Rapid Climate Change UK: Towards An Institutional Theory of Adaptation

Background

This project built on the principal investigator's research (fellowship, 1998-2000; PhD studentship, 1995-1998) funded under the ESRC Global Environmental Change Programme. Work highlighted social capital as a resource for coping with environmental hazard, and through a comparative analysis of three communities demonstrated the importance of institutional factors in shaping capacity to adapt to unexpected environmental hazard. The project was also influenced by research by Denis Smith, who provided expertise from research on risk and crisis management within large public and private sector organisations. John Dearing, who developed scenarios for rapid climate change used in discussions of adaptation with stakeholders. The project research assistant had researched in systems theory applied to rural development in Wales, useful in identifying stakeholders, and in developing guidelines for mapping institutional constraints on adaptation.

Project shape and aims were influenced by the Environment and Human Behaviour, New Opportunities Programme (EHB), which asked projects to bring together existing knowledge. In response, the project reviewed, and synthesised, literatures on adaptation to climate change and environmental hazards, organisational theory and institutional economics. The aim was to move research from a focus on typologies of adaptation towards an understanding the factors influencing adaptive human behaviour. A further request of EHB was to examine rapid climate change (climate cooling). Thus this project examined human behaviour and adaptation to rapid climate change.

The theoretical literature on adaptation to climate change has placed most emphasis on individuals and households. This has left a gap in our understanding of the social mechanisms that shape the adaptive capacity and action of organisations (public, private and civil society). Filling this gap is important not only for the survival of the organisations in question but, perhaps more importantly, because of the influence of these organisations over the policy and incentive environment that shapes the adaptive capacity of other actors (businesses, households and individuals).

Work on adaptation to climate change and natural disasters offers typologies of adaptive responses and examinations of the mechanisms leading to the choice of particular adaptations, to which this project principally turned (e.g. Smit et al, 2000; Adger, 2001). Social adaptations can be reactive, concurrent or anticipatory, spontaneous or planned, they can be short-term and tactical or longer-term and strategic. The importance of socio-economic context is not only in determining access to the resources to undertake adaptation, but also in stimulating incidental adaptation to non-climatic stimuli (Pelling, 2002). From the natural disasters literature a number of categorisations exist for adaptations, for example: Burton et al. (1993), distinguish between behaviours that: prevent loss, tolerate loss, spread loss socially, temporally or spatially, change use and activity and change location. Carter et al. (1994), differentiate between intervention types: infrastructural, legal and legislative, institutional, administrative, organisational, regulatory, financial, research and development, market mechanisms and technological

change. Other authors discuss the ordering of adaptation, so it may be for example that short-term reactive technological adaptations are followed sequentially by long-term, strategic administrative reforms. Adaptive capacity can be specific when relating to a particular hazard (say a flood of particular severity) or generic allowing adaptation to a range of stressors (economic, political and social as well as environmental). It is important to define the subject whose adaptive capacity is under review (e.g. a family farm) as some elements of capacity (e.g. economic savings) can be constrained by institutional controls that form part of the adaptive capacity of higher-order units (e.g. land use regulation).

The project was grounded in a broad literature that has applied institutional economics to environmental management or economic development (e.g. O'Riordan and Jordan, 1999). Institutions were defined after North (1990), as rules, norms and strategies which shape individual and organisational behaviour. While being the rules that constrain behaviour, institutions were interpreted as being simultaneously reproduced or reinvented through rounds of human interaction (Aoki, 1998). A distinction was made between formal (legislation, formal work guidelines and responsibilities) and informal (cultural norms, concepts of politeness and appropriate behaviour) institutions (North, 1990). Building an understanding of the ways in which institutions mediate individual and organisational behaviour meant connecting institutional theory and adaptation theory with work from the organisational and management literatures. Warner (2003), for example notes the interaction of leadership personalities, rules of the game and historical opportunity in public agencies in the Netherlands and Bangladesh in providing spaces for innovation and adaptive policy change to mitigate flooding. Within the broad literature on organisations and management the project reviewed literatures on social learning and associated literatures on social capital and communities of practice (Wenger, 1999).

Objectives

This section summarises how each project aim was met. Following discussion on methods and results provide additional material.

1. To extend the theory of organisational adaptation

Theory was built from a review of existing literature on institutional economics, systems theory, organisational theory, social learning, social capital and the climate change and natural hazards literature on human adaptation to risk. Theoretical development has the potential to reach beyond the initial scope of the project by contributing to parallel research agendas concerning the communication of risk and the decentralisation of rural governance in the UK.

2. To generate guidelines to map the institutional constraints on adaptation

Key themes from the literature were distilled down to generate guidelines. This process required initial scoping reviews of the literature identified under Aim 1. From here connections between literatures were established. Literature on institutional economics provided a background to the search for guidelines, with more detailed emphasis placed

on social learning and social capital. Guidelines were drawn out of this review by the distillation of core themes.

3. To identify stakeholder views on the appropriateness of theoretical and methodological tools

Guidelines underwent an initial pilot in two workshop discussions. This led to the reinterpretation of guidelines as a series of diagrams (see Annex 1) which could more easily be used to stimulate discussion by decision-makers on the adaptability of their own responsibilities and those of their organisations to rapid climate change (or other stressors), and the influence of the organisation's formal management structure and informal culture on adaptive capacity and action. Diagrams underwent some further minor changes during their final application in semi-structured interviews with key informants.

4. To generate preliminary data on the adaptive capacity of the UK agricultural sector

As a pilot survey the study surface indicative constraints and opportunities for enhancing adaptive capacity from the perspectives of a small number of key informants engaged with the UK's agricultural sector. A hypothetical scenario of future rapid climate change and a range of analogues chosen by respondents, were used to explore relationships between institutions and adaptation together with. The need to ground truth theoretical deductions meant that the balance of discussions shifted more towards the analogues, where participants could reflect on real life experience, than with the hypothetical rapid climate change scenario. It became apparent that to narrowly focus on the agriculture sector opened only a partial analysis of adaptation in rural UK. The focus was consequently broadened to a view of participants' adaptation within the rural sector.

5. To identify future research questions

Future research questions derived from theoretical and empirical work and from discussion with research users are presented in the final section of this End of Project Report.

Methods

Theoretical Review and Synthesis

Starting points for the theoretical review reflected the research strengths of the project team. A first working paper was written to review literature on adaptation to climate change and environmental hazards, this identified a number of themes that were then explored through working papers on institutions, social learning and social capital. A shared interpretation of power as relational provided a common epistemological bridge between the theoretical literatures (e.g. Fox, 2000). Development of an integrated theoretical perspective also built on the small number of papers that had made connections between institutions, social capital and adaptation (e.g. Pelling, 2002), and social learning and social capital (e.g. Lesser and Prusak, 2000). The development of guidelines was undertaken through a synthesis working paper, key themes from which were reduced down to a number of diagrams (Annex 1) following discussion with stakeholders.

To prepare for empirical research and background on potential rapid climate change analogues a working paper on crisis in the UK rural sector was written.

Empirical Grounding of Theoretical Propositions
This section justifies deviation for proposed respondent sampling and then presents methods used in data collection and analysis.

The planned methodology included gathering data from national and regional scale actors in workshops and local actors though interviews. The final method deviated somewhat from this with data generated from national stakeholders in interviews, regional stakeholders in interviews and a workshop and local stakeholders in a workshop. Changes with national level actors followed an initial interview with a stakeholder in DEFRA where it became clear that individual semi-structured interviews would be a more appropriate approach. At the regional level interest generated from an initial workshop fed into a series of follow on interviews both with workshop participants and with new participants and the project expended to accommodate this interest. At the local level, deviation form the proposed methodology reflects the introduction of the project team to the Grasshoppers group, the members of which constituted an excellent resource for an initial scoping of the theoretically derived framework. Offers for follow up individual interviews were extended but not taken up by respondents who preferred to make additional contributions via email and in response to the workshop report that was sent to all participants for their verification and expansion. Discussions and visits with a second farmers group did not result in the opportunity to conduct a workshop.

Workshops fed into the building of summary diagrams (Annex 1) that were then used as a core tool in key informant interviews. Each workshop had approximately 20 participants who new each other well and interacted professionally. Three project team members attended a meeting at the Welsh Assembly and two attended a meeting with the Grasshoppers group, this facilitated note taking. Workshops were held in venues local to the participants. Workshops commenced with presentations by the research team on rapid climate change (see Annex 2 for a summary of the scenario used) and a typology of adaptation, participants were then asked to discuss how rapid climate change might affect their professional concerns. The defining characteristics of climate change as a stressor were isolated and from this analogues were developed from past experience (Foot-and-Mouth, Common Agricultural Policy, Fuel Crisis etc.). These analogues were then used to explore real life examples of institutions shaping individual and organisational behaviour and adaptation. Reports of workshops were presented to participants as an opportunity for feedback and to verify the research team's interpretation of personal views. Reports were placed on the project web site for public access and wider comment.

Interviews were semi-structured, conducted with individual respondents in their offices and typically lasted 2 hours. Rapid climate change was briefly discussed in order to generate analogues pertinent to each interviewee. A series of diagrams (Annex 1) based on research themes were then used to help direct interviewees' attention to particular conceptual relationships. The diagrams were refined during the interview process, and so

have changed in form slightly since their initial conception. The diagrams were meant to trigger conversation about issues rather than represent a fixed or correct view. Interview notes were written up and sent to respondents as an opportunity for feedback and to verify the research team's interpretation of personal views.

Data Analysis involved the collection of views around key themes derived from theoretical work (the principal aim of the empirical research being to verify or challenge theoretical findings), but there was scope for inductively generated themes to be incorporated as they emerged.

Results

Key Themes Emerging from the Literature Review

Key themes from the literature review are summarised below. Key words taken forward into the empirical work are underlined. The discussion should be read alongside the diagrams in Annex 1: Figure 1 shows adaptive capacity as linked to social context and learning, Figure 2, unpacks social context.

In Annex 1, social context is used to identify the set of official and informal social relationships in which any one actor is embedded. It is structured by institutions that guide interaction within and between communities and networks (these can be made from official or informal relationships). Social context is represented as a vehicle through which an actor can access capacity. Learning is represented as the process through which capacity is evaluated as threats to the individual's goals change over time. Learning is presented as contributing to adaptive action in two further ways. First, when actors learn that learning is a beneficial tool in building adaptation (deutero learning). Second, when reflection leads to a distinction between learning how to do something better (single loop learning), recognising that aims or practices need adapting to protect some more fundamental objective (double loop learning). An additional form of adaptation represented in Figure 1 is recognised when an actor reorganises those elements of adaptive capacity to be brought to an adaptive action. Adaptation also takes place when an individual acts to make some change in the social context in which she/he is embedded. This can lead to a realignment of the institutional architecture and open or close spaces for future adaptive action. Finally the individual can make a direct intervention in their environment - a material adaptation. To date material adaptation has received most attention. An argument coming from this review is that such adaptations are only one surface expression of adaptation, and that understanding adaptive behaviour requires a deeper engagement with the actions and processes identified above and elaborated on below.

Adaptive capacity is a bundle of assets and entitlements that can be marshalled in response to a perceived threat. The translation of adaptive capacity into adaptive action is mediated by intervening institutions and competing demands on resources.

Institutions are seen as the rules of the game. The ability of individuals to negotiate institutions can open opportunities for institutional modification. This is important because it can alter flows of information and resources consequently changing adaptive

actions. Understanding how institutions might change requires an analysis of the power that flows through relationships and of the influence of structural forces on institutional fixity.

Learning is defined as changes in capacity to act arising through experience. It was used as a lens to understand how institutions and organisations evolve and interact. Because of the importance of social relationships in building, maintaining and operating adaptive capacity, a key research question emerging from the literature was how different social spaces enabled or constrained learning and communication. In particular the relative importance of formal and informal spaces and the interactions between them was flagged. It was hypothesised that the ability to respond to uncertainty, to negotiate and reassign resources and to undertake institutional modification lay at the boundary between the formal and informal, within spaces where there is enough order to act effectively, but enough space to change quickly. While less managed spaces are almost by definition hidden from management, understanding how they give rise to learning and communication is important. Their theoretical role in providing opportunities for adaptation could inform policy to enhance their positive contribution.

Less managed or informal spaces have been termed the shadow system: the system of tacit and informal relationships that permeate organisational life. Shadow systems can be an asset for organisational effectiveness and an important source of adaptive capacity. They can also be used negatively to subvert or control behaviour within organisations and to prevent change. Understanding adaptive capacity will require an analysis of the relationships between shadow systems and officially sanctioned institutions and behaviour.

Drawing on literatures of social capital and social learning allowed theory to build connections between the shadow and formal systems. Institutional architecture is used to describe the mix of communities also termed communities of practice identified by shared values and identity, and networks indicating relationships that straddle the boundaries of communities of practice where members may not identify with more than a small number of others. The distinction between communities and networks is often mute but the analytical categories were preserved for empirical testing. Both communities and networks are supported by trust built out of shared cultures that give structure to informal space and points of contact with the formal system. It was hypothesised that unpacking the institutional architecture can be a useful analytical approach for understanding the shaping of adaptive capacity and action in organisations and regimes.

A Consolidation of Interview and Workshop Findings

Responding to rapid climate change

There was a good awareness of the need to adapt practices and policy in the light of climate change. But some disquiet about the uncertainty that surrounds climate scenarios, especially how to respond to low likelihood, high impact scenarios like rapid climate change which offer a reversal of the climate warming trends that are already being prepared for mentally and institutionalised through policy and guidance.

Respondents acknowledged distinctions between reactive and proactive adaptation and specific and generic adaptive capacity, but felt there was a lack of decision-support tools to help make planning choices. Risk management tools required levels of data input that were not available for uncertain future risks. Horizon scanning within DEFRA was an important attempt to respond to this gap with work essentially undertaking futures research. It was felt that horizon scanning would be an important avenue for the institutionalisation of rapid climate change as a stressor to the UK policy system and therefore an important component shaping adaptive capacity. The challenge for horizon scanning was to develop and support the practices that would allow individuals to influence the course of public policy and decision-making in the face of competing claims on the attention of policymakers. This implies that as well as economic and knowledge bases, relationships and opportunities for communication and coordination across organisational boundaries (between public, private and charity sectors and across scaled levels of governance) were considered important resources for adaptive capacity to rapid climate change.

The interaction between potential adaptations and existing institutions was expressed as a barrier to change with examples from nature conservation and food production. This pointed to the important role of institutional modification (for example through internal meetings in DEFRA on rapid climate change, or cross-departmental seminars on climate change in the Welsh Assembly) as a precursor to material proactive adaptations.

Institutions and adaptation

A central claim arising from the theoretical review was that institutions matter in giving shape and form to adaptive capacity and action. Respondents provided examples of institutions operating as formal rules and guidance influencing the procedures and routines, roles and responsibilities, records and categories, aims and objectives of work during periods of stress analogous to that expected from rapid climate change.

Institutions were perceived as playing different roles depending on the viewpoint of an actor and as having a negotiated quality. This meant that institutions could be re-negotiated over time as different individual and organisational actors become involved and as priorities change. Climate change caused one respondent to reflect on the possibility of institutions offering 'a more sophisticated mechanism' for negotiating human behaviour than regulation.

Power to change institutional arrangements was not found to be evenly distributed amongst actors, with the direction of resource flows in relationships affecting the balance of power and use of institutions in those relationships. This imbalance was expressed most keenly when individuals felt a tension between their personal and/or professional agenda and the need to interact with institutions that had been determined by other actors (at times other organisations) and where the costs in time and energy of renegotiating or circumventing these institutions was high. But respondents also valued the capacity of institutions to enable coordinated behaviour and to provide a repository for knowledge and (what individual's viewed as) effective practice during past periods of stress. Coordinated behaviour was associated with formally constituted teams, groups or inter-

organisational collaboration but also with informal groups of actors shaped by informal institutions. The interlocking nature of collaborative action enacted in and through formal and informal institutions and collectives (organisations, departments, groups) was frequently identified by respondents.

Learning and adaptation

Learning and communication were constant themes throughout the interviews and their relationships to adaptive capacity with respect to rapid climate change and its analogues were described in many different ways. Empirical evidence was generated to support the theoretical claim for learning to be associated with adaptive capacity and action. There were examples where learning was fostered by organisational life and where the outcomes of learning were formalised or remained as part of the informal knowledge circuit of a group or organisation.

One respondent warned of the danger of actors uncritically accepting lessons from experience without probing their relevance to new situations. Good communication skills and institutions that can facilitate the development and application of communication were sited as important resources when faced with uncertainty, for intra-organisational learning but also for learning from and influencing behaviour within the wider public. There was some discussion on the limits to transparency and the responsibility of public agencies not to overwhelm or unnecessarily alarm the public, some suggested that flagging rapid climate change as cooling could undermine public trust in science.

Communication required skills such as knowing who to communicate with, where to find them and how to communicate effectively. Communication was mediated by conventions that created barriers and opportunities for learning. The appropriate combination of learning and communication strategies available to actors was shaped by the cultural characteristics of the organisational setting producing a knowledge culture for an organisation. Examining the knowledge culture of organisations provided much evidence to support the theoretical proposition that informal and tacit channels are at least as important for knowledge building as formal and explicit pathways.

Adaptation and the shadow system

Respondents identified shadow systems and acknowledged that the informal is an essential part of organisational life. An exception was the view of a high level civil servant in central government who stated that 'a civil servant has but one public persona, that of the representative of his minister'. This suggests that organisational setting and role influence the relative emphasis placed on formal and informal communication by individuals.

The character of shadow systems were recognised as contributing to an organisation's capacity to act. For example, where individual initiative was incentivised this opened up a major resource for the organisation for learning and adapting to a changing environment. Respondents saw tension between the need in public life for transparency, the rigour of formal organisational structures and institutions to reduce corruption and nepotism, and the informal flexibility offered by shadow systems. Organisational cultures

that became too rigid benefited less from informal spaces and built conflict between personal and organisational expectations. For formal management, accommodating informal space was acknowledged as a challenge, not least because informal space was often resistant to management effort. For some the best compromise was to recognise the role of the informal and to accept a degree of imprecision in management, trusting individuals to work around the systems where required. A more positive strategy may be to find ways to report on the shadow system and to incentivise individuals to use their skills in creating and maintaining informal relationships for the corporate good. Underlying this was the identified need to foster individuals with competencies relevant to navigating the shadow system. Interviewees produced a range of examples of their capacity for skilled informal interaction. The question arose: where do these skills come from? Prior experience seemed to be an important resource with motivated individuals experiencing the satisfaction of enhanced effectiveness in meeting their formal goals.

The shadow system was not experienced as an unquestioned public good. Shadow systems were also identified as a source of social exclusion and vehicle for mistaken learning.

The institutional architecture of adaptation

Many communities of practice, where members held common interests and values, were identified. Community boundaries did not necessarily reproduce those of the formal organisational contexts in which they occurred. Thus communities tended to arise through mutual engagement rather than management fait, and were very much part of the shadow system - although formal management had on occasion provided space for them to grow. From the individual's perspective, communities could be a significant resource, opening up opportunities for adaptive action as shared interests and similar worldviews facilitated learning and the negotiating of change.

Networks were also observed bridging different communities and aiding the communication and transplanting of new ideas and information, thus providing opportunities for building adaptive capacity and action. They were more flexible than communities and associated with transitory collective action such as reactive adaptation to a specific environmental hazard (e.g Foot-and-Mouth).

It may be that operating in a network required individuals to have a different skill set to operating in a community. Some management effort had been expended on formalising networks, but this had met with mixed results, at worst ending in a paper exercise and discontent. Respondents claimed that both communities and networks were founded in relationships of trust, in communities this arose from shared interest, in networks enough to negotiate a mutual interest. Trust was identified with known individuals but was also conferred to unknown individuals by membership of known communities of practice or (less frequently) formal organisation. Trust was important in building adaptive capacity and action because it enabled social action and decreased the amount of effort involved in maintaining communities and networks. Evidence suggested that neither communities nor networks were fixed categories, but that institutions and sets of social relationships changed over time and were experienced differently by different individuals.

Activities

Programme Activities

Pelling, M and High C Learning to change? Learning to adapt to climate uncertainty, Research Users Workshop, Policy Studies Institute (PSI), 23 June 2004

Pelling, M, High, Dearing, J, Smith, D Rapid climate change UK: towards an institutional theory of adaptation, Final Programme Workshop, PSI, 20-21 May 2004.

Pelling, M., High, C Institutional theory and societal adaptation. ESRC inter-programme workshop: theoretical approaches to policy change and human behaviour, PSI, 1 October 2003.

Pelling, M. What are Institutions? First Programme Workshop, PSI, 11 February 2003.

Outputs

Papers

Pelling, M and High, C Understanding adaptation: what can social capital offer assessments of adaptive capacity, *Global Environmental Change A* (in press)

Pelling, M., High, C., Dearing, J., Smith, D. It's the relationships that matter: social learning and adaptation to climate change in organisations. *Environment and Planning A* (draft).

High, C. & Pelling M (2004) Social learning and the shadow system - The institutional architecture of adaptation in the UK rural sector, *Sociologia Ruralis* (draft).

Conference papers

High C, Pelling M, Rengasamy, S. Local agency, adaptation and the shadow system: the institutional architecture of social learning in rural areas of India and the UK. XI World Congress on Rural Sociology, Trondheim, 25-30 July 2004.

Pelling, M and High C Waganegan Exploring the relational space of adaptation, Challenges of Complexity in Coping with Climate-related Disasters, Wageningen Disaster Studies, Wageningen University, The Netherlands. 14-15 June, 2004.

Pelling, M. Discussion convenor and raporter ‘Communities and Vulnerability Assessment'. International Workshop on Social Vulnerability and Capacity Analysis, International Federation of the Red Cross and Red Crescent, Geneva, 25-26 May, 2004.

Pelling, M Social capital, hazards and adaptation strategies for the vulnerable, Justice in Adaptation to Climate Change, Tyndall Centre, University of East Anglia, 7-9 September 2003.

Other dissemination
The project website www.rcc.rures, the ESRC Data Archive and EHB research briefs.

Impacts
None at the time of writing.

Future Research Priorities
Empirical case studies are needed to more clearly understand the interaction of social capital and social learning in shaping the institutional architecture that directs organisational adaptation.

How can knowledge of the mechanisms shaping adaptation (social learning, institutional architecture and communication) best be marshalled to help decision-makers support adaptation to climate change set against competing demands of social, economic and political risk, and particularly when they need to communicate risk associated with counterintuitive or contradictory climate change scenarios?

How might supporting adaptation in organisations and regimes through the shadow system impact on capacities to meet the demands of transparency, accountability, efficiency and equity of outcome?

What tools can assist decision-makers in moving from risk management to living with uncertainty?

What tools can enhance the positive contribution of the shadow system to managing uncertainty?

In the UK, there are a lack of individuals and organisations that can generate adaptation through crossing organisational and community boundaries. How might the educational system and professional practice best meet this need?

If the need for greater informal and interpersonal interaction to build adaptive capacity is extended what are the implications for national and international policy on social development?

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Word length: 5000

ANNEX 1

Figure 1: Learning and Adaptation

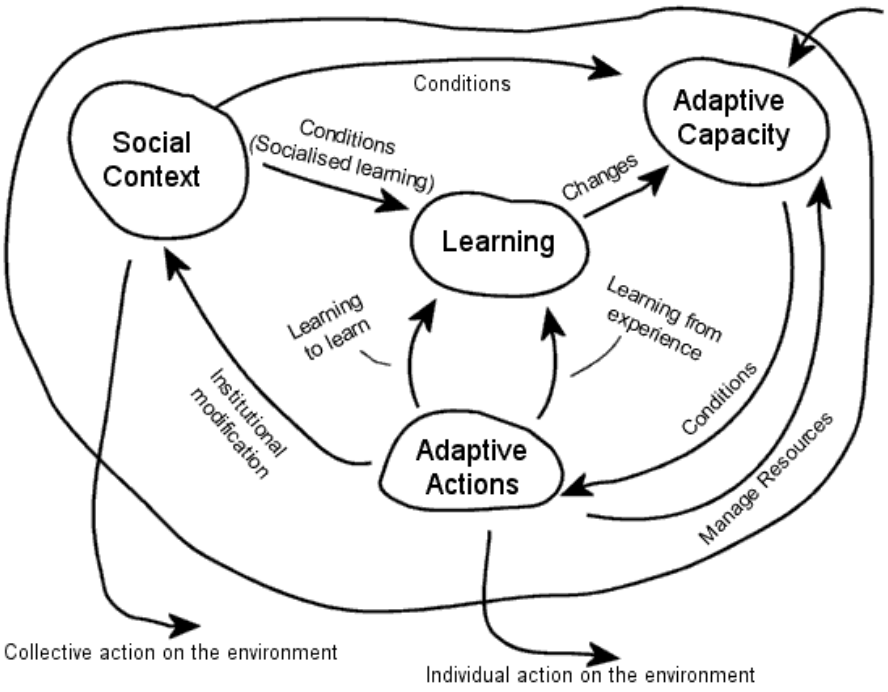
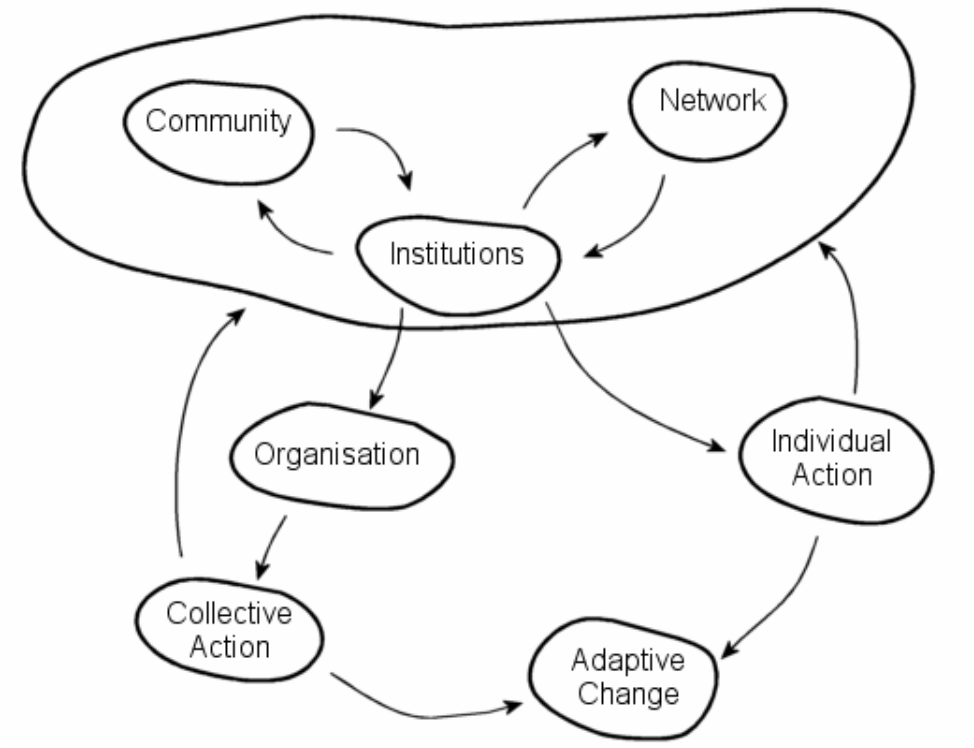


Figure 2: Social Context



ANNEX 2

Summary of Rapid Climate Change Scenario Presented to Respondents

Mainstream Scenario: Welsh climate in the 21st century (UKCIP98 predictions for 2080 – 250km x 250 km grid size)

- greater warmth all year round by 1.1-2.9 ^{o}C
- more precipitation in winter by 7-24 %
- less precipitation in summer by 7-14 %
- greater annual precipitation by 2-9 %
- a rise of sea level of 18-79 cm
- a higher mean windspeed by 1-4 %
- more evapotranspiration by 13-27 %
- more variability from year to year the number of extreme years will increase
- more frequent and more rain in violent storms intense storms
- more drought years by 10 %
- more very severe gales by 10 %

Source: Wales - Changing climate, Challenging choices, Summary report February 2000. The National Assembly for Wales

Cooling scenarios for Wales/Central England:

'Reasonable' mid-21st century scenario – a 2^{o}C rise in mean temperature followed by a ~4^{o}C cooling.

	max temp	mean temp	min temp
modern (Cardiff)	16	10	4
future pre-shut down	18	12	6
future cooling	14	8	2

- Still believed to be low probability, high impact in next 100 yr – but THC (thermo-haline circulation) is weakening.
- Future pre-shut down scenario similar to SW France.
- Cooling scenario similar to N. Scotland/S. Norway.
- The above *mean* cooling scenario is as cold as the coldest *single year* in 17th C Little Ice Age.
- Could take place within 10 years after shutdown.
- Probably a more disproportional temperature reduction in winter – i.e stronger seasonality – with more ice and snow days.
- Reduction in growing season
- Dislocation of sectors in more frequent exceptionally cold years (eg. 1963 winter becomes a one in seven occurrence)

Sources: Wood, R.A et al (2003). *Phil. Trans. Roy Soc. Lond. A*., 361, 1961-1975; BBC Horizon, **The Big Chill**, 2003; www.worldclimate.com