-1
8	Real interdisciplinarity is a pipe-dream	-4	0
9	Interdisciplinary research opens up the framing of problems	2	1
10	It's a way for politicians to control funding	-4	1
11	Interdisciplinary research is less cutting edge than pure disciplinary research	-2	-1
12	Interdisciplinary science is more accountable to society	-1	-4
13	The problems of doing interdisciplinary research are about philosophies than disciplines	1	2
14	The problems of doing interdisciplinary research are more about individual personalities	-3	2
15	Interdisciplinarity is an end not a means	-5	-4
16	Finding a common language is the biggest problem in interdisciplinary working	4	5
17	Interdisciplinary brings science closer to the needs and concerns of citizens and consumers	4	-2
18	Disciplines are stifling	0	-2
19	Working with researchers from different disciplines is a way to improve my own research	3	5
20	It is important to maintain the boundaries of disciplines	-3	-1
21	Research is about constructing disciplines	-4	-4
22	Some disciplines are better equipped than others for interdisciplinary collaboration	0	1
23	The structure of project is more important than the disciplines involved	-1	1
24	Disciplines determine individual's research priorities	0	0
25	Interdisciplinary research better serves the economy	1	-2
26	Problems are more important than disciplines	2	3
27	Disciplines structure methodologies	0	3
28	I don't care about disciplines	0	-3
29	Interdisciplinarity promotes innovation	1	0
30	Interdisciplinary research promotes application of research in policy and practice	5	0
31	The boundaries between social science disciplines are fuzzier than those in the natural sciences	0	-3
32	The promotion of interdisciplinarity is a threat to autonomous science	-5	-1
33	I don't privilege any particular way of framing a problem	-1	-3
34	Working with other disciplines is about broadening my horizons	4	1
35	Some disciplines are rife with internal divisions anyway	-1	0
36	Different disciplines offer more than just different perspectives	1	4
37	Interdisciplinarity is about synthesis and integration	2	0
38	Some disciplines have a naturally subordinate position when working with others	-3	-2
39	Working with other disciplines helps challenge ingrained assumptions	3	4
40	Social sciences are more suited to a 'delivery' role	-1	-5

Table 3: Sort 2 Factor Arrays

Sort 2 Factor 2: Problem explorers

This factor explains 19% of the overall variance. In this view, prior experiences of interdisciplinary work suggest that working with other disciplines is a vital way to improve ones own research (19 = +5). Different disciplines offer more than just different perspectives (36 = +4), such as different methodologies (27 = +2), and accordingly, working with other disciplines helps to challenge ingrained assumptions (39 = +4). The real world is not divided up by academic disciplines (2 = +2), and solving real world problems is more important than disciplines in any case (26 = +3; 1 = +2; 21 = -4). As such, a key benefit of interdisciplinary research comes from working together to find things out (5 = +4).

Despite these benefits, working with others can cause problems. Finding a common language is a key issue (16 = +5) as are the different personalities (14 = +2) and philosophies (13 = +2) that can be found in interdisciplinary research projects. This can mean that it takes longer to do (6 = +3). Indeed, those of this view have more doubt than others about the extent to which interdisciplinarity is about synthesis and integration between disciplines (37 = 0) and about whether or not real interdisciplinarity is in fact a pipe-dream (8 = 0).

Whilst interdisciplinarity serves to challenge assumptions and improve research, consortium members' experiences suggest that it should not be taken as a measure of successful science (3 = -5). It is a means rather than an end in itself (15 = -4) and it's important that different disciplines are treated equally within this process. For example, social science disciplines do not have fuzzier boundaries than the natural sciences (31 = -3) and are not more suited to a delivery role (40 = -5). As such, interdisciplinary research should not privilege any particular framing of a problem (33 = -3), and whilst disciplines are important, are not seen as stifling (18 = -2) and should be cared about (28 = -3), research should not be about constructing disciplines (21 = -4) or necessarily maintaining their boundaries (20 = -1).

Importantly, whilst interdisciplinarity can help to open up the framing of problems (9 = +1), it does not necessarily promote innovation (29 = 0), better serve the needs of the economy (25 = -2) or bring research closer to the needs and concerns of citizens and consumers (17 = -2). Indeed, there is a slight suspicion in this view that interdisciplinarity might be a means of giving politicians more control over funding (10 = +1) which is perhaps why those within this view were less certain whether or not it posed a threat to autonomous science (32 = -1).

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