The balancing act, using climate science to inform adaptation decisions: a case study on the UK Climate Projections 2009.

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Abstract

The UK Climate Projections 2009 (UKCP09) provides climate information designed to help those needing to plan how they will adapt to a changing climate. We conducted an empirical analysis of the science-policy interface to determine how useful and usable UKCP09 is for adaptation decision-making. We used a mixed methods approach that includes analysis of adaptation reports, a quantitative survey and semi-structured interviews with key adaptation stakeholders working in the science-policy interface: they included decision-makers, knowledge producers and knowledge translators. We used the knowledge system criteria to assess the credibility, legitimacy and saliency of UKCP09 for decision-makers use. We found UKCP09 to be perceived as credible and legitimate due to its sophistication, funding source and contributing parties. However, due to tight tradeoffs, added complexity for decision-making and a potentially greater diversity in users, its saliency was found to be dependent upon the scientific competence and familiarity of the user(s) in dealing with climate science information. An example of this was the use of Bayesian probabilistic projections which improved the credibility and legitimacy of UKCP09's science but reduced the saliency for decision-making. This research raises the question of whether the tailoring of climate projections is needed to enhance their salience for decision-making. In a

rapidly changing landscape, both in scientific and policy terms, this case study demonstrates how difficult it is to balance the three knowledge system criteria at the science-policy interface of adaptation to climate change.

Keywords: Adaptation decision-making, Science-policy interface, Knowledge system criteria, UKCP09.

Acknowledgements

The authors would like to thank all of the individuals that participated in the study. In addition, thanks should be given to David Demeritt and Henry Rothstein for commenting on earlier drafts of the paper. Thanks also to Megan Gawith of UKCIP and Sophie Millin and Anna Steynor-Greenwood formerly of UKCIP, for sparing their time to discuss this research. Any errors remain our own.

1. Introduction

Future changes in climate are inevitable, making adaptation a fundamental societal response option alongside the traditional focus on mitigation. In contrast to mitigation, adaptation aims to deal with the consequences rather than causes of climate change. As such, adaptation is "an adjustment in ecological, social or economic systems in response to observed or expected changes in climatic stimuli and their effects and impacts in order to alleviate adverse impacts of change or take advantage of new opportunities" (Adger *et al*, 2005, p. 78). Adaptation actions aim to reduce the negative impacts (and provide benefits) from actual or expected climatic changes (Fussel, 2007).

In the UK, the Climate Change Act 2008 provided Government with special 'Adaptation Reporting Powers' to request 'bodies with functions of a public nature' and 'statutory undertakers' (e.g. utility companies and harbour authorities) to report on the risks and benefits posed by changes in climate and how they plan to adapt to them (Defra 2011a). Consequently, with adaptation planning a requirement, demand for information to support climate-related policy and investment decisions has grown rapidly (Hulme and Dessai 2008a; Tribbia and Moser, 2008; Dilling and Lemos, 2011). Therefore, the need to produce and disseminate comprehensive, robust, and trustworthy scientific information to inform policy

design is essential (Dilling and Lemos, 2011). In fact, since 1997 the UK Government has invested significant political currency in evidence-based policy-making with bold commitments made in the White Paper, '1999 Modernising Government' (Young et al, 2002; Sutcliffe and Court, 2005).

Various UK Government subsidiaries, including: Department of Environment, Food and Rural Affairs (Defra); Department of Energy and Climate Change (DECC); UK Climate Impacts Programme (UKCIP); Environment Agency (EA); and UK Met Office Hadley Centre (MOHC), have provided stakeholders with both general and specific information on how to assess the risks and benefits in order to develop their adaptive capacity. For instance, in 2003, Defra and DECC provided the MOHC as the lead agency (alongside other organisations) with £11 million to develop state-of-the-art climate projections of future changes in the UK known as UKCP09 (UK Climate Projections, 2011a); which have experienced significant uptake, resulting in its emergence as the "standard benchmark set of climate information in use by the UK impacts and adaptation community" (UKCIP, 2011a, p. 28).

However, whilst Central Government is keen to encourage adaptation action at all levels of society, informed by the best available scientific information, research has identified various obstacles to its effective use in policymaking (see Demeritt and Langdon, 2004; Gawith et al, 2009; Arnell, 2011; Reeder and Ranger, 2011). Consequently, it is possible to question the practical usability of science being produced to inform policy. Notably, in the UK, the Government has made a large investment into providing free climate information for decision-makers to use in UKCP09, yet, few observations and assessments have been undertaken to determine the efficacy of that investment and how the information translates into informing policy decisions. Therefore, given the Government has requested key infrastructure providers to report on adaptation measures, it is timely to consider whether, how and why UK climate information is being used to inform adaptation decision-making.

This paper utilises UKCP09 as a case study to investigate the science-policy interface. It will determine if key stakeholders (decision-makers, knowledge producers and knowledge translators) perceive UKCP09 to be usable for adaptation decision-making. The paper consists of the following: Section 2 contextualises the paper within the science-policy interface literature; Section 3 introduces a brief background of UKCP09; Section 4 presents the research methods employed; Section's 5 and 6 assess and discuss our findings; and finally, Section 7 identifies a number of conclusions.

2. Developing Science for Policy

2.1 Modes of science

Scientific expertise, knowledge and progress are key reference points for societal deliberation about how to address climate change (Braun and Kropp, 2010; Kropp amd Wagner, 2010). Yet, many attempts at disseminating science for policy have experienced variable success, leading a number of researchers to speculate about a 'disconnect' between the science produced ostensibly to inform decision-making and actual policy processes (Lemos and Moorhouse, 2005; McNie, 2007; Sarewitz and Pielke Jr, 2007; Dilling and Lemos, 2011; Meyer, 2011). Several reasons for this disconnect have been suggested, the most commonly referred to being the realisation that the traditional "linear model" or "loading dock approach" for providing scientific information to inform decision-making is now outdated. It is thought that science produced using the linear model makes "a number of unsubstantiated assumptions about the resources, capabilities and motivations of research users" (Eden, 2011: 12); that science produced is expected and presumed to be useful (and usable) to help intended recipients (and society) address problems they may face (Dilling, 2007a; McNie, 2007; Sarewitz and Pielke Jr, 2007; Dilling and Lemos, 2011; Eden, 2011).

However, crucially, research has shown a whole range of contextual and intrinsic factors affect adaptation governance, including: informal and formal institutional barriers; what the decision and policy goals are; the information's spatial and timescale resolution; level of skill required to utilise the information; and level of trust, among others (Cash et al, 2003; Lemos and Morehouse, 2005; Cash et al, 2006; Dilling, 2007a; McNie, 2007; Sarewitz and Pielke Jr, 2007; Hulme and Dessai, 2008b; Kirchhoff, 2010; Lemos and Rood, 2010; Dilling and Lemos, 2011; Eden, 2011). Therefore, in essence, the linear model oversimplifies the complexities within the science-policy interface.

Consequently, alternate models and relationships have been suggested that emphasise and recognise the need for stronger linkages between science and society, in order for science to more effectively assist stakeholders applying adaptation decisions. Though different in their details, "mode-2" (Nowotny et al, 2001; Lemos and Morehouse, 2005), "post-normal" (Funtowicz and Ravetz, 1993) or "use-inspired" (Stokes, 1997 cited in Dilling, 2007b) science all aim to improve the connection between supply and demand by being socially distributive, application-orientated, trans-disciplinary, and subject to multiple accountabilities by encouraging knowledge producers to consider the social, physical, institutional and

political context of decision-makers (Cash and Buizer, 2005; Dilling, 2007a; McNie, 2007; Sarewitz and Pielke Jr, 2007; NRC, 2009). The basic idea is that effective decision support emerges when the information decision-makers' need is identified and aligned alongside with what is feasible for science to deliver (NRC, 2009).

Similarly, the creation of 'boundary organisations' and 'boundary objects' between knowledge producers and decision-makers helps facilitate a better exchange and increases usability of science because they not only help to bridge the science-policy disconnect but also link science and policy across different levels (Guston, 1999; Cash, 2001). Therefore, proponents of these approaches commonly argue that the complexities of the science-policy interface are recognised and subsequently minimised because of the iteration and interaction between stakeholders creating the science and stakeholders writing the policies (Guston, 1999; Cash, 2001; Lemos and Morehouse, 2005; Kirchhoff, 2010; Dilling and Lemos, 2011).

Nonetheless, despite the principles and arguments for mode-2 science, doubt remains over the usability of information produced due to difficulties in addressing the contextual and intrinsic factors that affect adaptation governance and different actors perceiving the usefulness of scientific information differently (Lemos and Rood, 2010). In addition, it is suggested science has moved beyond the capabilities of societal understanding and implementation (McNie, 2007; Tribbia and Moser, 2008; Braun and Kropp, 2010), since more accurate science does not necessarily make decisions easier. Hence, it has become "a sociological truism today that a greater supply of knowledge will not ensure a greater degree of certainty in decision-making" (Kropp and Wagner, 2010, p. 813). Therefore, although the theory implies science produced in this manner will be more practical and usable for decision-makers, in practice it remains hard to distinguish what constitutes better (usable) science.

2.2 Knowledge system quality criteria for usable science

A number of researchers have suggested science for policy needs to be considered holistically as a knowledge system which consists of three quality criterion (Cash et al, 2003; Cash and Buizer, 2005; McNie, 2007). More specifically, for scientific information to be useful and usable, decision-makers must perceive it "to not only be *credible*, but also *salient* and *legitimate*" (Cash et al, 2003, p. 8086); where they simultaneously perceive the information's technical evidence and arguments to be scientifically sound, relevant to their needs, and produced (and distributed) in an unbiased transparent conduct that considered

among other factors potential opposing views, values and beliefs (Cash et al, 2003; Hulme and Dessai, 2008b; Munang et al, 2011).

In order for scientific information to exude these criteria, each criterion must consist of various distinctive characteristics decision-makers recognise. For instance, information is likely to be deemed credible if the science is accurate, valid, of high quality, supported by some form of peer-review, and funded from a recognisable or established institution(s). To ensure the information is legitimate, it must have been produced and disseminated in a transparent, open and observable way that is free from political suasion or bias. To be salient, information must appear context-sensitive and specific to the demands of a decision-maker across ecological, spatial, temporal and administrative scales. Therefore, by ensuring science for policy possesses these characteristics, decision-makers will perceive the information to be usable.

Significantly though, multiple stakeholders generally have different perceptions of what makes credible, legitimate and salient information (Cash et al, 2003; Lemos and Morehouse, 2005; Lemos and Rood, 2010; Dilling and Lemos, 2011). As a result, the criteria cannot simply be incorporated without case specific consideration of the user. Thus even by incorporating these criteria, producing information that is usable for a number of potential decision-makers remains difficult. Additional difficulties arise from two complex linkages between the criteria. Firstly if the science is perceived to be seriously lacking in any of the criteria, its likelihood of producing influential information falls significantly; and secondly due to tight tradeoffs amongst the criteria, efforts to enhance one succeed at the expense of the (an)other(s), undermining the information's overall influence (Cash et al, 2003; Cash and Buizer, 2005).

Nevertheless in spite of these difficulties, the knowledge system criteria is a good indicator to assess decision-makers' perspectives of what constitutes usable science because it considers the entire process (from inception to dissemination) of the scientific information in question. Indeed credibility can be used to assess stakeholders' perceptions of the quality of science underpinning the disseminated information; legitimacy can assess stakeholders' perceptions of the level of transparency and bias of the individuals and institutions involved in its development; while saliency directly assesses stakeholders' perceptions of its relevancy to their needs and requirements.

3. UK Climate Projections 2009

Climate change projections (or scenarios) are increasingly visible in national and international public policy debates. Based upon peer-reviewed science, projections provide quantitative or semi-quantitative descriptions of possible future climates that carry considerable authority. Importantly, when projections are utilised by decision-makers, projected changes depend on the emission scenario selected, the geographical region of concern and how far in the future is of interest (Hulme and Dessai, 2008b).

In the UK, the first Government funded suite of projections was published in 1991. Five generations later, the latest suite of projections, 'UKCP09' (released in June 2009), represents seven years of work by a consortium of organisations including Defra, UKCIP and MOHC. UKCP09, which provides projections of changes in climate based on a 1961-1990 baseline data, were "purposefully designed to meet the needs of a wide range of people who will want to assess potential impacts of the projected future climate and explore adaptation options to address those impacts" (UK Climate Projections, 2011b). To achieve this aim, UKCP09 consists of a wealth of climate information grouped together in a number of broad parameters, including: a briefing report; climate change land projections (e.g. variables of temperature and precipitation); marine and coastal projections (e.g. variables of storm surge and sea-level changes); observed trends in climate data; weather generator; and 11-member regional climate model output ensemble (Jenkins *et al*, 2009; Street *et al*, 2009; UKCIP, 2011a).

Notably, these parameters, collectively and individually, are highly sophisticated and complex in parts, and denote a change from predecessor projections. For example, for the first time, climate scenarios quantified uncertainties explicitly in a probabilistic fashion; the 25km (instead of 50km) grid squares provide greater spatial resolution, as do pre-defined aggregated areas which offer more specialised climate information for administrative regions, river basins and some marine regions. In addition, unlike earlier projections UKCP09's management process went to some length in attempting to incorporate decision-makers' suggestions (via a User Panel) alongside the scientific development, to ensure a wide range of opinions were considered, and thus produce the most comprehensive package of climate information.

Arguably, these changes produce various benefits that were previously unavailable. For instance, decision-makers can now assign probabilities to different future climate outcomes; they can reflect on the uncertainties of data in more detail; and UKCP09's User Interface allows data to be visualised and interrogated to produce maps and graphs or be downloaded as numerical outputs, thus providing specific extraction and manipulation of

data. However, like any suite of climate information various uncertainties exist (modelling uncertainty, natural climate variability and emissions uncertainty), resulting in a number of assumptions being made to run the models (for more information see Jenkins *et al*, 2009; Street *et al*, 2009). Furthermore using probabilistic projections is not without controversy, since the type of probability used, Bayesian, is not necessarily the type decision-makers are familiar with or want (Dessai and Hulme, 2004; Stainforth *et al*, 2007). Bayesian projections are often less favoured by decision-makers because of their difficulty in practical application which encourage a less robust decision-making approach (Smith et al, 2009; Arnell, 2011; Reeder and Ranger, 2011).

4. Methods

4.1 Assessing usability of UKCP09

In order to research the usability of UKCP09 the perceptions of key adaptation stakeholders (decision-makers, knowledge producers and knowledge translators) were collected over eight weeks between June and August 2011. These stakeholders were selected because they represented three distinct groups across a spectrum of actors that regularly interact with science for policy, and thus are likely to know of UKCP09. In this study, knowledge producers are individuals directly involved in developing or conducting academic research with UKCP09 (or predecessor projections); knowledge translators are individuals who represent boundary agents that provide specialist advice on a consultancy basis to organisations responsible for adaptation planning and policy-making; and decision-makers are individuals from organisations with adaptation responsibilities.

Data collection consisted of a mixed methods approach that combined a quantitative survey, semi-structured interviews and secondary data analysis of published 'Adaptation Reports' (see Defra 2011b).

4.2 Questionnaire survey

The survey (conducted online) used a mixture of open-ended, single and multi-fixed response, and agreement-scaling questions to explore decision-makers perceptions of UKCP09 and collect basic demographic data. For example, respondents were asked if they

had created an adaptation report, whether they had utilised UKCP09 for that report and why, and if they associated the terms credible, legitimate and salient with UKCP09.

130 decision-makers were emailed (Figure 4.1) with follow up emails after three and five weeks, and a direct call after week six. The survey universe was complied in two ways. 80 were selected from organisations Defra (2011c) had requested "to prepare reports on how they are assessing and acting on the risks and opportunities of a changing climate" due to the 'Adaptation Reporting Power' of the Climate Change Act 2008. An additional 50 were chosen to represent those sectors not requested by Defra to produce an adaptation report but whose functions (which have a public interest) are likely to be affected by changes in climate. Furthermore, they were selected on the size of the organisation and region they manage.

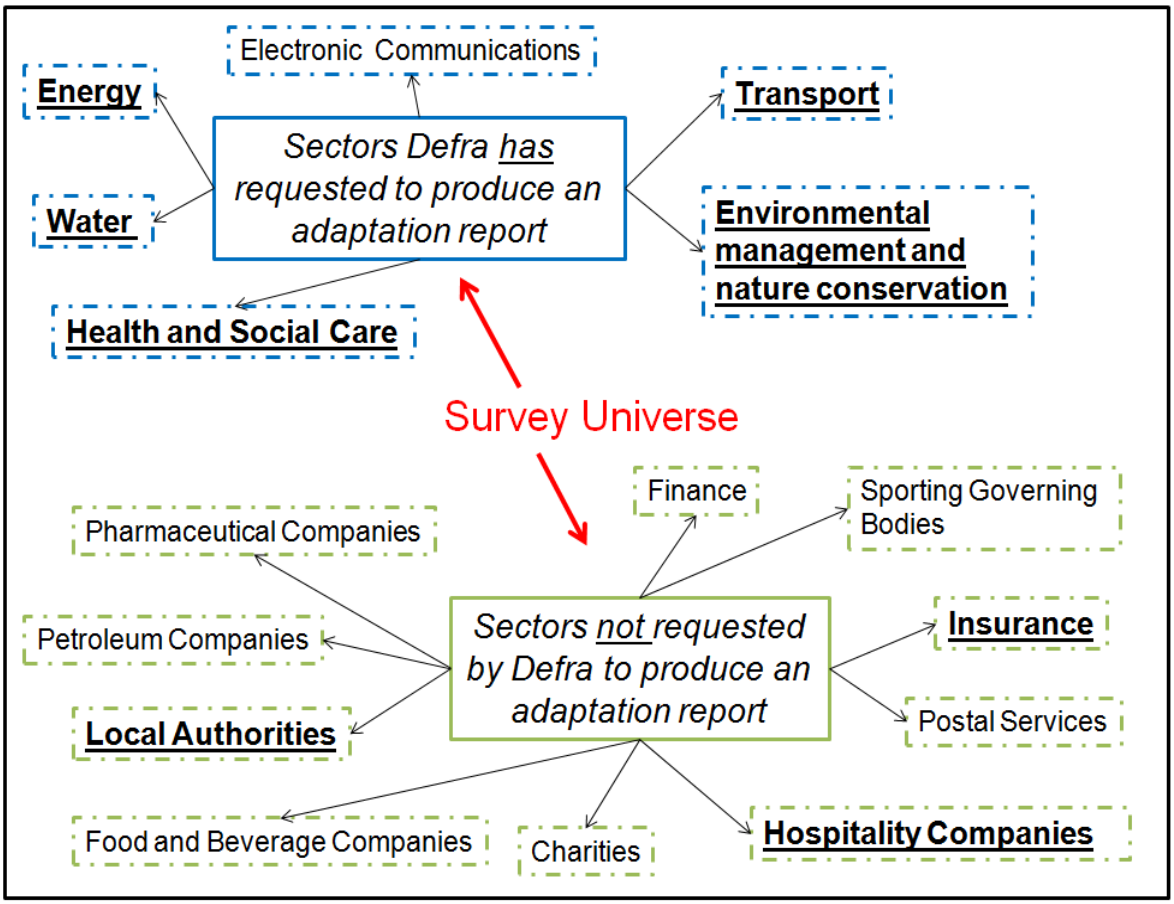

Figure 4.1: A diagram showing sectors' of organisations' approached to participate in the questionnaire survey. The survey universe consists of sectors' (organisations') that were Defra mandated and those non-Defra mandated to produce an adaptation report. Sectors underlined and highlighted in bold participated in the study.

A response rate of 25% (n=33/130) was received. Of the 33 respondents 24 had created or were creating an adaptation report, with nine of these employing consultants

(including individuals representing Jan Brooke Consulting, UKCIP, Met Office, and Academics) in some form. Consultants assisted in the formulation of the report, aided decision-makers to understanding the UKCP09 data set and how to use it, help critique decision-makers risk assessment tools, compile an inventory of climate change risks decision-makers should consider, to review the full report, to create specific impact scenarios arising from the projections, and to reduce workload on staff and save time.

Of the 24 decision-makers 21 utilised UKCP09 representing five sectors: Water (n=7), Transport (n=6), Local and Regional Authority (n=2), Environment (n=3), and Energy (n=3). These decision-makers were asked to select one reason ('It was the best option', 'Recommended to', 'No alternative', 'Other') for why they chose to utilise UKCP09 in their adaptation report. Responses indicated 10 of 21 surveyed decision-makers utilised UKCP09 because 'It was the best option', four were 'Recommended to' use it, two felt 'No alternative' existed, and five provided alternate reasons which were positive in nature; for example, 'UKCP09 is the most up-to-date sophisticated projections' and 'UKCP09 supplemented information previously developed'. Amongst these decision-makers, UKCP09 has a positive reputation and is perceived to be an important source of information; indeed, initial analysis of published Adaptation Reports indicates the majority utilised UKCP09 in their report. Analysis also highlighted several additional reasons for why UKCP09 was utilised, including: it represented an updated version of UKCIP02 (the previous generation of UK climate change scenarios published in 2002) with advancements in knowledge and information; it provides the tools to undertake quantitative options analysis; it is the most definitive evidence base on the UK's future climate; and it is perceived as a highly reliable data set.

In terms of the three non-users of UKCP09, unfortunately they did not provide direct reasons for why they did not utilise the projections however, one respondent noted that instead they used a combination of information sources consisting of the UKCIP Local Climate Impacts Profile (LCLIP), a self-administered media trawl and various local case studies from local officers.

4.3 Interviews

Semi-structured interviews were conducted with all stakeholder groups either face-to-face or by telephone. Interview questions were driven by the survey, aiming to expand on responses collected by soliciting more detail. For example, stakeholders were asked if they were familiar with science like UKCP09, whether they had extensively used UKCP09 (how,

why and what for), if they required expert help to utilise UKCP09, if they were aware of other sources (and had they used them), and whether communicating known sources of uncertainties and some information as Bayesian projections affected the usability of UKCP09.

Interviewees were identified in three ways. Decision-makers snowballed from the survey. 65 knowledge producers were identified from lists naming contributing individuals (whether as a developer, reviewer or a user panel member) to UKCP09s development on the UK Climate Projections (2011d) and UKCIP (2011b) websites, and from a web-based search (on Google Scholar) for individuals involved in research using previous or current UK Climate Projections. In addition, 12 knowledge translators were identified from a web-based search (on Google Scholar). All individuals were contacted initially via email, with follow up emails after two and four weeks (no direct follow up calls were undertaken). Table 4.1 illustrates our interview sample, including each interviewee's area of expertise, employer sector and relationship to UKCP09 (self-assessed).

Interviewee	Area of expertise	Employer sector	Relationship to UKCP09
Decision-maker A	Network modelling specialist	Water	Moderate user
Decision-maker B	Climate change co-ordinator	Environment	Low user
Decision-maker C	Facilities and strategy team specialist	Health and social care	Low user
Decision-maker D	Policy advisor on climate risk	Environment	Moderate user
Decision-maker E	Environment specialist	Water	Moderate user
Decision-maker F	Waste and carbon management	Water	Moderate user
Decision-maker G	Climate change advisor	Water	Moderate user
Decision-maker H	Regulatory compliance specialist	Energy	Low user
Decision-maker I	Natural sciences	Transport	Low user
Decision-maker J	Asset engineer and sustainability	Water	Moderate user
Decision-maker K	Environment officer	Transport	Moderate user
Knowledge producer A	Climate modelling	Higher education	Directly involved in development
Knowledge producer B	Climate modelling	Government related	Directly involved in development
Knowledge producer C	Marine physics and climate modelling	Research	Directly involved in development
Knowledge producer D	Advising decision-and-policy-making	Higher education	Related expert (used UKCP09)
Knowledge producer E	Climate change, flood and coastal risk management	Regulator	User panel and review group member
Knowledge producer F	Sea-level and land motion change	Higher education	Review group member
Knowledge producer G	Climate science communication advisor	Government related	Steering group member
Knowledge producer H	Climate change modelling	Regulator	User panel member
Knowledge producer I	Climate change adaptation	Higher education	Related expert (used UKCP09)
Knowledge producer J	Coastal management and sea level change	Higher education	Contributed to development
Knowledge producer K	Senior scientist	Government related	Steering group, Review group and User Panel member
Knowledge translator A	Sustainability advisor	Consultancy: engineering	User panel member
Knowledge translator B	Climate change advisor	Consultancy: engineering and environment	Provides advice to others
Knowledge translator C	Impacts and economic costs of climate change, and the costs and benefits of adaptation	Higher Education and Consultancy: climate change, environmental and economic policy advice	Provides advice to others
Knowledge translator D	Statistical analysis and science communication	Consultancy: climate adaptation scientist	Provides advice to others

Table 4.1: Summary of the interviewee participant population

4.4 Data analysis

Collected survey responses were initially entered into a spreadsheet and then into SPSS for cross-tabulation and further statistical analysis. Nominal and ordinal coding was performed to help quantify responses and identify patterns. Cross-tabulation between sectors was performed in order to draw comparisons between sectoral perceptions of UKCP09.

Interviews were taped and transcribed verbatim. Following transcription, content analysis was applied to identify response themes. The theme categorisation used was based

on the knowledge system criteria (credibility, legitimacy and saliency). Stakeholder groups were initially analysed on their own and then compared to the two other groups.

To ensure individual and group perception consistency, decision-makers' survey and interview responses were compared, then additionally compared to their relevant Adaptation Report on Defra's website (2011b) for further confirmation.

5. Results

5.1 Credibility and legitimacy

Responses from both the survey and interviews indicated that UKCP09 is perceived as credible and legitimate. For example, decision-makers were asked in the survey to choose how much they agreed ('Not at all', 'A little', 'Moderately', 'Quite a bit', 'Extremely', 'No opinion') with using the terms 'Credible' and 'Legitimate' to describe utilisation of UKCP09. Results indicate, primarily UKCP09 is described as 'Quite a bit' credible (62%) and legitimate (52%), whilst 23% and 33% chose to describe UKCP09 as 'Extremely' credible and legitimate, respectively.

In addition, it emerged that stakeholders perceived the two criteria to be overlapping concepts and difficult, in practice, to distinguish from one another. For example they were often cited interchangeable in expression (on purpose and by mistake), as shown by the following quotation, a decision-maker's perception on the open communication of uncertainties:

> *"I think it's more credible because it's a realistic and honest approach"* (Decision-maker B).

Decision-maker B denotes credibility through the use of 'realistic' (which is a synonym for credible) and legitimacy through the use of 'honest' which implies they perceived the process to be open due to the explicitly discussion of uncertainties. Therefore, while in theory credibility and legitimacy are distinct, in practice they are perceived to be so closely intertwined that the typology is hard to use.

Nevertheless, different stakeholder groups provided different reasons for why UKCP09 was credible and legitimate. Decision-makers tended to stress the importance of UKCP09 being government funded and nationally (and internationally) recognised.

> *It's essential that it's a national thing. It's credible that it's endorsed by those various different organisations and used uniformly. I think it's really key"* (Decision-maker B).

This suggests, with Defra and DECC the main funders for UKCP09, amongst decision-makers there is an innate assumption that the Government is not going to produce highly sensitive (and potentially controversial) information available for public use that is particularly vulnerable or prone to criticism related to a biased political agenda (Braun and Kropp, 2010; Kropp and Wagner, 2010). Hence due to the funders, decision-makers believed other information sources without government approval were not as credible and legitimate; as shown by the following quotation:

> *"Actually I don't see much point in getting another tool that doesn't have the UK Government stamp of approval on it"* (Decision-maker A).

This perception of government approval resulted in decision-makers considering UKCP09 to represent *'a common framework'* for all sectors to utilise when assessing future climate risks. This is because, as asserted below by Decision-maker A, it was perceived by utilising something that is nationally accepted (e.g. UKCP09), your results will be accepted and you will be seen as compliant by the regulator.

> *"...let's say were doing some kind of project that requires Environment Agency sign off and approval. If you're actually using a tool that isn't actually nationally recognised, then you have to go through this process or persuasion of what you've actually got is fit for the job. If you've got something that actually is nationally accepted, the results are accepted, processes of using it are accepted, then actually what it means is that from our perspective the processes go a lot smoother"* (Decision-maker A).

This implies UKCP09 was utilised to ensure regulatory approval was met. Therefore, the accuracy of the science is not as important for decision-makers as the fact that their reports will secure them whatever regulatory approvals might be needed. This sentiment is supported by the below quotation:

"Using UKCP09 also allows Defra and anyone else to compare plans across the water industry and other industry's plans if required" (Decision-maker J).

In contrast, knowledge producers and knowledge translators had a slightly different take on what made UKCP09 credible and legitimate. For them, this emerged from the incorporation of Bayesian probabilistic projections which were perceived to enhance scientific accuracy and validity. More specifically, they perceived Bayesian projections encourage uncertainties to be further explored if possible and/or allow uncertainties to be accommodated for within future plans. Indicating a belief that utilisation of UKCP09 will create a more realistic and thorough decision-making process because the decision-maker has to consider a variety of potential outcomes instead of one deterministic outcome. This perception is exemplified by the following response:

"I think it [Bayesian probabilistic projections] enhances credibility. Importantly, it makes people realise the inherent uncertainties and should lead to better planning" (Knowledge producer H).

Significantly, this difference between stakeholder groups (decision-makers to knowledge producers and knowledge translators) reasons for why they perceive UKCP09 to be credible and legitimate begins to raise wider implications for the knowledge system criteria. In particular it indicates that stakeholder's are likely to consider what makes UKCP09 usable for decision-making differently, an issue which has been raised in previous research (Cash *et al*, 2003; Lemos and Morehouse, 2005; Lemos and Rood, 2010; Dilling and Lemos, 2011). Furthermore, this points to some important underlying differences in the understandings of the applications of climate information and thus of the saliency of UKCP09 for decision-making.

5.2 Saliency

Unlike credibility and legitimacy, perception of saliency is less positive and certain amongst stakeholders. Decision-makers, in particular, were split in how they described UKCP09's saliency; 14% chose 'A little', 33% chose 'Moderately', 33% chose 'Quite a bit', 14% chose 'Extremely', and 6% had 'No opinion'. Notably this variation is also shown in a

sectoral comparison. Specifically, in terms of modal response, 42% of the Water sector felt UKCP09 was 'Extremely' salient, 67% of Energy and 100% of Environment perceived it was 'Quite a bit' salient, 83% of Transport perceived it was 'Moderately' salient, while Local Authority responses were split equally between 'A little' (50%) and 'Moderately' (50%).

When pressed further on the issue during interviews, decision-makers stressed UKCP09 provided irrelevant answers to the questions they asked because the information provided was largely indigestible for decision-making and too complex and rich in detail to interpret. The below quotation is typical of the views expressed by four decision-makers:

> *"...in terms of creating our adaptation report and adaptation strategy there was less using of UKCP's outputs and more using of the stuff that is there in the maps that is used for public consumption rather than any sort of raw data that comes from UKCP"* (Decision-maker F).

Therefore, instead of using the full technical capabilities of UKCP09 that so impressed knowledge producers', many decision-makers preferred simply to borrow from heavily digested summary reports that were less complex. This tendency can be demonstrated by analysis of the (published) Adaptation Reports. For example, Manchester Airport Group (2011) believed the inclusion of certain specific variables of temperature and precipitation data, such as relative humidity and cloud amount, would have introduced unnecessary complexity for their planning. Therefore, as Severn Trent Water Ltd. (2011, p. 48) put it, "the UKCP09 data and tools are so wide ranging it is difficult to know which is the best method / tool / dataset to use".

Additionally, analysis of Adaptation Reports highlighted, in spite of UKCP09 being perceived as invaluable in helping planning, it did not provide the specific information they directly required due to limitations in the projections predictions. For example, a number of Adaptation Reports (see National Grid gas, 2010; London Stansted, 2011; Port of Sheerness, 2011; and SP Energy Networks, 2011) commented that UKCP09 lacked useful information concerning the frequency and intensity of ice storms, wind (direction and speed), snow storms, lightening storms, heat waves and droughts. A view held even in light of the (November 2010) UKCIP published technical notes (which provided some advice on these variables) as decision-makers perceived data from these was not easy to extract. A few other examples include:

- Severn Trent Water Ltd. (2011, p. 39) stating they could not assess the impact of summer convective storm events on sewer systems because there are limitations in predicting the intensity and frequency of such events whilst using UKCP09;
- SP Generation (2011, p. 13) suggesting that the Weather Generator' usability is limited because it does not constitute "a profound extreme event analysis suitable to assess the change in likelihood of extreme events in the future";
- And, RWE Npower (2011, p. 16) concerns that estimations for the implications of the UKCP09 projections on the 'aquatic environment' are not available. Therefore, resulting in the overreliance on the autonomous (and resource consuming) implementation of supplementary models (such as a rainfall-runoff model).

Besides the lack of salience, these statements also point towards a perceived lack of credibility, because UKCP09 does not deal with the issues these organisations are interested in.

These findings lead us to suggest that the information of UKCP09 is one or two steps removed from what decision-makers want or need. This is unsurprising, given that UKCP09 is climate information and not the impact information some decision-makers would like. An issue directly mentioned by four decision-makers and exemplified by the following quotation:

> *"Within our risk assessments the information I need is not climate information it's environmental impact information"* (Decision-maker D).

Hence, given the comments above, arguably UKCP09 has a saliency gap due to the knowledge it can actually provide for decision-making. Notably this finding is consistent with emerging research from the sectors, in particular the water and building services industries (see Arnell, 2011; Mylona, 2012 respectively).

Why UKCP09 has a saliency (and not a credibility and legitimacy) gap can partly be attributed to the incorporation of Bayesian projections, which result in much greater complexity and information richness. Although many stakeholders perceive that the inclusion of such information enhances scientific credibility (abovementioned in Section 5.1), they perceived the information produced is difficult to integrate successfully into decision-making and moves the individual away from a decision. For example, knowledge producers and knowledge translators, who like the arguments of Dessai and Hulme (2004), Smith *et al*

(2009), Arnell (2011) and Reeder and Ranger (2011), believe decision-makers are familiar with a different type of probability that is less complex to interpret and apply. The below quotation is representative of this perception for 5 knowledge producers' and 2 knowledge translators':

> *"All the probabilistic estimates they did are all very difficult to interpret because there not probabilities in the way that a decision-making would use probabilities"* (Knowledge producer D).

Considering the above quotation and similar responses by other knowledge producers and knowledge translators, there is a perception within the scientific community that Bayesian projections place decision-makers into a decision-making arena with which they are somewhat unfamiliar. Therefore, by choosing a particular technique for uncertainty quantification, UKCP09 has inadvertently led decision-makers to particular decision-making frameworks, such as optimisation and risk assessment. Subsequently this demonstrates an ongoing disconnect in the science-policy interface between what scientists produce and what users want or require, creating wider challenges for end users. For example, the decision-making process becomes time consuming because Bayesian projections produce several outcomes which require additional evidence (or research) to determine which represents the best choice. The challenge is compounded by the fact that whoever undertakes the research is usually not the same individual that makes the decision; since typically the actual decision-maker is someone from senior management who does not understand the science in great detail (or not used to dealing with a probabilistic framework) and due to time constraints, wants one answer instead of several possible outcomes to choose from. Therefore, although decision-makers reflected that having a range of outcomes was useful in highlighting uncertainty, in reality they actually bemoaned how they could be used practically for decision-making.

> *"UKCIP02 gave you a figure, whereas UKCP09 uses this probabilistic approach which I think is a more realistic approach, but in itself trying to write those in a report to your management team is hard. You struggle sometimes with making decisions with that variability, but that's the reality, they [management] still want to know a figure"* (Decision-maker B).

Decision-maker B reaffirms the widespread perception amongst sampled stakeholder groups, that Bayesian projections reduce the capacity for decision-making. In addition, Decision-maker B iterates the view that senior management is unwilling to consider a range of possible outcomes when trying to make cost-effective adaptation strategy decisions. Therefore, although decisions made are perceived to be more robust and realistic, the actual decision-making process is considered to be harder and less engaging to decision-makers needs.

This highlights wider implications for the science-policy interface. Firstly, effective decision-making (for adaptation planning) is not only limited by the science available but also partly by subconscious barriers organisations have constructed through institutional self-governance. For example, traditional use and overreliance on deterministic information to make decisions has resulted in senior management's stubbornness to make decisions that have multiple potential outcomes because they are used to only having to consider one outcome. Significantly this finding supports the sentiments of Demeritt and Langdon (2004), Adger *et al* (2005), and Dilling and Lemos (2011) that the science-policy interface is severely impacted by an informal and formal institutional barrier. Secondly, perceptions indicate calls for flexibility in decision-making – which would permit adaptation strategies to be scaled up, or scaled back, as conditions dictate (Lemos and Morehouse, 2005; Reeder and Ranger, 2011) – have yet to be listened to nor subsequently implemented in practice. This implies decision-making is still being undertaken through a linear approach regardless of its negative perception within research spheres, and the promotion of alternate approaches (mode-2 science).

This leads us to consider the science of UKCP09, in particular the use of Bayesian projections, is not solely to blame for the perceived lack of saliency decision-makers (and other stakeholder groups) feel. This implies the individual's ability to interpret the data (from the Bayesian projections) and willingness to utilise new methods also affect perceived saliency. A quote from Decision-maker D supports this assessment, as they recognise the lack of ability some decision-makers have in utilising the information:

> *"I think the problem that many people have in terms of decisions-makers; they can't articulate a policy question in a way that makes it easy to interpret that information. ... There is a real gap between the way policy questions are framed and the way that scientists and experts need to articulate those questions to use something like [UK]CP09"* (Decision-maker D).

Notably then, this mismatch is not only dependent upon the type or style of information in UKCP09. According to these responses, *who* the user is has a major influence on how salient UKCP09 appears. More specifically, we found the user's familiarity in dealing with climate information and whether they had been scientifically trained affected how salient they perceived the projections to be and thus how able they were to utilise them. In fact when knowledge producers and knowledge translators reflected on their own (direct and indirect) use of UKCP09 and what made the projections usable to them, the majority (circa to 80% of combined sample) referred in some way to their scientific training, background and familiarity. Indeed, as the below quotation shows, Knowledge producer E recognised the value and advantage of being closely involved in its development because they gained a more detailed understanding:

> *"Yeah [it was difficult to interpret the information I used], though I've been involved with the background of UKCP09 for the last 5-6 years so I roughly understand what it's about. ... I think it's virtually impossible for somebody relatively new to pick it up and apply it"* (Knowledge producer E).

Subsequently, they naturally perceived that decision-makers who are familiar with climate information and are scientifically trained (e.g. underwent training from experts or educated to the level of PhD) would be able to utilise the projections more effectively.

> *"It's an enormous amount of information for somebody who is not normally dealing with that sort of thing allied with dealing with issues of understanding probability and all that kind of malarkey, you know it's quite indigestible if your coming in cold"* (Knowledge translator A).

Significantly three decision-makers acknowledged this perception in the above quotation, that having a scientific background, training or expertise was an advantage when utilising UKCP09.

> *"I think if you have a scientific background you are used to using this type of data or the methodologies. If you're not used to it, then it is harder"* (Decision-maker G).

Hence, our findings suggest saliency of UKCP09 is enhanced as a user's level of familiarity and scientific competence increases because as Decision-maker G referred, they are able to understand the data better. To a degree this is additionally supported by survey results as no mid-range decision-makers (stated they required medium detailed information) perceived UKCP09 to be 'Hard' to use unlike 33% of low-end decision-makers (stated they required low detailed information) that did. Therefore, implying the range of decision-makers able to utilise science effectively for policy is narrow, which has wider implications for the science-policy interface given that increasing numbers of decision-makers are using scientific information for purposes other than pure research (UKCIP, 2006; Gawith *et al*, 2009). A trend that is broadening the user community, causing diversity to replace narrowness.

6. Discussion

6.1 Interactions of the criteria and the implications for the science-policy interface

When the perception of each knowledge system criteria for UKCP09 is compared to its historical equivalent from its predecessor, UKCIP02, interesting implications emerge. For example, UKCP09 is perceived to be more credible than UKCIP02 because it characterises the underlying science through explicit discussion of the associated uncertainties which was not undertaken in UKCIP02 (Hulme and Dessai, 2008b). In terms of legitimacy, the inclusion of a wider range of organisations (or contributing agents) like UKCIP in the development and management of UKCP09 helped to enhance transparency and reduce the previously held perception that UKCIP02 was slightly biased due to the close relationships between the funding agents and researchers producing the science; where the relationship acted like a barrier of exclusivity preventing other institutions, research groups and models from contributing and reviewing the projections (Hulme and Dessai, 2008b). In contrast perception of saliency is largely unchanged, since according to Hulme and Dessai (2008b) and the findings in this paper, both UKCIP02 and UKCP09 are perceived to lack relevancy for certain decision-makers needs regardless of being constructed under the auspices of UKCIP. Consequently, the study implies over time the UK Climate Projections has improved its credibility and legitimacy, whereas saliency has remained the same.

Why UKCP09 is perceived to be credible and legitimate and not salient can be linked to the complex nature and difficultly in balancing the three knowledge system criteria effectively to produce usable science for decision and policy-making. It further emphasises

the tight tradeoffs Cash *et al* (2003) noted to exist between the criteria; where enhancements in one affect the ability of (an)other(s). For example, although stakeholders perceived that the incorporation of a technique (Bayesian projections) produced more credible and legitimate science (in UKCP09), the subsequent information disseminated is perceived to be less salient because of the projection type. With improvements in UKCP09's credibility apparently coming at the expense of saliency, this raises wider questions for the production of science for policy. For instance, how do you decide on which technique to use that satisfies all three criteria? Should more emphasis be placed on one criterion over another? And how do you reconcile the supply and demand of scientific information between knowledge producers and decision-makers?

However, tradeoffs are not the only implication to consider. The study additionally indicates perceived saliency is also largely affected by who the user is. Arguably UKCP09 is being used by a range of decision-makers more diverse in scientific and technical ability and information requirements than developers anticipated. Due to this explosion of users, saliency of information becomes a significant issue because diversity of users and uses widens the disconnect between what scientists develop and what users want (Lemos and Rood, 2010). Thus for many decision-makers the science may be too advanced or not salient enough for them to make sensible decisions (McNie, 2007; Sarewitz and Pielke, 2007; Tribbia and Moser, 2008), a problem recognised by the following quotation which is representative of 4 knowledge producers and 2 knowledge translators:

> *"If there people who need to know a little bit about what's going to happen, then I'd say yes definitely use it. If there people who actually wanted to do some data analysis with it and some modelling work I'd say yes you can use it but use some other sources as well"* (Knowledge producer D).

Knowledge producer D affirms the view that although the data set is varied, due to this new diversity of users and uses there is a lack of specific guidance on how to use the data for different types of risks, resulting in reduced usability and misuse of the information. This implies the science-policy interface is still lacking in the right level of support information Gawith *et al* (2009) called for. Therefore, despite Defra's intention of UKCP09 being developed with a range of *uses* in mind, in reality its usability is limited by who the *user* is.

This raises an interesting issue of how the generation and dissemination of scientific knowledge is creating inequalities amongst decision-makers, an implication which has been

observed elsewhere (see Lemos and Dilling, 2007), whereby the most vulnerable (to climate change) are unable to benefit from the science available because they are constrained by accessibility, communication issues and their own ability to interpret the information (because of their level of education and expertise). This presents wider dilemmas and questions for the science-policy interface, including: how do you decide on who finds the science usable and who does not? Where do you stop compromising? And how do you cater for all needs and levels?

Nonetheless, in regards to UKCP09, why there appears to be a more diverse set of decision-makers utilising the science can potentially be linked to a mismatch of expectations between what contributing scientists were developing and what Defra intended to receive from its investment. Given how much UKCP09 cost to develop, it is not unreasonable to assume Central Government stressed to Defra that they must make good on their investment. In their 'Statutory Guidance to Reporting Authorities' Defra (2009), although not directly stated, strongly imply that organisations (many of whom were reporting on adaptation measures officially for the first time) should consider utilising the projections (as a component of the methodology) to help assess the impacts of climate change to their functions. For example, under the heading "What evidence is available about the future climate?" Defra (2009, p. 8) only explicitly discusses UKCP09, with other pertinent information only briefly mentioned in a supporting capacity. Therefore, by Defra placing this indirect emphasis on utilising UKCP09 they inadvertently put pressure on decision-makers to utilise it when other sources of information may have been more relevant. One decision-maker whilst reflecting on others use of UKCP09 said:

> *"[UK]CP09 is not the first place for them to start, so they need someone to translate that into something more relevant for them"* (Decision-maker D).

While another went as far to say:

> *"...I think if we didn't make any reference to it then you would have to wonder why. I think therefore the reader would wonder why we haven't made reference to it and would probably think it's more carelessness on our part than a failing of UKCP09"* (Decision-maker F).

These quotations imply that amongst some decision-makers there is wariness in using UKCP09; suggesting UKCP09 is in danger of becoming a constant or 'rite of passage' that must be included when writing adaptation reports. Perhaps inadvertently, the government has created a perception amongst decision-makers that UKCP09 is the only 'game in town' when it comes to adaptation planning.

This raises several implications for the science-policy interface surface. Firstly, expectations between what is wanted as a return from an investment and what can be delivered from that investment needs to be managed more closely to ensure the subsequent science is used in the best means possible and be deemed usable. Secondly, if every decision-maker utilises the same information source the safety net created by diversity in information sources is removed because *if* the science turns out to be categorically incorrect everyone who utilised it will be affected; meaning in the case of the UK, the entire national infrastructure will be particularly vulnerable to changes in climate (cf. Hall 2007). This highlights the dangers of placing too much emphasis on using one scientific source of information as a standalone to support policy decisions, and the need to continually state that other sources must be used in conjunction with specialist information like UKCP09. These observations are consistent with an emerging literature that emphasises robust decision-making – predicated on identifying strategies immune to wide ranges of uncertainty – over a predict and optimise approach (Dessai *et al*, 2009; Lempert and Groves, 2010; Wilby and Dessai 2010).

7. Conclusion

Historically, UKCP09's predecessor projection's (UKCIP02) were perceived to be salient, though they lacked a degree of credibility and legitimacy (Hulme and Dessai, 2008b). Advances in scientific understanding and greater acknowledgement of uncertainty have helped improve the credibility and legitimacy of the climate projections. However, this has come at the expense of saliency for decision-makers because saliency is dependent upon both their ability to understand and interpret the science and also on what information they require.

Consequently, although UKCP09 is perceived by decision-makers to represent a common framework for assessing future climate changes because of its credibility and legitimacy, paradoxically, it is not actually a common framework for all sectors to utilise because UKCP09 lacks saliency for some decision-makers. This saliency disconnect is

caused by a recent explosion of users due to societal and regulatory pressures to plan for a changing climate.

Arguably, this suggests that national climate change projections/scenarios are no longer fit for purpose and are unable to cater for the full spectrum of users. To that end, focus should be placed on producing specific, tailor-made projections that contain high degrees of user input (in conjunction with expert knowledge) to ensure saliency is increased alongside credibility and legitimacy. As Gawith *et al* (2009) have noted it is not enough to simply make information available, there needs to be more user specific guidance and support for participants to attend some form of training before they utilise the information to avoid it from being misused and from being perceived unusable. Hence, boundary organisations like UKCIP need to be continually involved throughout the decision-making process.

One of the limitations of our study is the small number of stakeholders who participated. This makes it difficult to extrapolate wider conclusions for each stakeholder group's perception. It is likely that with a larger sample, greater variation in perception would emerge. For example, we would expect credibility to erode slight as we are aware of disagreements amongst the academic community, for example, one of the reviewers of UKCP09 was concerned that the results were "stretching the ability of current climate science" (Heffernan, 2009). Further in-depth, ethnographic work with a wide range of stakeholders is necessary to better understand how climate science is currently informing decision-making and how this process can be improved for greater societal benefits.

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