

Dynamic Systems and the Challenge of Sustainability

STEPS Working Paper 1



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CONTENTS

1. Introduction	1
2. Why dynamics?	2
3. Challenges to equilibrium thinking: new sciences for sustainability?	9
The science of complexity	10
New perspectives in ecology	12
Dynamic social and technical systems in industrial contexts	15
Policies, organisations and management responses in dynamic settings	20
Towards dynamic systems approaches in development	24
4. Pathways to sustainability: responding to dynamic contexts	29
5. The reflexive turn: towards a heuristic approach	35
6. Conclusion	42
References	46

LIST OF FIGURES

Figure 1: Understanding a complex system: first steps to an analytical heuristic	36
Figure 2: Dynamic system properties – across time (temporality) and origin (provenance)	39
Figure 3: Sustainability and four necessary but individually insufficient properties	40
Figure 4: Approaches to understanding sustainability: a very tentative schema	43

1. INTRODUCTION

Dynamism, uncertainty and complexity dominate today's world. Of course many papers open with such a statement: we know intuitively that dynamics are central to understanding complex, interacting systems – we must negotiate these every day. No-one can deny the complexity of most developing world agricultural systems or the interactions between livelihoods and health and disease or the multi-level uncertainties arising in water management. At one level, then, issues of complex dynamics appear to be widely recognised. Yet many policy interventions ignore this understanding, and so often fail. What is often missing is a rigorous and systematic approach to addressing these issues, one that encompasses an understanding of complex system dynamics and provides a useable guide to action. This paper, by a team at the newly established STEPS Centre at Sussex, is our first attempt to address this challenge.

The paper aims to explore different ways of thinking about dynamic systems¹ and to come up with an approach to guide further research which can reflect on diverse pathways to sustainability in complex, dynamic contexts. The first section explores why attention to dynamics is important. The paper then moves on to review briefly a range of different approaches that explicitly incorporate dynamics thinking, addressing in turn the science of complexity, ecological systems, industrial socio-technical systems and, finally, policy, organisational and management responses. This allows for a reflection on the diverse literatures on dynamic systems and a highlighting of elements which are important, and also those that are often missing. These literatures are in turn related to wider theoretical and definitional debates about the much-discussed concept of sustainability. We argue that, if a normative-political understanding of sustainability is adopted, then this forces us to address questions of dynamics in particular ways. The final section takes this forward with the presentation of a simple heuristic framework for addressing dynamic contexts in debates about sustainable

¹ By dynamic systems we mean ones characterised by complexity, non-linearity and often non-equilibrium patterns exhibiting high levels of uncertainty in system properties. 'Dynamics' refers to the patterns of complexity, interaction (and associated pathways) observed in the behaviour over time of social, technological and environmental systems.

development. This highlights three things: the need to address diverse framings of both system structure and function, the need to assess trade-offs between system properties that underlie attempts to achieve sustainability and the need to be continuously reflexive about the diverse options implied.

2. WHY DYNAMICS?

In exploring pathways to sustainability in the domains of agriculture and food, health and disease, water and sanitation - and their intersections - the STEPS Centre is interested in the interactions of biological/ecological and social/economic/political systems in the developing world, and the mediating role of technology in altering and being altered by natural and social-political systems. Taking such interactions seriously, we argue, is key to understanding, governing and designing pathways to sustainability that tackle poverty, inequality, social injustice and environmental degradation.

But to meet such high aims, we must take into account the multi-scale, complex dynamic nature of change across systems. There are plenty of statistics to show that there are accelerated rates of change in the world today. Companion papers on Agriculture, Health and Water resources highlight these, for example (STEPS Working Papers 4, 5 and 6). In natural systems, the impacts of climate change, land use shifts, hydrological pressures and pollution, for instance, are well documented. They link with changes in demographic pressures, disease incidence and technological advance, driven by changing patterns of mobility – people, microbes, ideas and technologies – and globalised economic change, as some areas of the world transform, while others remain in deep poverty. But we have to go beyond evocative descriptions of such change to understand the underlying patterns and processes at play. What are the rates of change of different elements of socio-ecological systems in different places? How do these interact? Over what scales? Addressing such questions of system dynamics is critical to contemporary policymaking and intervention strategies for sustainability, but is so often missed.

However, it is not as if an appreciation of dynamic systems is a new phenomenon. As ecologists have long described, non-linear interactions in very simple systems can result in highly dynamic patterns over time (May 1976, 1981). In recent years, research ranging from the study of economic change to sub-cellular gene-protein functions has revealed that dynamic systems – character-

ised by complexity and uncertainty – are the norm, rather than the exception. For example, at the macro level, an examination of the histories of macro-economies shows patterns which are much more effectively explained by models emphasising non-equilibrium, sometimes chaotic, dynamics, rather than conventional linear, general equilibrium approaches (cf. Puu, 1993). At the other end of the scale of enquiry, molecular biology increasingly demonstrates how genes do not simply map onto function in a neat, linear way as perhaps hoped in the high-profile genome mapping projects of the recent past. Post-genomic biology reveals how cross-genome interactions result in different pathways to expression depending on genome ecology and context (cf. Brookfield, 2005; Auerbach et al, 2002; Kellam, 2001).

Thus wherever one looks – in biological, social, economic or political systems, and particularly in their interactions - complex dynamics are important, and indeed have been so forever. Yet dynamics – both old and new – have often been ignored in conventional approaches to development. Why is this? A number of reasons can be identified.

First, approaches which we now recognise as disciplines usually start with a descriptive phase, where detailed observation and basic categorisation dominates over the modelling of generalisable patterns and regularities. Thus, for example, modern biology was preceded by a natural history approach that only with time gave rise to theories of natural selection and evolution or ecological systems and population biology. In some disciplinary areas – and biology is a good example – such generalised models and aggregate statistics are critiqued, finessed and elaborated, and complex dynamics become part of the disciplinary terrain. In recent years this has been massively enhanced by the capacity for sophisticated modelling work due to exponentially increasing computing power. In other disciplinary areas, however - and particularly those associated with applied policy advice - the simple, generalised, often equilibrium-based models, and aggregative statistical approaches remain resistant to such developments, as they become locked in with particular institutional and policy frameworks and associated professionalised practices. In the context of development, the applied sciences of range management, forestry and agriculture, for example, have been dominated by such equilibrium thinking, ignoring complex dynamics, despite the fact that in the wider science of ecology, for example, such ideas have become mainstream. In applied policy arenas, then, the last century has seen the emergence of certain ways of thinking which has defined 'good' science (both social and natural) and so guided policy thinking and intervention. Such thinking is often rooted in standard equilibrium thinking, where the practices of modellers and statisticians is often seen to defer a treatment of complexity, uncertainty and variability in favour of a focus on what are assumed to be

underlying aggregative, equilibrium patterns. Thus in economics, the macro-economic techniques of general equilibrium modelling have been the sine qua non of economic planning for development (cf. Starr, 1997). In the same way, epidemiological models of disease transmission, based on often highly simplified understandings of interactions between disease organisms, hosts and the wider ecology have guided many public health interventions (cf. Gerstman, 2006; Rothman, 2002). Clearly, such analyses are only one part of a wider array of methodologies and approaches within these very broad disciplinary areas, and many professional economists, ecologists, engineers and epidemiologists are exploring non-equilibrium perspectives that grapple with complex, dynamic systems. The point, however, is that in the application of ideas in the practice of development and policy more broadly it is often the more simple, equilibrium perspectives that hold sway, very often reinforcing professional biases, funding streams and disciplinary hierarchies in favour of such approaches.

A focus on equilibrium perspectives of course echoes much longer, deep-rooted cultural understandings in the west about the relationships between people and nature. The somehow elemental, natural 'balance of nature' has become so deeply accepted that it guides both public discourse and policy thinking, informing in turn the way academic debates are framed². Notions of balance or equilibrium in nature have a long tradition in western thought, traceable to Greek, medieval Christian and eighteenth century rationalist ideas (Worster 1977, 1993 a,b). Ecology, a term first coined by Haeckel in 1866 (Goodland 1975), not surprisingly drew on such concepts as a way of explaining the structure and functioning of the natural world. George Perkins Marsh in 1864 (Marsh 1965) argued that:

'Nature, left undisturbed, so fashions her territory as to give it almost unchanging permanence of form, outline and proportion, except when shattered by geological convulsions; and in these comparatively rare cases of derangement, she sets herself at once to repair the superficial damage, and to restore, as nearly as practicable, the former aspect of her dominion'.

This tradition of equilibrium thinking can be traced to the present in much popular environmentalist discourse, as well as more academic strands of social science thought. Yet the debate in ecology that disputes this view has also spanned the last 75 years. Charles Elton in his famous textbook of 1930 noted: "The balance of nature does not exist and perhaps never has existed" (Elton 1930). Connell

² This section draws on Scoones (1999)

and Sousa (1983) came to a similar conclusion 50 years later: “If a balance of nature exists, it has proved exceedingly difficult to demonstrate”. But despite such commentaries, the science of ecology over much of this century has been built on equilibrium notions, ones that assume stasis, homeostatic regulation, density dependence and stable equilibrium points or cycles.

Such embedded styles of thinking have had profound influences on the way contemporary debates have been constructed around discourses of conservation, preservation and maintaining balance. Divergences from what is assumed to be the norm are seen as necessarily negative, and in need of rectification; thus ignoring the potential alternative interpretations that systems are not ‘naturally’ in equilibrium at all, and shifts between stable states or continuous variability are in fact the norm around which responses must be constructed.

With neo-classical economics by far the most dominant influence in the development field, a long-running resistance to addressing the dynamics of ‘real markets’ can be identified. From the classic work of Joan Robinson (e.g. 1974) to more recent debates within economics (cf. Lawson, 2005; Khalil, 1997), especially as applied to developing country settings (cf. De Alcantara, 1993), this has been an on-going debate. The focus on equilibrium understandings can in part be understood in relation to the disciplinary commitment to modelling economic processes primarily in terms of rational utility-maximising individuals. These foundational assumptions thus result in divergences from pure market functioning being seen in terms of ‘imperfections’ or ‘distortions’, rather than the core of the issue. More empirical approaches to looking at markets – for instance in economic anthropology from Sahlins’ classic text (1972) onwards – show how markets have to be understood in located, cultural and social terms, with such complexity generating non-linear, dynamic interactions mediated by social, cultural and political relationships not amenable to simple equilibrium modelling approaches. While institutional economics puts market imperfections at the centre of its analysis, looking for example at information asymmetries between market players (e.g. Grossman and Stiglitz, 1980), much of this work still relies on the neo-classical assumptions of rational, utility-maximising individuals (Harriss et al, 1997).

Of course standard equilibrium models do have their merits. One clear advantage of a simple model is that its limitations are there for all to see. These can be hopefully (though not always) debated, challenged and revised by diverse groups of (sometimes non-professional) stakeholders. By contrast, highly complex dynamic models may end up describing complexity and other dynamic characteristics more completely, but hiding from view the critical assumptions in a welter of complex equations. Thus as a heuristic device, the equilibrium models

of economics and epidemiology, for example, are a useful way of thinking about what might happen if certain aggregate conditions hold. In some settings such conditions do indeed hold (more or less), and the models have some important utility for planning and policy. But in other contexts, models developed for one setting – usually a more controlled, managed one – are found seriously wanting in others. This is particularly the case when models are exported from the developed to the developing world, or from the laboratory or research station to the field. It is therefore not just dynamics that matter, but, as we argue later, it is dynamics-in-context which are particularly critical.

This is the second reason why dynamic perspectives have often been ignored in development. Much of the history of development – from colonial times to the present – can be read as a history of the export of inappropriate, doctrinal models (Cowen and Shenton, 1996). Whether in economic policy or the management of forests, soils, agriculture or water resources (see Leach and Mearns, 1996, Scoones, 2001; Fairhead and Leach, 2003; Mehta, 2005), we see time and time again, the confident assumption that a particular model applied in Europe or North America will work when transplanted into Africa or Asia. And, whether in neo-liberal prescriptions for economic reform and adjustment or sustained yield management of forests, we see such models too often failing the intended beneficiaries.

Yet such failures do not seem to offer a deterrent. When dynamic contexts result in the model prescriptions failing, the response is usually not to blame the model and its assumptions, but either to see this as 'implementation failure', urging reapplication of the model with greater force, or to blame the context. There often appears to be a blindness to the basic adage that 'context matters', and because it does, contexts can undermine the neat assumptions of imported models, however worthily applied and argued for. This lack of reflexivity is, we argue, at the heart of the problem. How we understand the world is deeply intertwined with cultural, disciplinary, political and social norms and worldviews. Development efforts exist at this interface, and a failure to reflect on the framing assumptions behind models – most critically the understanding of the system's functioning and the normative objectives for system outcomes – too often means failure in well-meaning development activities (Pieterse, 1996).

The reasons why simplistic, blueprint-driven, managerialist development fails are well known (see Chambers, 1982, 1997). But it still persists. This requires us to look at the wider institutional and political context for development, and its underlying framings. Mainstream debates about development in the 'south' are often couched – implicitly if not explicitly – in terms of notions of 'progress' (Crush, 1995; Esteva, 1992). The assumption is often that such progress is

achieved through the transfer of ideas, models, technologies and practices from the 'developed' north to the south. Within this framing are often embedded ideas about how development occurs in stages – from backward to modern, from old to new, from under-developed to developed. A social Darwinist vision of evolution often lurks not far beneath the surface (Scoones and Wolmer 2002). There is often assumed to be a singular path to progress, and to be hitched onto this you have to be 'pro-innovation', 'pro-technology' and so on. While there are of course a variety of critiques to this mainstream perspective on development – coming from a variety of populist and political economy stances from a range of different scholars and activists from both north and south (cf. Sachs, 1992) – the fact is that such views remain, despite such challenges, the accepted mainstream view. Thus the denial of alternative, multiple pathways towards a broader goal of poverty reduction, social justice and environmental sustainability is very common in mainstream development discourse. In considering the multiple pathways to such ends, there is a need to accept that there is no single pathway to progress (and as Goran Hyden (1983) cautioned no short-cuts either). Accepting dynamic contexts, interacting with dynamic systems over time and space, means that inevitably - indeed from first principles – there will be multiple possible routes available. Which one is chosen, and with what results is of course a wider choice – discussed in STEPS Working Paper 2 on Governance – but one that must take into account underlying dynamic conditions in particular contexts.

A key question addressed in some of the literature discussed later, is why is it that conventional bureaucratic, administrative and policymaking institutions and routines find this so hard to cope with? This is a near universal problem, but one that has particular characteristics in the developing world. The export of models for development since colonial times discussed above was of course accompanied by the export of professional practices and associated institutions. These took on particular characteristics, often in more extreme versions than their originators (see contributions in Leach and Mearns, 1996). Thus across much of the developing world, forestry departments, ministries of agriculture or water boards were populated with professionals trained by the colonial powers in institutions steeped in a particular way of thinking and doing. The new departments, ministries and boards that were set up – and continue to be set up or reformed at the margins – were of course modelled on their counterparts in the north; and this despite the fact that they were dealing with very different issues, in very different contexts, with very different resources and capacities. As such they became professionalised gatekeepers, controlling knowledge and managing access, and exercising power through forms of governmentality (Agrawal, 2005; see STEPS Working Paper 2 on Governance).

The patterns established over the past century continue to be reinforced. In a globalised world where the professional and practical signals for 'good science' and 'effective performance' are taken from outside the developing world, the opportunities to question ways of doing things are highly constrained in most bureaucratic and policy settings (Keeley and Scoones, 2003; Fairhead and Leach, 2003). The 'room for manoeuvre' (Clay and Schaffer, 1984), the potential to look outside the box and to imagine alternatives, is restricted by the way the development enterprise is both conceived and constructed. Instrumentalist, managerial visions of development thus dominate and continue to be co-constructed through the interactions of development agencies, national governments and indeed many NGOs. James Scott (1998) eloquently describes this phenomenon, describing how forms of governmentality (cf. Burchell et al, 1991) create ways of 'seeing like a state' which reinforce the predilection for what he terms 'high modernist' planning approaches which offer a limited, restricted vision of what is possible, excluding dynamics and politics in the process (Agrawal, 2005).

But is such a dismal view where we end? Our argument – while accepting the thrust of these critiques – is that we must look forward to new ways of thinking and doing that take dynamics seriously. This is perhaps one of the major challenges for development in the twenty-first century. We are optimistic that there are new ways forward. This optimism derives from three sources. First, that the failures of equilibrium approaches to intervention and policy – 'seeing like a state' (Scott 1998) – are everywhere to see. The new dynamic contexts presented by a globalised, inter-connected world make these all the more evident. As described in the Agriculture paper in this series (STEPS Working Paper 4 on Agriculture), there are emerging 'backlashes' against the standard view – from nature, from social movements, from politics – which help encourage alternatives.

Second, despite the often confusing and contradictory debate about sustainability and sustainable development in particular (see below), the broad, normative perspectives at the core of this discourse, highlighting the intersection of economic, social and environmental objectives, are now centre-stage, and barely disputed across geographical location - north and south - and political persuasion - left and right. The widely recognised imperative of addressing climate change, for example, has brought global environmental change and development issues to the top of the political agenda internationally. This agenda – and the challenge of sustainability - is par excellence one where social-ecological-economic-political dynamics must be at the core of any analysis.

And third, there is an emergent, yet rather remarkable convergence of thinking, across an array of fields of enquiry and disciplinary perspective, which points

towards the importance of dynamics, complexity and non-linearity as critical to both understanding and, importantly, policy and practice. Such areas of work are often rather nascent, and certainly remain largely peripheral to the core disciplines to which they refer. But there are some important common themes – as well as interesting divergences and dissonances – that we explore in the following section.

3. CHALLENGES TO EQUILIBRIUM THINKING: NEW SCIENCES FOR SUSTAINABILITY?

This section therefore tries to engage with some of these diverse literatures with the aim of exploring both common and divergent themes. At the end, we draw out some of the key elements which we believe are of value in the challenge to understand dynamic pathways to sustainability in the developing world, as well as some of the issues not fully addressed by the available literatures. What follows, then, is a very partial and necessarily highly contracted review of a huge array of different perspectives presented across diverse literatures. This is far from comprehensive, and the brevity certainly does violence to some of the more nuanced and specific debates within such areas of work. Our review work has been done as a team covering a range of disciplines and perspectives, and we have had plenty of debates and discussions in the process of compiling this paper. Our aim here is however not to cover every dimension of each sub-debate, but to generate a general picture from which we can begin to construct a more integrated, heuristic framework for addressing these issues. This then is a particular perspective framed by our overall objective and so necessarily incomplete. But we hope it is one that will resonate with those working in each of these areas, and provide links and connections between them.

Enough of the qualifications. The review below is grouped into five sub-sections. The first two look at the science and economics of complexity, drawing on wider work on complexity sciences before turning to perspectives from non-equilibrium thinking in the ecological sciences. The third explores dynamic perspectives in the understanding of industrial and technological systems through a look at areas of work in industrial ecology, processes of ‘ecological modernisation’, multi-scale interactions of environmental flows and the dynamics of socio-technical transitions. The fourth turns to policy, organisational and management responses to such dynamic settings, highlighting perspectives from ‘soft systems’ approaches to management, non-linear perspectives on policy

processes and the rethinking of the role of expertise in a 'post-normal' science responsive to conditions of uncertainty. The final section, in turn, begins to look forward to a new dynamic systems approach for development. Drawing on past experiences with systems thinking in development, and focusing on agriculture as an example, this section engages with the important perspectives of adaptive management and policy emerging from a central consideration of resilience and sustainability properties in dynamic systems.

THE SCIENCE OF COMPLEXITY

Over the past century a wide field known as 'complexity science', with a variety of strands, has evolved. This began with the early recognition of intractabilities in the dynamics of simple deterministic systems, such as the famous 'three body problem' in celestial mechanics addressed by Poincaré (Peterson, 1995). Facilitated by progress in recursive differential and complex number calculus, a rich variety of non-linear properties have since been recognised and explored. Sophisticated new concepts have been developed to explain and explore them, including the notion of strange attractors in the study of stability (Ruelle, 1989); the idea of fractional dimensionality in topology and geometry (Mandelbrot, 1967) and new understandings of phenomena of bifurcation in system dynamics (Feigenbaum, 1979). This process has inspired – and been informed by – parallel developments in experimentation, which have revealed the highly unexpected behaviour of dissipative structures in chemistry (Prigogine, 1980) and yielded refined understandings of common features in material phase transitions (Anderson, 1997). Perhaps most importantly, progress in the understanding of complexity has been accelerated by radical enhancements of computational capabilities and capacities to process large datasets, which have revealed pervasive new statistical structures like scale invariance (Zinn-Justin, 2002) and power law distributions (Zipf, 1932; Newman, 2005). Improvements in computer processing power have also enhanced capabilities for visualising complex multi-dimensional phenomena like catastrophe curves (Thom, 1989) and fractal geometry (Mandelbrot, 1982).

These developments reinforce an emerging new relationship between quantitative and qualitative thinking. Although all deriving from (or expressed in) a quantitative idiom, each of these concepts involves some important qualitative insight into the epistemological limits of traditional reductive-aggregative, quantitative understandings. Together, they contribute to a growing appreciation of the importance of dynamic (rather than static) perspectives, based on holistic (rather than reductive) analysis, acknowledging context-dependence and the

conditioning effects of structure. In short, they point to the inevitability of uncertainty even in some of the most deterministic of systems. Of course, such concerns over reductionism, determinism and spurious quantification have been long established in other disciplines (Koestler, 1967; Bertalanffy, 1968; Bateson, 1972; Philips, 1976; Hofstadter, 1979; Rose, 1982; Goodwin, 2001). Yet – largely eschewing quantitative approaches themselves – these have hitherto failed to gain much purchase in the more positivistic areas of scientific enquiry. The new complexity sciences are, however, succeeding in sustaining a cautious qualification of positivism, without resorting to a pessimistic subjectivism.

Over the past two decades, insights from complexity studies have become increasingly influential across a range of different disciplines – as well as in wider social and policy discourse. An apparently insatiable market has developed for (sometimes rather breathless) popular science writing on these themes. Lurid accounts of catastrophe theory (Woodcock and Davis, 1978) join glossy expositions of chaos (Gleick, 1988; Ruelle, 1991; Lewin, 2000) and enthusiastic advocacy of complexity studies (Casti, 1991, 1995; Gell-Mann, 1995; Kaufmann, 1995). These jostle on the shelves with competing volumes proclaiming the importance of emergence (Holland, 1998; Fromm, 2004) and (confusingly) simplicity (Gribbin, 2004; Cohen and Stewart, 1994). Centres of activity in these areas – notably the Santa Fe Institute in New Mexico – have achieved almost cult status (Waldrop, 1992; Horgan, 1995). Indeed, so intense has been the intellectual energy and exposure in this area, that some key ideas from these literatures have achieved globally iconic status. Examples include the evocative image of the 'butterfly effect' (Lorenz, 1963; Hilborn, 2004), the influential notion of the 'tipping point' (Schelling, 1978; Gladwell, 2000) and the transcendent, graphic beauty of the Mandelbrot set (Peitgen and Saupe, 1988; Barnsley, 1993).

Alongside this intrinsic importance as background themes in contemporary scientific, policy and wider social discourse, 'complexity science' (in its broadest sense) has – despite the hype – begun to make significant contributions to the substance of current thinking on the relationships between society, technology and the environment. Drawing on different permutations of the concepts and insights referred to above, these may variously be organised under a variety of aspiring new disciplinary labels.

Non-equilibrium thermodynamics, for example, explores the generation of structure in open non-linear physical systems (Nicolis and Prigogine, 1977), encouraging new approaches to evolutionary (Georgescu-Roegen, 1976), co-evolutionary (Gowdy, 1994), institutional (Hodgson, 2000) and ecological economic theory (Stagl and Common, 2005). As a distinct offshoot, chaos

theory illuminates the conditions under which apparently simple systems can generate surprisingly complex outcomes (Stewart, 1989) – an example of the many applications in the social sciences (Kiel and Elliott, 1997) being the ways in which apparently simple rule-based behaviour in ‘evolutionary games’ (Maynard-Smith, 1982) can hold important insights for the social dynamics of co-operation (Axelrod, 2006). Catastrophe theory, in turn, preceded the rise of chaos theory (but is now often effectively subsumed within it, under the general study of bifurcations) and focuses on discontinuities and exponential episodes in the dynamics of otherwise continuous processes (Zeeman, 1977), with significant implications for the modelling of economic (Rosser, 2006), environmental (Diamond, 2005), technological (Nelson and Winter, 1982) and social (Tainter, 1988) change.

Arising to prominence more recently, complexity theory is in some respects both the converse and a broader generalisation of chaos theory: addressing ways in which multiple interactions in complex, inter-coupled systems can give rise to relatively simple emerging structures (Kauffman, 1993). These are issues now explored in the rapidly growing field of agent-based modelling (Gilbert and Troitzsch, 2005) and in the study of emergent structures (Sawyer, 2005), diversity (Ostrom, 2005) and power law distributions in social phenomena (Ball, 2005).

As a distinct aspect of (or alternative vocabulary for) complexity, general notions of self-organisation in evolutionary studies focus on the ways in which the emergence of order need not always be seen as a consequence of hierarchical causal relationships (Jantsch, 1980; Bak, 1996) – an insight applied in some branches of economics (Krugman, 1996) and geography (Allen, 1997). Finally (and related closely to the study of self-organisation), the more specific ‘branded’ concept of autopoiesis has arisen in systems theory applications to molecular and evolutionary cellular biology and (Varela et al, 1974) and has inspired from there newly-intensified attention to the implications of recursivity, self-referentiality and reflexivity in general social theory (Luhmann, 1995; see also the discussion of ‘soft systems’ below).

NEW PERSPECTIVES IN ECOLOGY

As discussed earlier, for many years, both in scientific and popular discourse, the dynamics of ecological systems were thought of in terms of ‘balance’ and ‘equilibrium’ (Scoones, 1999; Zimmerer, 1994; Botkin, 1990), with disturbance from stable states seen as a divergence from a ‘natural’ condition. In popular

discussions these understandings led to notions of the 'balance of nature' and framed understandings of how human interventions in ecosystems should be understood. In applied management applications, an equilibrium view led to ideas like 'carrying capacity' or 'stable state succession', where limits were imposed on use and harvesting to avoid shifts from an assumed stable state.

While some ecosystems of course demonstrate stable, equilibrium-type properties, many do not. Both theoretical and empirical studies in ecology over the last 30 years have demonstrated how it is important to understand systems in terms of multiple stable states and shifts between stability domains (DeAngelis and Waterhouse, 1987; May, 1977, 1986). Other systems are truly non-equilibrium, where dynamics are dominated by external drivers (such as rainfall) which are highly variable. In these, the population dynamics of (say grasslands and animals) are not primarily governed by the classic density-dependent feedback mechanisms assumed for homeostatically-controlled equilibrium systems (Ellis and Swift, 1988; Behnke and Scoones, 1993)³.

Understanding complex ecosystems in terms of the sum of networks of interactions with food webs or nutrient cycles, for example, suggests a particular perspective on non-linear dynamics (DeAngelis, 1992; Pimm, 1991, 2002). Even relatively simple, deterministic model systems, based on a few interactions of relatively few components, can of course result in chaotic, non-linear dynamics (May, 1989), so it is hardly surprising that studies of real ecosystems show a high degree of stochasticity resulting from non-linear interactions. A challenge in the ecological sciences, then, has been to develop understandings – and in turn predictive models – which reflect such dynamics, and move away from misleading understandings based on too rigid an acceptance of equilibrium perspectives (cf. Chesson and Case, 1986; Holling, 1973; Sullivan, 1996; Sullivan and Rohde, 2002; Rohde, 2006).

³ In the literature a distinction is sometimes maintained between 'non-equilibrium' systems where density dependence is not apparent, and where systems dynamics are understood in terms of density independent factors, and 'disequilibrium' systems, which are often not at equilibrium, but may exhibit multiple stable states and transitions between these or phases of equilibrium and non-equilibrium dynamics depending on the relative importance of density dependent and density independent drivers. For the purposes of this discussion, we will refer to the contrast between equilibrium and non-equilibrium approaches, accepting that in practice many systems exhibit a range of properties along a (dynamic) continuum. All such approaches are amenable to modelling approaches – including dynamic, stochastic approaches for looking at multiple component, non-linear systems – but will be based on different starting assumptions and premises dependent on the characterisation of the system and its properties.

Such a non-equilibrium view of ecosystem dynamics has many important applied management implications. Thus the 'new' rangeland ecology has rejected the simplistic application of carrying capacity approaches to rangeland management, shifting to a more spatially and temporally attuned approach. A spatial approach highlights the importance of differences in patch dynamics in different parts of a rangeland landscape, contrasting 'key resource' areas where more equilibrium properties are evident with large areas of dry rangeland where rainfall variations dominate dynamics. Different management responses are needed in each area and over time, with an approach to 'opportunistic' management, which tracks available resources over space and time seen as the most appropriate. Thus in dry, pastoral areas in Africa, it is argued that the most efficient and effective response to high levels of spatial and inter-annual variability in rangeland productivity is mobility, combined with rapid-response disposal and restocking of animals to track fodder availability (Sandford, 1982; Behnke et al, 1993; Scoones, 1995; Roe et al, 1998; Sullivan and Rohde, 2002).

In forest management, critiques of a simple successional model of vegetation change have highlighted how shifts between different forest types and savanna vegetation are driven by variations in soil, fire regimes and rainfall over time and space. There is thus no one 'natural' forest type to be protected or conserved, or against which human use might be judged as 'disturbance'. Rather, forest management must respond to ecological dynamics and their interaction with use practices in relation to different objectives for management, whether production forestry, biodiversity conservation or supporting local livelihoods (Shugart and West, 1981; Sprugel, 1991; Terborgh et al, 1996; Shinneman and Baker, 1997; He and Mladenoff, 1999; Fairhead and Leach 1996, 1998). Appreciation of dynamic ecologies has also had an impact on other areas of management, including fisheries (Hilborn and Gunderson, 1996), soils (Scoones, 1997, 2001), pest control (Royama, 1984; Walters and Holling, 1990) and restoration ecology (Suding et al, 2004), each suggesting wider implications for resource management under conditions of uncertainty (Ludwig et al, 1993).

Such non-equilibrium thinking also applies to disease ecologies, and the way disease control and management takes place. Simple epidemiological models of transmission and disease spread may not be appropriate, as disease organisms interact in non-linear ways with both the wider environment and the organisms that any disease virus or bacterium infects (Anderson, 1994). Instead, more sophisticated understandings of disease-host-environment interactions are needed, requiring different modelling approaches (cf. Manfredi and Williams, 2004; Ahmed and Hashish, 2006), as well as more located understanding of disease contexts through approaches such as participatory epidemiology (Mariner and Roeder, 2003; Catley, 2006).

Thus, drawing on ideas from the wider field of complexity science, non-equilibrium perspectives in the diverse applications of ecology and epidemiology provide a challenge to the first-approximation static, equilibrium models that dominated early work in these fields. New approaches – while by no means being dominant in the applied contexts of development policy and practice – draw on non-equilibrium and complexity thinking, offering new approaches to analysis and in turn new perspectives on management and policy.

DYNAMIC SOCIAL AND TECHNICAL SYSTEMS IN INDUSTRIAL CONTEXTS

A large body of work has emerged in recent years which has examined dynamic systems in industrial contexts in the context of debates about (largely) environmental sustainability. This has drawn selectively from some of the debates described above, often applying metaphors and analogies from debates in dynamic ecology and complexity science. The focus here is on areas of debate in industrial ecology, ecological modernisation, environmental flows and socio-technical transitions, where different perspectives on underlying dynamics – and particularly the interaction between ecological and industrial-technical systems – are used. While to date largely applied to northern, industrial settings, the approaches being developed have relevance to thinking about contexts of rapid urbanisation and industrialisation in the developing world.

For example, the field of industrial ecology places industrial design and production management firmly within the biosphere, and seeks to break down historic divisions between industrial and natural systems by reconsidering the industrial system as one kind of ecosystem, with an interacting distribution of flows of materials and energy (Ayres and Simonis, 1994). Key to industrial ecology is the study of industrial metabolism with an interest in the array of productive and waste flows. As Erkman (1997:2) argues:

The idea is first to understand how the industrial system works, how it is regulated, and its interaction with the biosphere; then, on the basis of what we know about ecosystems, to determine how it could be restructured to make it compatible with the way natural ecosystems function.

This of course begs the question about understandings of 'natural' ecosystem function, including whether this is seen in equilibrial or non-equilibrial terms (see above). Thus, whether as metaphor, model or theory, contrasting kinds of ecological thinking will lead to distinct industrial systems and seek different re-

lations with the natural world. Does one strive for a balanced industrial complex; or an adaptive production and consumption system? Industrial ecologists call for mimicry of the 'best features' of natural ecosystems, including diverse and resilient systems, and an emphasis on the productive use of detritus (Frosch and Gallopoulos, 1989). But, of course, the critical, normative questions around which 'best features', and for whom, are again left hanging, as well as wider questions about how socio-technical-ecological systems are mutually constructed.

Unsurprising for an engineering-based approach, technology is a central component: technologies mediate the relations between artificial and natural systems. Thus, clusters of technology development are considered central in the transition from unsustainable industrial systems to industrial ecosystems. In contrast to pollution prevention and cleaner technology strategies of individual processes or firms, industrial ecology attempts to integrate between processes and activities, such that 'waste' from one becomes 'raw material' for another (Pauli, 1997).

A few celebrated cases, such as the 'industrial symbiosis' developments in Kalundborg in Denmark, and other industrial 'eco-parks', are repeatedly marshaled to illustrate the practical potentials of this approach. Attempts have been made to extend these industrial 'food webs' regionally through the creation of systemic material/waste exchange facilities and intermediary organisations. Less holistic, more pragmatic expressions of an industrial ecology approach include: coordinated attempts to green supply chains for a given product; improving the environmental performance of specific materials as they weave through the economy; or focusing on a specific geographical area or watershed.

Whilst industrial ecologists are interested in the distribution of material and energy flows from an engineering and organisational point of view, the key driver of global distributions is political economy. Industrial ecology therefore seeks a reconfiguration of industrial systems along ecological lines. However, the insights from ecology have been criticised by some as superficial and failing to engaging with wider political economy questions. There are also suggestions that 'mimicry' of ecology is based on older notions of stability and symbiosis, and not the complex, non-equilibrium dynamics of the 'new ecology'.

Ecological modernisation theory emerged to prominence in environmental sociology in the 1990s. It maintains that solutions to the environmental problems of modernity can be found and are emerging in modernity itself. Its basic tenets are that re-modernisation of (post-) industrial societies is already leading to environmental improvements, and that continued, market-oriented investment in new technology will decouple economic growth from environmental degrada-

tion (Mol, 1995; Spaargaren and Mol, 2000; Cohen, 1997). Thus the rationality of late modernity can be used to save itself. This is a rationality that recognises the need to internalise and account for the environmental services necessary to secure future productive output, and that holds that modern industrial institutions can steer economic activity onto a sustainable pathway. Industrial ingenuity can therefore fix industrial society (Janicke, 1985; Simonis, 1988).

Ecological modernisation has in turn proved to be an attractive (if implicit) framework for Western environmental policy and sustainable development efforts (Weale, 1992). In this analysis, a new role is recognised for the 'environmental state' in steering, facilitating and encouraging ecological modernisation (Mol and Buttel, 2002). More broadly, the 'environment' is considered to have greater 'autonomy' by exercising greater demands in terms of monitoring and governing, and thereby to attain increased 'agency' in political and economic systems (Buttel, 2003).

A focal point for debate, however, is whether this is an adequate analysis of what is actually happening, or a normative argument for what societies ought to be doing. York and Rosa (2003) argue that 'ecological modernisation' has to demonstrate at least four different kinds of dynamic at a high level of aggregation if the central claims are to remain credible. Each is highly demanding. These are: first, that the institutional adaptations to environmental problems in modern societies are actually leading to environmental improvements; second that late-stage modernisation leads to the ecological transformation of production and consumption at high frequencies; third, that firms and sectors that do improve environmentally do not contribute to problem displacement; and fourth, that the pace of relative environmental efficiency improvements in economies are not being outstripped by total increases in production. Evidence for such patterns, beyond a few cases (Mol, 2001), is, however, limited (York and Rosa, 2003).

Much debate in this area is interested in the emerging dynamics of production systems at aggregate scales, without attending to the way such dynamics are enmeshed in environmental dynamics – other than claiming that environmental 'problems' are increasingly shaping social and technological dynamics, and that these are creating 'solutions' in terms of cleaner production. But, as with many other approaches, the 'environment' is implicitly self-evident and relates to certain, focal pollution or (less frequently) raw material issues. Addressing such issues, some key contributors to these discussions have recently turned their attention to the question of 'environmental flows', bringing social science interest in flows of complex hybrids of money, images, investments, people and information in the context of globalization (cf. Castells, 1996; Appadurai,

1997) into contact with the material and energy flows of concern to industrial ecologists and environmental scientists. This seems to offer a more dynamic conceptualization of the environment and through analysis of social-material 'hybrids', a more integrated view (Buttel, 2006). By focusing on socio-political explanations of environmental flows, wherever they arise, and wherever they go, problems of narrow boundary setting appear to be resolved (Spaargaren et al, 2006).

Wider questions arise, however. For example: how are the different environmental flows 'framed' and what meanings do they take (e.g. whether certain flows are problematic, or beneficial, controlled, or chaotic, and for whom, and by whom)? How do we distinguish flows according to quantities, qualities, meanings, interactions, and their effects? What does access to flows and exclusion from flows for different social groups really mean in terms of their ability to construct pathways to more sustainable livelihoods?

The socio-technical transitions perspective in turn considers some of the social, political and economic processes that hinder the consideration of more fundamental redesigns of production and consumption systems. Thus a core policy goal of sustainability in production and consumption systems implies a different kind of innovative activity to that traditionally associated with a single product or new business practice (Berkhout, 2002). Combinations of socio-technical regimes, including consumption patterns, user preferences, regulations, infrastructures as well as artefacts will need reconfiguring for the sustainability challenge (Hoogma et al, 2002). Research identifies how greener innovation is embedded within larger-scale 'socio-technical regimes'. The niche literature, both on strategic niche management and on the transition management approach, has been concerned with change at this level. The term 'socio-technical regime' has been coined to capture the ways that interacting and mutually adapting social and technological processes channel the development of practices along certain trajectories. Reinforcing this focus is a realisation that radical changes at a whole system scale are needed to deliver the material efficiencies and emission reductions that sustainable development demands (Rotmans and Kemp, 2001).

This perspective draws upon ideas and lessons from the history of technology, evolutionary economics and the sociology of technology. Evolutionary economics has brought consideration of the channeling of innovation along defined trajectories, such as the routines of engineers, firm capabilities, market and industrial structures, and research institutions (Nelson and Winter, 1982; Dosi et al, 1988). The sociology of technology has broadened consideration to include user expectations and practices, livelihoods and lifestyles, policy and

regulations, and social meanings and constructions of technological practice (Bijker, 1997). Both stress how wider infrastructures (social and technological) play an important role in the working of individual technology artefacts. The history of technology has provided inspiration for work on how these 'socio-technical regimes' develop over time and, especially, how transitions from one regime to another have proceeded in the past, and therefore might be encouraged in the future (Hughes, 1983). Thus mutually reinforcing cognitive, technological, social, economic and institutional processes channel the development of practices along certain trajectories, affected by a complex structure of artefacts, institutions, and agents. The term 'socio-technical' is thus used "to stress the pervasive technological mediation of social relations, the inherently social nature of all technological entities, and indeed the arbitrary and misleading nature of distinctions between 'social' and 'technical' elements, institutions or spheres of activity" (Russell and Williams, 2002: 128; see Geels, 2002; Schot, 1998; Rip and Kemp, 1998; Smith et al., 2005; Smith and Stirling, 2006).

Imposing a normative goal like sustainable development upon existing regimes implies connecting and synchronising change processes at a bewildering variety of points within and beyond the regime. But socio-technical processes constitute and reproduce regimes whose logic makes it difficult to break away from incumbent development trajectories and strike off in pursuit of more sustainable pathways (Smith, 2006). Historical experiences suggest that radical changes begin within networks of pioneering organisations, technologies and users that form a niche practice on the margins of the regime. These 'niche' situations (e.g. niche applications, demonstration programmes, social movements) provide space for new ideas, artefacts, and practices to develop without being exposed to the full range of pressures that favour the dominant regime (Schot, 1998; Geels, 2004; Rip and Kemp, 1998). Research has looked at the internal dynamics of alternative, sustainable niche development (Schot et al., 1994; Kemp et al., 1998; Hoogma et al., 2002), sometimes situating niches at the base of a multi-level system, beneath incumbent socio-technical regimes and overarching landscapes (Geels, 2004). Models of 'multi-level transitions' (Elzen et al., 2005) pose questions about whether different contexts lead to different transitions pathway (Berkhout et al 2004), about the relationship between scales (niche-regime-landscape) (Smith, 2006); about boundary definition and understandings (Smith and Stirling, 2006); and about the dynamics of agency and power (Smith et al, 2005).

In sum, different streams of work attempt to get to grips with the highly dynamic social underpinnings of technology development, and try to understand technological practices embedded in ecological contexts. These approaches share a role in pushing the normative goal of environmental sustainability more force-

fully and influentially into the development of products, services, businesses and industries. And yet, given their focus and orientation, the substantive character of the pathway to sustainability is taken as a given. Thus the approaches tend towards 'hard systems' rather than 'softer systems' perspectives. This has two, related consequences. First, analysis tends not to link back to the political-economic reasons why industrialisation has historically tended (and continues) to underplay these technological-ecological dynamics. Second, contested framings of the appropriate orientations for diverse sustainability pathways are not considered. Nor are strategies developed for dealing with the balancing of choices across contending pathways in an adaptive and reflexive way.

POLICIES, ORGANISATIONS AND MANAGEMENT RESPONSES IN DYNAMIC SETTINGS

Given such dynamic complexity in ecological, economic, social and technical systems, how should policies, organisations and management respond? This question has been at the centre of a number of areas of enquiry, which offer some important pointers to ways forward.

Nearly all organisations are complex systems, particularly those associated with the complex and dynamic challenges of sustainable development. What are the organisational and management requirements in such settings? Ray Ison and colleagues (Ison et al, 1997: 262) point out that there are two different, possible ways of responding to complexity. Complexity can be seen as "something that exists as a property of some thing or situation; and that, therefore, can be discovered, measured and possibly modelled, manipulated, maintained or predicted", or by contrast "as something we construct, design, or experience in relationship to some thing or event". These two perspectives have very different implications for management and organisational change. With the first 'descriptive' approach to complexity, the challenge is first to describe, then to model and finally to respond prescriptively. By contrast, the second 'constructed' approach "entails engaging in situations of complexity and using systems or complexity thinking to learn our way towards purposeful action that is situation improving" (Ison, 2004). This latter perspective implies a 'soft systems' approach (Checkland, 1981; Checkland and Scholes, 1990; Bawden, 1991, 1995; Forester, 1994) to management and organisational change. Soft systems approaches evolved in response to the limitations of 'hard systems' analysis, based on cybernetics, structural modelling and mechanistic thinking. This latter engineering approach was seen to be inadequate for the types of complexity found in organisational and management issues.

Such approaches put the practitioner and analyst at the centre, for understanding the world from a 'soft systems' perspective is critically based on the positionality and subjectivity of the observer. As Schindwein and Ison (2004:30) emphasise:

Making a choice of one epistemological position or another in a given context is not an act of discarding or deciding against the other position - it is an act of being aware of the choice being made and taking responsibility for it.... Being epistemologically aware opens up more choices for action.

A number of commentators in this field follow the biologist Maturana (1998) in arguing that "responsibility replaces objectivity as the ethical basis of praxis". Ison et al (1997) comment:

According to a soft-systems view, people appreciate the same context in different ways based in line with their experiences and worldviews, or *Weltanschauung* and purposes. What results is a number of different 'systems' (constructions of a situation) which are relevant to the stakeholders concerned, but not necessarily to all stakeholders, in the sense that they relate to their various purposes and worldviews. Systems analysis, and synthesis, seeks to reveal the different, and sometimes conflicting, perspectives of stakeholders and to show that the many different ways of viewing the situation can be equally rational. This process leads to 'problem formulation' rather than 'problem identification' (Ison and Ampt, 1992) and prepares the ground for mutual understanding and negotiation of the problem(s) in question. In this process, the researchers are themselves central actors rather than objective, dispassionate observers: acting as if such an external, objective position were possible allows researchers to avoid responsibility for the results of their research outcomes (von Foerster, 1992; Ceruti, 1994).

This negotiated, reflexive understanding of complexity, from a variety of different frames, echoes Donald Schön's perspective on the 'reflective practitioner' (Schön, 1995, 1987). To be effective, practitioners must engage with different system and problem framings and negotiate solutions. Such a practice-based perspective accommodates uncertainty, complexity and competing versions and does not seek to define a single model. Indeed, a critical process, particularly when confronted by controversy, is that of 'frame reflection' (Schön and

Rein 1994) whereby competing frames are examined at higher (meta) levels in order to seek routes for common understanding and moving forward.

Such perspectives overlap with the idea of the 'learning organisation' (Senge 1990, Argyris and Schön, 1978) and with critiques of 'stable' states (Schön, 1973) committed to technically-driven, blueprint-based modernist development (Scott 1998). Learning organisations are thus effective where incremental change in the face of complexity and uncertainty is based on sequential action, reflection and cumulative learning (Kolb, 1984; Bawden, 1994). A number of analysts and many practitioners observe how large organisations very often fail to respond effectively to dynamic complexity (Mosse et al, 1998; Mehta et al, 1999; Pimbert, 2004). Thus, for example, Chapman (2002) observes 'system failure' in the UK National Health Service, while Uphoff (1996), Thompson (1995) and Korten (1980) comment on similar dynamics in irrigation systems and rural development in Asia.

Thus these different organisational change and management perspectives – whether 'soft systems', 'reflective practitioner' or 'organisational learning' approaches – respond to dynamic complexity – within organisational systems and in relation to shocks and stresses from outside - through processes centred on reflective practice and experiential learning.

However, conventional perspectives on policy change have tended to rely on a simple, linear model whereby broad agenda setting is responded to by an expert-led approach to policy analysis, leading in turn to recommendations and implementation. In such a schema, the political and technical remain separated, and policymaking is seen as distinct from implementation (John, 1998; Hill, 1997). The reality of policy processes is of course different, and this is particularly the case when policy processes must respond to highly complex and dynamic systems. In most areas of environmental and technology policy, for example, a huge range of variables, a range of uncertainties, and often significant controversies are present, making any policy response necessarily non-linear and highly dynamic.

A large range of literatures, from a huge range of disciplinary perspectives, with different theorisations of politics and power, knowledge and expertise and state-society interactions, have been elaborated to help understand complex, dynamic policy processes (Keeley and Scoones, 1999, 2003; Wynne, 1992; Jasanoff and Wynne, 1997)⁴. Each perspective has its pros and cons, and these are much

⁴ For further discussion of these themes, see the Governance paper in this series (STEPS Working Paper 2)

debated in the literature (e.g. Howlett and Rayner, 2006). Some, for example, focus on the framing of systems (structures, dynamic properties and functions) and the wider context through such approaches as 'narrative' analysis (Roe, 1991), perspectives on discourse formation (Shore and Wright, 1997), 'frame reflection' (Schön and Rein 1994) or policy controversy (Nelkin, 1992). Others emphasise the way different actors and associated networks interact in policy debates through the formation of 'discourse coalitions' (Hajer, 1995), 'advocacy coalitions' (Mazmanian and Sabatier, 1983; Sabatier and Jenkins-Smith, 1993) or 'policy networks' (Jordan and Richardson, 1987; Marsh and Rhodes, 1992), as part of an institutionalised 'sub-politics' (cf. Beck, 1992). Still others emphasise the underlying interest politics at play through an assessment of the competing policy positions in pluralist democratic systems (Dahl, 1961), often with analyses of competing interest groups highlighting tensions between the state or corporate actors and 'civil society' or social movements (McAdam et al, 2001; Tarrow, 1998; Tilly, 1978).

Keeley and Scoones (2003) argue that all such perspectives offer important contributions to make. But together, by looking through different lenses at the dynamics of knowledge/discourse, actors/networks and politics/interests in any policy processes, a more complete perspective on complex processes of policy change can be achieved. Thus, for example, in understanding policy change around agriculture, environment and livelihoods in Ethiopia, Keeley and Scoones (2000) identify two policy narratives that have dominated policy thinking over the past decades – one focusing on boosting agricultural productivity (a 'Green Revolution' narrative) and one focusing on problems of environmental degradation and soil erosion in particular (an 'environmental rehabilitation' narrative). Each frame the problem in different ways, and each are associated with different, well-connected actor networks and associated interests. Because of the nature of the framing process, and the way such policy narratives are constructed, reflective of the interests of different individuals and groups, the opportunity for a wider debate about future pathways for development have often been absent or obscured. Over a long period in Ethiopia, such policy processes have acted to black-box uncertainties, smother complexities and divert controversies. A fuller appreciation of the highly non-linear and inevitably political process of policymaking thus provides the opportunity for a more reflexive engagement in policy processes, opening up debates about alternatives in the process, including an emergent perspective focused on more participatory approaches to natural resource management and agriculture.

What particular challenges do dynamic systems contexts therefore suggest for such policy process analysis? As discussed above, such policy contexts are characterised by a combination of irreducible uncertainty and multiple framings

of policy perspectives - both of problems and solutions. Funtowicz and Ravetz (1993) argue, for example, that in such settings a different type of 'post-normal' science must be applied to policy problems that transcends – but complements – 'normal' expertise. This suggests in turn a different relationship between expertise and policy, in which recognition of multiple framings of issues, and reflexivity around these, is essential (Fischer, 2000; Jasanoff, 2005), and where policy problems and solutions are 'opened up' through addressing uncertainty, dissent and controversy rather than 'closed down' by narrow versions of policy appraisal (Stirling 2005). This in turn requires an approach to policymaking which is often incremental and adaptive (see Lindblom, 1959, 1979), based on deliberation and learning (Hajer and Wagenaar, 2003; Fischer, 2003), and one where the political interests – and associated framings – are brought explicitly into the picture. As STEPS Working Paper 2 on Governance argues, this means that faculties for reflexivity and flexibility, with respect to failure as much as success and with respect to the diverse ways that success may be defined, need to be central.

TOWARDS DYNAMIC SYSTEMS APPROACHES IN DEVELOPMENT

Systems perspectives in development thinking have a long tradition. But these are often based on 'hard systems' analyses and so fail to address the dynamic complexities arising from 'constructed' or 'soft' systems (see above). For example, in agriculture, systems approaches date back to classic descriptions and typologies of farming systems (Ruthenberg, 1971). Farming Systems Research (FSR) evolved in the 1970s (Gilbert et al, 1980; Shaner et al, 1982; Byerlee et al, 1982) as a response to earlier simplistic, technical approaches which focused only on single system elements – such as seeds and inputs – as part of technical transformation and transfer. This classic Green Revolution model did not take much account of complex system dynamics, and worked best in areas where sources of variability and uncertainty were reduced. But in the vast majority of agricultural settings in the developing world, a more complex, diverse and risky (cf. Chambers, 1982; Chambers et al, 1989) context existed. Here a more interactive, systems-oriented analysis was required which was more holistic and integrative, and in particular addressed the wider social and economic issues together with technical questions.

However, much FSR practice was little more than adaptive on-farm research which extended the linear, technical model to wider contexts. Agroecosystems analysis, which emerged through work in northern Thailand in the early 1980s (Conway 1985), however, was an attempt to move beyond this restricted frame,

and develop a systematic approach to examining system properties in agricultural settings. Drawing inspiration from dynamic ecology and the work of Holling (1973, 1978) and others, the framework developed by Conway (1987) highlighted four system properties of interest: productivity (output per unit of interest – land, labour, capital etc), stability (variability of productivity over time), sustainability (ability of patterns of productivity to continue when subject to shocks and stresses) and equity (the distribution of productivity to different people). The approach thus incorporated conventional agronomic/economic measures of productivity and distribution, with a concern for dynamics – the stability and sustainability properties of the system.

The focus of field-level agroecosystems analysis was on the trade-offs between these properties. Did a focus, for example, on increasing the productivity of a particular cropping system result in decreased stability (i.e. increased variation in yields and so exposure to risk) and question marks about sustainability (e.g. if such productivity increases were to be achieved by the applications of increased pesticides or fertilizer, both potentially resulting in long-term stresses on the system)? Agroecosystems analysis, as originally practised, was largely expert-led field analysis, pushing technical experts as part of farming systems research teams to look at these wider questions, not normally part of the frame of agronomists or plant breeders.

However, the methodological innovation that became part of agroecosystems analysis – particularly the visualisation and mapping of systems and farm landscapes – provided a focus for interaction with another emerging approach to analysing agricultural and rural development settings at that time - rapid rural appraisal (Howes and Chambers, 1979; Chambers, 1981) and participatory 'farmer first' approaches (Chambers et al, 1989). Such approaches increasingly emphasised participation as central to diagnosis and design in rural development (Cohen and Uphoff, 1980; Chambers and Jiggins, 1986; Oakley, 1991), and, drawing on long traditions in social anthropology, emphasised local understandings and 'indigenous technical knowledge' (Richards, 1985; Warren, 1990; Warren et al, 1995, 1989) as central to any analysis. However, in the more populist versions of such approaches in development – and particularly in the many applications of what came to be labelled 'participatory rural appraisal' (Chambers, 1994 a-c) – the politics and dynamics of such knowledge construction in participatory approaches was often not acknowledged (Mosse, 1994; Cooke and Kothari, 2001). Very often 'indigenous knowledge' was seen as a helpful adjunct to a technical, expert-led process of systems analysis and design, and not fundamental to the wider politics of framing and negotiation of systems, their functioning and purpose (Scoones and Thompson, 1994).

Some of these issues are central to a line of thinking and practice which has been labelled 'adaptive management', linked to wider debates about the science of resilience and sustainability derived from non-equilibrium ecological thinking. For example, in the opening editorial of the journal *Conservation Ecology* (now *Ecology and Society*), Holling laid out a prospectus for a new applied ecology which took dynamics and complexity seriously (Holling, 1998). This emphasised integration, holism, uncertainty and surprise as key elements for effective management of complex ecosystems, with ideas of system resilience being central to meeting the challenges of sustainability. The work of the Resilience Alliance (www.resalliance.org) has elaborated these ideas over a number of years, exploring both ecological and social dimensions of dynamic systems in diverse settings – from dry rangelands (Anderies et al, 2002; Janssen et al, 2004), to forest pest outbreaks (Ludwig et al, 2002), to coral reefs (Bellwood et al, 2004) to lakes (Carpenter et al, 1999) to wetlands (Gunderson, 2001; Ollson et al, 2004) and marine systems (Hughes et al 2005).

This work has emerged from the practical challenges of managing ecosystems where dynamic ecologies undermined attempts derived from conventional approaches due to the existence of multiple stable states, non-linear dynamics and uncertainty (Holling, 1973, 1986, 1994, 2001; Ludwig et al, 1993). Thus, for example, the 'maximum sustained yield' approach to fisheries management was found wanting (Larkin, 1977), as was conventional forest management in the face of episodic and uncertain pest outbreaks of spruce budworm (Holling, 1978). Approaches to adaptive management – based on experimentation and incremental learning about system dynamics – were seen as more effective than conventional blueprint management models in such complex systems (Walters 1976; Walters and Hilborn, 1978).

These approaches to the management of resilience in complex ecosystems emphasise in particular how system scales and hierarchies (Allen and Starr, 1982; O'Neill et al, 1989; Wilbanks and Kates, 1999; Turner et al, 2001) interact with multi-level system dynamics, with 'cascade effects' (Folke et al, 2004), 'scale mismatches' (Cumming et al, 2006) and networks potentially emerging and affecting resilience properties (Janssen et al, 2006). Resilience is thus seen as an emergent property, linked to processes of adaptation and transformation (Carpenter et al, 2001; Walker et al, 2004). This moves beyond 'engineering' focused definitions where resilience is seen in relation to return times to previous stable states (cf. Pimm, 1991), to assessments of 'ecological' resilience through measures of how far a system could be perturbed before shifting to a wholly different system regime (Holling and Meffe, 1996).

In recent years, there has been an increasing emphasis on linked social-ecological systems in this body of work (Berkes and Folke, 1998; Berkes et al, 2003), associated with ideas of 'panarchy' (Gunderson and Holling, 2002), where understandings of resilience emerge from nested and interacting social and ecological systems. This leads in turn to questions of system governance and the principles of learning, participation, networks, trust and leadership this requires (Walker et al, 2006; see STEPS Working Paper 2 on Governance).

Emerging from similar concerns, but from different starting points and disciplinary perspectives, an overlapping set of issues has been raised in attempts to define a new 'sustainability science' (Kates et al 2001; Turner et al, 2003; Clark and Dickson, 2003). Geographers in particular have highlighted the need for an integrative science of sustainability, linking natural and social sciences, to address the challenges of global change and 'regions at risk' from natural hazards and disasters (Hewitt, 1997; Kates and Kasperson, 1983; Wisner et al, 2004). Here again questions of scale interactions – across both time and space – and uncertainties resulting from complex system dynamics are highlighted. A regional, place-based approach is advocated, allowing such integrative approaches to environment and development problems to be pursued in located ways.

Thus across these admittedly vast and diverse areas of enquiry, a number of common threads can be identified. There is a common recognition of the need to move away from the analytical assumptions of equilibrium thinking, centred on linearity, predictability, homogeneity and simplification, to ones that encompass non-linearity, complexity, heterogeneity, uncertainty, ambiguity and surprise. There is also a repeated identification of scale interactions as critical. No longer is it adequate to separate off disciplinary foci into 'the micro' and 'the macro', the 'local and the 'global', but it is the interactions across scales, with dynamics operating at different rates across them that is key. This requires an openness to concepts of hierarchy and cross-scale analysis, with a focus on interaction and integration in analyses and responses. These perspectives on key drivers and system functioning suggest, too, different ways of approaching the complex questions that dominate management and policy issues. The narrow and closed equilibrium models that have dominated past perspectives must be used with extreme caution, with multiple health warnings attached. And yet we continue to see institutions geared towards working with these models and associated perspectives. A non-equilibrium perspective, by contrast, requires a more experimental approach to learning and an incremental approach to developing understanding under conditions of uncertainty, where surprises are always around the corner. This in turn has important implications for the design of institutions capable of working in this way (Ostrom et al, 1993; Becker and Ostrom, 1995).

This does not mean any less sophistication – indeed it requires more. In particular there are challenges of how to go beyond narrow modelling approaches that close down options and obscure, or factor out, variability. This applies too to our statistical routines, suggesting the need to question our assumptions about normal distributions rooted in standard statistical tests of proof. Dealing with outliers, contingent events and complex combinations requires new ways of judging and appraising outcomes (Riley and Fielding, 2001). Nevertheless, there are some cautions. A key lesson emerging from some approaches to understanding complex systems is to avoid going down the route of describing everything and learning little. Adaptive experimentation, double-loop learning and an open-ended perspective on research and appraisal are key attributes of a new approach which may get over the ‘model everything’ trap. But these are not easy to grasp and even more difficult to institutionalise in settings so used to the standard way of doing things (see STEPS Working Paper 3 on Designs).

This has perhaps been a key lesson of the explosion of interest in participation in development in the last few decades. Local knowledge, context-specific understandings and inclusive forms of engagement among diverse, knowledgeable stakeholders has been at the core of the argument for participation in development. As a challenge to the blueprint, instrumentalist, managerial approach to development participation was seen by many as the new opportunity. But just as with other approaches, ‘participation’ can be routinised, narrowed and closed down, captured in the process by particular interests and locked in bureaucratic procedures that subsume participation in their exclusion of complexity, dynamism and uncertainty, along with alternative perspectives and marginalised interests (Cooke and Kothari, 2001). ‘Participation’, in turn, can then be used to justify almost anything, even the most managerialist of aims, and the empowering opportunities of opening up debates to inclusive deliberation and reflective practice are thus lost.

In our intellectual and practical struggles to envision a science for sustainability, it is perhaps this area which the reviews above point to as an area key to future challenges. For many of the discussions in the literature reviewed above skirt around this rather central issue of reflexivity – the capacity to engage with the ways in which framings of systems are plural, conditioned by divergent social values, economic interests and institutional commitments.. Many of the perspectives highlighted are unquestionably useful in gaining an understanding of complex systems – but they often fail to interrogate questions of wider framing. If systems are constructed, as suggested by soft systems theories, and our understandings deeply dependent on where we are coming from and what our policy objectives are, then we must engage in a reflexive examination of framing

assumptions. Participation and deliberation can potentially contribute to this, but only under certain governance conditions and approaches (an issue further explored in STEPS Working Paper 2 on Governance).

As discussed earlier, the reasons why a wider vision of sustainability, which encompasses dynamic understandings and diverse framings, goes unrealised relate, at heart, to politics. Three factors stand out, ones that are often only implicitly discussed in the dynamics and complexity literatures discussed above. The first flows from the political economy of equilibrium and certainty. Driven by processes of investment and capital seeking certainty and stability of returns, there are broader reasons why complex and dynamic contexts are avoided. The second arises from institutional and political inertia: we do what we do because we do it (and it sometimes has worked in the past or in other contexts). Such inertia arises within institutions, organisations and professions, and is often reinforced by processes of internationalisation and globalisation in development. And finally, the politics of knowledge in development policy and practice mean that contested framings are not routinely deliberated upon as powerful interests hold sway, and an underlying lack of reflexivity means that contradictions and tensions remain unaddressed.

In sum, our understandings of complexity and dynamic systems must be tied in with political and normative understandings which take the arena of politics seriously. Debates about pathways to sustainability are necessarily situated, politicised and almost invariably contested, and these situated framings have to be central to our understanding of system dynamics, as well as our prognoses and recommendations.

4. PATHWAYS TO SUSTAINABILITY: RESPONDING TO DYNAMIC CONTEXTS⁵

How do these reflections influence our understanding of sustainability? The incorporation of an explicitly normative stance, together with a dynamic complexity perspective, contrasts strikingly with more technicist, managerial and equilibrium approaches to 'sustainability', where key aspects of dynamism

⁵ This first part of this section draws heavily on Scoones (forthcoming) and the second on Stirling (unpublished)

and complexity were often ignored and normative positions were rendered opaque. An emphasis on pathways implies debates about politically contested goals and objectives, but also, given the way such pathways are constructed in highly dynamic, uncertain and complex settings, the need for reflexivity in path-building, whereby destination, routes and directions are continuously re-considered by multiple participants.

Sustainability must be one of the most-used policy terms of the past two decades. Sustainability has become, par excellence, what Gieryn (1999) calls a 'boundary term' - one where science meets politics and politics meets science. The building of 'epistemic communities' (cf. Haas, 1992) of shared understanding of and common commitment to linking environmental and economic development concerns - has become a major concern across the world. But, like all such terms, sustainability has a history. It was not always that it had such significant connotations. Several hundred years ago, the term was first coined by a German forester, Hans Carl von Carlowitz in his 1712 text *Sylvicultura Oeconomica*, to prescribe how forests should be managed on a long-term basis. It was, however, not until the 1980s that 'sustainability' came into much wider currency. With the birth of the contemporary environmental movement in the late 1960s and 70s, and debates about the 'Limits to Growth' (Meadows, 1972), environmentalists were keen to show how environmental issues could be linked to mainstream questions of development. The commission chaired by Gro Brundtland, former prime minister of Norway, became the focal point for this debate in the mid-1980s, culminating in the landmark report 'Our Common Future' in 1987 (Brundtland, 1987). The now classic modern definition of sustainable development was offered:

Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs (1987:43)

The term sustainability, and more particularly sustainable development, drew on longer intellectual debates across disciplines. From the 1980s there was an explosion of academic debate about these issues, as the terms were projected onto the centre stage of policy debates globally, particularly in the run-up to the World Conference on Environment and Development held in Rio in 1992.

As the previous sections have demonstrated, ecologists have long been concerned with how ecosystems responded to shocks and stresses, and mathematical ecology had blossomed through the 1980s, with important work from the likes of Holling and May on the stability and resilience properties of both model and real biological systems (May, 1977; Holling, 1978). Sustainability could thus

be defined in these terms as the ability of a system to bounce back from such shocks and stresses and adopt stable states (Holling, 1993; Ludwig et al, 1997; Folke et al, 2002). Neo-classical economists drew on theories of substitutable capital to define (weak) sustainability in terms of the constancy of human and natural capital in delivering constant consumption goods over time, with market failures due to externalities corrected. Within economics, debates raged over whether such a 'weak' definition of sustainability was adequate or whether a stronger definition highlighting the lack of substitutability of 'critical natural capital' was needed (Pearce and Atkinson, 1993; Turner, 1992; Goodland, 1995; Goodland and Daly, 1996)⁶. Ecological economics traces more concrete links with ecological systems, generating such fields as life cycle analysis, ecological footprint assessment and alternative national accounting systems (Common and Perrings, 1992; Common and Stagl, 2005). Building on these different debates, Herman Daly and others developed an economic vision of sustainable development which challenged standard growth models (Daly 1991, 1996; Lele, 1991). Elements of this were picked up by the business community and notions of the 'triple bottom line' emerged, where sustainability was seen as one among other more conventional business objectives, resulting in a whole plethora of new accounting and auditing measures which brought sustainability concerns into business planning and accounting practice (Welford, 1995; Elkington, 1997). The World Business Council for Sustainable Development was launched with much fanfare (Schmidheiny, 1992; Holliday et al, 2002), bringing on board some big corporate players. Drawing on wider popular political concerns about the relationships between environment, well-being and struggles for social justice, political scientists such as Andrew Dobson (1999) delineated political theories that incorporated a 'green' politics perspective, and where sustainability concerns were put at the centre of a normative understanding of social and political change. Others offered integrative syntheses, linking the economic, environmental and socio-political dimensions of sustainability into what Kates and colleagues dubbed a 'sustainability science' (Kates et al, 2001).

By the 1990s, then, we had multiple versions of sustainability: broad and narrow, strong and weak, and more. Different technical meanings were constructed alongside different visions of how the wider project of sustainable development should be conceived. Each competed with each other in a vibrant, if confusing, debate. But how would all this intense debate translate into practical policy and action on the ground? The 1992 Rio conference, convened by the United Nations and attended by 178 governments, numerous heads of states and a veritable army of over a thousand NGOs, civil society and campaign groups,

⁶ See also the debate between Wilfred Beckerman and Herman Daly and others on economic measures of sustainability (Beckerman, 1992, 1995; Daly, 1995; Common, 1996)

was perhaps the high point – the coming of age of sustainability and sustainable development. This was the moment when many hoped that sustainability would find its way to the top of the global political agenda and would become a permanent feature of the way development, both north and south, would be done (Holmberg et al, 1991).

The Rio conference launched a number of high-level convention processes – on climate change, biodiversity, and desertification – all with the aim of realising sustainable development ideals on key global environmental issues (Young, 1997, 1999). Commissions were established, and national action planning processes set in train for a global reporting system against agreed objectives (Dalal-Clayton et al, 1994) and a whole plethora of economic valuation, indicator measurement and auditing/accounting techniques were elaborated. For example, David Pearce, Kerry Turner and colleagues at the Centre for Social and Economic Research on the Global Environment (CSERGE) developed approaches to environmental valuation as a means to ensure that environmental issues were taken into account in economic accounting and appraisal (e.g. Barbier et al, 1990; Pearce and Turner, 1990; Pearce and Warford, 1993; Turner et al, 1994)⁷, while others joined the growth industry of producing sustainable development indicators (e.g. Pearce et al, 1996; Rennings and Wiggering, 1997; Bossel, 1999; Pannell and Glenn, 2000; Bell and Morse, 1999). At the same time a more local-level, community-led process was conceived – Agenda 21 – which envisaged sustainability being built from the bottom up through local initiatives by local governments, community groups and citizens (Lafferty and Eckerberg, 1998; Selman, 1998). These were heady days indeed. But what did implementing sustainability mean? The result was an exponential growth in planning approaches, analysis frameworks, measurement indicators, audit systems and evaluation protocols which were to help governments, businesses, communities and individuals make sustainability real.

However, for many commentators writing in the last few years, the simplistic managerialism of many initiatives labelled ‘sustainable development’ left much to be desired (see Berkhout et al, 2003). Critiques focused on the lack of progress on major targets set in 1992, the endless repackaging of old initiatives as ‘sustainable’ this or that, and the lack of capacity and commitment within governments and international organisations genuinely to make the ideals of sustainability real in day-to-day practice (Vogler and Jordan, 2003). With the default bureaucratic mode of managerialism dominating – and its focus on

⁷ See reviews of these and other approaches by Hanley and Atkinson (2003); O’Connor and Spash (1999) and Hanley and Spash (1993).

action plans, indicators and the rest – the wider political economy of sustainable development was being ignored, with key elements of the sustainability debate being captured by powerful interest groups (Meadowcroft, 1999; Redclift, 1987, 1992). And with mainstreaming and bureaucratisation the urgency and political vibrancy was lost, and, with this came a dilution and loss of dynamism in a previously energetic and committed debate.

But all was not lost. Debates in recent years have refocused on some big issues which hit the headlines internationally, substituting for the emblematic issues – of the ozone hole, acidification, biodiversity loss and desertification - that dominated the run up to Rio. These have resulted in both public and, usually later, political reactions. For example, the controversy around GM crops which peaked in Europe in the late 1990s/early 2000s, had many political and policy reverberations internationally (GEC, 1999). This was a debate about, inter alia, the sustainability of farming systems, the future of food, human health and biodiversity and corporate control of the agri-food system. In the same way, the climate change debate really only began to be taken seriously post-2000. No longer was this a discussion on the arcane specifics of global climate models, but a real political and economic issue, which people and governments had to take seriously. Concerns about the environment and development drivers of new global diseases and pandemics were also pitched into the public and political realm, first with SARS and then avian flu. All of these issues – and the list could go on – are centred around classic 'sustainability' questions: they each involve complex and changing environmental dynamics having an impact on human livelihoods and well-being; they all have intersecting ecological, economic and socio-political dimensions; and, as with an increasing array of environment-development issues, they have both local and global dimensions.

But what is equally sure is that the existing 'sustainable development' institutional and policy machinery is incapable of dealing with them effectively. The Kyoto protocol on climate change has all but collapsed, and the options for a post-Kyoto settlement, that involves the US, China and India, has yet to be elaborated. Questions of biosafety surrounding GM crops have not been resolved, and nor does the UN Biosafety Protocol necessarily deal with these effectively. And recent disease scares have shown that neither global institutions nor local health systems are able to deal with the likelihood of a global pandemic.

So what of the future? Will sustainability become the unifying concept of the 21st century as many so boldly proclaimed just a few years ago? Certainly the 1990s managerialism and routinised bureaucratisation has been shown to have its limits. While 'sustainability' related commissions, committees and processes

persist in various guises, they have perhaps less political hold than before. But with climate change in particular – and wider risks associated with environmental change, whether in disease, biodiversity loss or water scarcity - now being seen as central to economic strategy and planning, there are clear opportunities for the insertion of sustainability agendas into policy discourse and practice in new ways.

What is required, we argue, is a more concrete clarification of what is meant by sustainability. For example, the classic Brundtland definition of sustainable development (above) highlights notions of needs and limitations. Explaining these concepts, it defines 'needs' as "in particular the essential needs of the world's poor, to which overriding priority should be given" and limitations are seen in relation to "the state of technology and social organization on the environment's ability to meet present and future needs" (Brundtland, 1987: 43). However, we must ask whether, given the complex, uncertain and dynamic contexts in which negotiations of sustainability must take place, such static notions of needs and limits are appropriate. Colloquial usage of the term 'sustainability' simply refers to the general quality of being "capable of being maintained at a certain rate or level" (OED, 1989), and is inherently conservative and not dynamic. This may be used in general terms to refer to any kind of structure or function and has no necessary normative connotations. Indeed, the particular structures and functions involved may often not even be specified.

In the post-Brundtland, post-Agenda 21 policy debates on sustainability, however, the intended usage is, as discussed, explicitly normative, referring to a broadly identifiable, but often poorly specified set of social, environmental and economic values. Although the details are often ambiguous, contested, and context-dependent, the functions concerned include the securing of particular standards of social equity, economic wellbeing or environmental quality. In this policy context, then, structures – such as particular laws, technologies, infrastructures or institutions – are not ends in themselves, but means to the functional ends of delivering on these (or similar such) stated normative aims. Following the discussion above, we argue that the sustainability debate must shed its managerial pretensions, and become recognised as a contested, discursive resource – a boundary object – that facilitates argument about diverse pathways to different futures. This brings sustainability firmly into the realm of the political, where debates around 'justice', 'democracy' and 'citizenship' have been for centuries.

In this, it is useful to distinguish the general, colloquial connotations of 'sustainability' (beginning with a lower case 's'), implying the maintenance of system properties in a general sense, from the specific normative, implications of

'Sustainability' (beginning with an upper case 'S'), referring to those properties valued by particular social groups or in the pursuit of particular goals. It is clear that the difference between sustainability and Sustainability is sometimes the object of ambiguity, elision or manipulation. It is often highly expedient that non-specific rhetorical appeals to sustainability can be used to obscure complex or contested interpretations and interests around the particularities of Sustainability. In this way, for instance, the UK government agriculture and environment ministry (DEFRA) makes prominent claims for support for 'sustainable farming', which mean in practice little more than the 'sustaining' of existing (unSustainable) agricultural strategies.

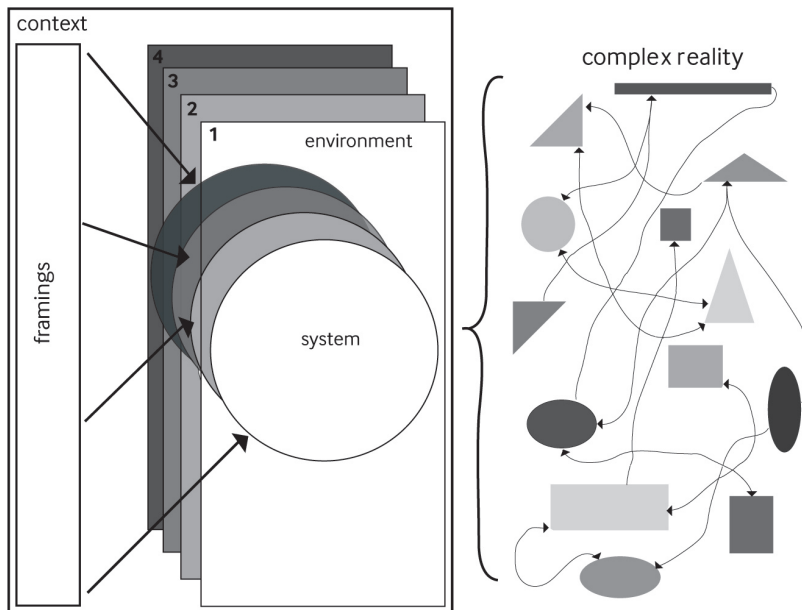
Successful transitions to Sustainability – and the envisaging of future pathways to Sustainability thus require attention not only to a formidable range of social, technological and environmental systems, but also to the ways in which knowledges, interpretations and aspirations diverge across the framings of different social actors. Whilst 'sustainability' may in principle be viewed either in terms of system structure or function, the focus in policy discussions of Sustainability is on a very particular set of social, economic and environmental functions; and needs to recognise possible contestations between different Sustainabilities. Although the details vary across contexts, the functions important to Sustainability hold in common the general property of being vulnerable to a variety of trends in the co-evolution of inter-coupled and social, technological and environmental systems. In short, the complex, non-linear, path-dependent and emergent dynamics of these systems and their respective contexts give rise to a multitude of particular vulnerabilities.

5. THE REFLEXIVE TURN: TOWARDS A HEURISTIC APPROACH

Following on from the discussion above, it is clear that 'systems' must be seen as simultaneously 'objective' (things, and their interactions, existing in a context) and 'subjective' (relating to different 'framings' under divergent perspectives on the system and its contexts). This is so, both in relation to the 'structures' and the 'functions' of the system. Such structures concern the ways in which the system and its boundaries are constituted, its internal and external relationships and the patterns in which its defining processes unfold. System functions, on the other hand, concern the 'outcomes' that are held to be delivered by the

system, as well as associated notions of purpose and meaning, and thus include inherent normative and political commitments. Informed in this way, a starting point for building a practical heuristic approach, which reflexively addresses the full picture of dynamism and socially-constructed complexity may therefore take the form of a simple picture of a 'system' in its 'environment', the latter including its social setting. Indeterminacies in the dynamics of both the system and the environment mean that this relationship is subject to a variety of different socially-contingent 'framings', which collectively comprise a 'context' for all such pairings of system and environment. The relationships between these key concepts are illustrated schematically in Figure 1.

Figure 1: Understanding a complex system: first steps to an analytical heuristic



Conceived in this way, positivist and constructivist perspectives can be integrated into a single picture, in which each representation of the 'system' is constituted by its associated 'context'. This context might then be comprehended in two ways. First, it might be seen in terms of 'objective' understandings of the environment in which the system is set. For instance, this environment might take the form of the international water management infrastructure in relation to a specific water and sanitation system; the global macro-economy

for a particular region or industry, or the wider biosphere in relation to a focal agro-ecosystem. Second, the context might be seen in terms of more explicitly subjective understandings of the socially-contingent framings which condition this view of the system. Here, the 'contexts' in which such water and sanitation systems, regional economies or agro-ecosystems might be represented could include a variety of stakeholders (e.g. research and development organisations, regulators or campaign NGOs) or disciplinary perspectives (e.g. social, physical or life sciences). Under each viewpoint, the structure, substance and bounding of the system in question will differ quite substantively.

Dynamic social, technological or environmental systems must be understood in relation to both their structures (e.g.: boundaries, components, networks, institutions and relationships) and their economic, institutional or ecological functions (e.g. services, outputs, consequences, meanings). Thus in the case of an agro-ecosystem structures would include both the physical elements (soils, water, crops, technologies) as well as institutions of research, extension and marketing for example. Such structures exist across multiple scales from the farm field to the international settings for standard setting and trade. System functions might include production for home consumption and food security, for marketing and trade and the generation of economic growth and foreign exchange, as well as environmental functions of conserving environmental services and biodiversity. How these structures and functions are viewed will of course vary under different framings, which will define both objectives and outcomes, as well as boundaries and relationships of the system.

As our earlier discussion has highlighted, debates about pathways to Sustainability are fundamentally about normative choices about system function and outcomes and must take into account trade-offs around overlapping objectives of poverty reduction, social justice and environmental care. But this is not a simple choice requiring some technical recourse to science (although of course the science of the environment, social-political processes and economic change remain important) – it requires debate, contestation and deliberation among diverse views and understandings. These are inevitably all deeply imbued with power and politics, and suggest multiple potential pathways to Sustainability. Whose vision of Sustainability counts is thus inevitably a political process, one that must grapple with uncertainty, complexity and dynamic implications.

In order to assess different potential pathways to Sustainability, there is thus a need to take a closer look at how systems respond to internal and external changes, both transient and persistent. Drawing on the type of complex systems approaches discussed above, we can differentiate between different internal (stability, durability) and external (resilience, robustness) properties of

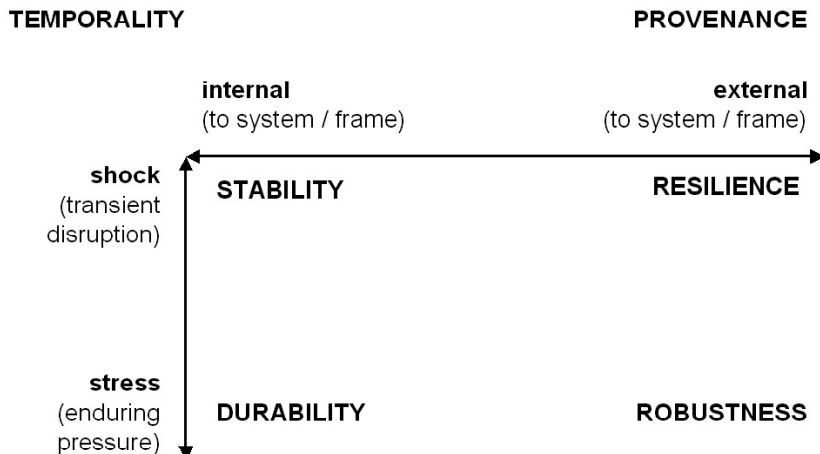
dynamic systems, and examine how the system responds both to transient shocks and more enduring stresses. These in turn may each originate either inside or outside any given construction of the system. Crucially, when seen under this dual positivist-constructivist heuristic, the natures of such shocks or stresses may be viewed equally as arising from shifting framings of actors' understandings of the system and its environment, or from shifting conditions in the systems and environments themselves.

This framework thus addresses both the temporality and the provenance of dynamic system interactions. Temporally, in any system we may distinguish vulnerabilities that arise under transient disruptions (shocks) from vulnerabilities associated with enduring pressures (stresses). This distinction is of considerable practical importance, because strategies for maintaining system function in the face of transient disruptions (like storm surge weather conditions in coastal areas) may be entirely different – and even antagonistic to – strategies for maintaining system function in the face of enduring pressures (like sea level rise under climate change). In the former case, we might look more to engineered barriers, in the latter more to managed retreat, for example.

In terms of their provenance, we may also distinguish vulnerabilities that arise in 'internally' in relation to a given framing of the system itself, from those that arise externally in relation to the system environment or its context. Again this is of some practical importance, because governance measures intended to address the vulnerabilities originating in the system itself will typically be very different from those aimed at addressing those originating in its context (see STEPS Working Paper 2 on Governance). In the case of water management, for example, we might in practice be dealing with strategies to mitigate internal vulnerabilities to engineering failure or skill shortages (shocks) or long-term patterns of water scarcity or changes in water demand (stresses). These both contrast with more external vulnerabilities to various forms of natural disaster, acts of violence, market disruptions or wider geopolitical developments (shocks) or demographic, industrial, political or climate change (stresses).

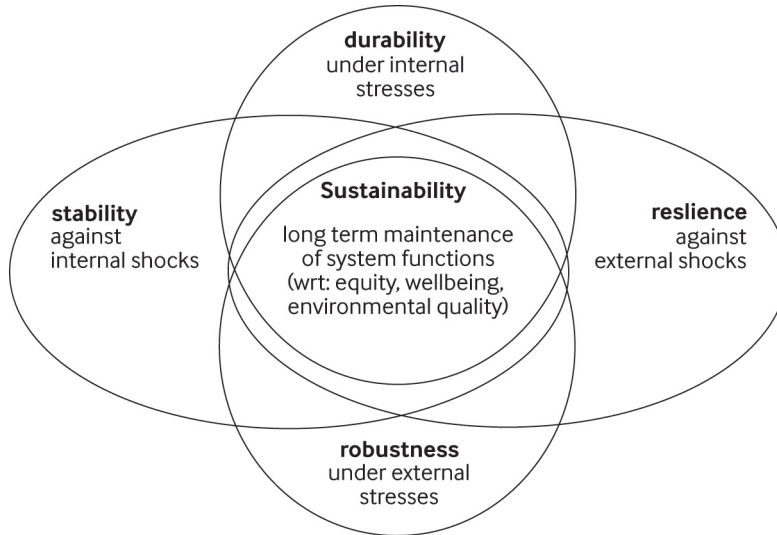
Taking the four-fold permutations yielded by relating the contrasts between shocks/stresses and internal/external sources, four dynamic system properties can be identified. These are: stability, durability, resilience and robustness (Figure 2). These are of course terms which are frequently referred to in the literature – often in the senses proposed here – but with meanings that are sometimes implicit, ambiguous and/or contested. This schema allows a more precise and rigorous characterisation of these crucial aspects of system dynamics and their framings. Each is critical to any understanding or deliberation concerning appropriate pathways to Sustainability.

Figure 2: Dynamic system properties – across time (temporality) and origin (provenance)



What then is the relationship between these 'dynamic system properties' and the overarching concept of Sustainability? In its colloquial sense, sustainability refers to a quality of being "capable of being maintained at a certain rate or level". If the object of such maintenance is viewed under the simple system/context model introduced in Figure 1, then Figure 2 encompasses all permutations of possible temporalities and provenances for the vulnerabilities against which systems functions must be maintained. In other words, properties of stability, durability, resilience and robustness (as defined here) may be recognised as each individually necessary and collectively sufficient for the overarching quality of sustainability (Figure 3).

Figure 3: Sustainability and four necessary but individually insufficient properties



It is a crucial consequence of the reflexive inclusion of both positive and constructivist understandings of system contexts (Figure 1) that the task faced in Sustainability appraisal (as addressed in the accompanying paper on 'designs', STEPS Working Paper 3 on Designs) amounts to more than just a technical assessment of objective dynamic properties. As shown in Figure 2, stability, durability, resilience and robustness may each also be addressed in terms of the dynamics of the multiple framings of the system and its environment and functions. What is the system? What is its purpose and meaning? What is Sustainability? – All are inevitably contested. In considering this extended heuristic, then, there is a need for explicit elaborations of the diverse framings in any particular area, for example with respect to:

- Diverse views on desired outcomes (poverty, environment, justice), in relation to who and with what definition of 'desired' (i.e.: defining sustainability).
- Diverse views on the impacts and consequences of internal and externally driven change (and definitions of system boundaries and their environmental contexts across scales).

- Diverse views on the impacts and consequences of short-term shocks and long term stresses on desired outcomes, and the trade-offs across scales.
- Diverse views on the trade-offs between system properties; for example between wanting a robust/resilient system and a stable/durable one.

Pathways to Sustainability are thus constructed through decisions which must explicitly tackle trade-offs between each dynamic system property as seen under different perspectives. Critically, this requires incorporating a reflexive process, whereby assessments become necessarily positioned and partial, constructed in relation to the social-economic-political subjectivities of the analyst. Adaptive and reflexive management of these 'systems' cannot follow a sequential process, whether as stages or through simple cycles, as different framings of the system, and its functionality, will be disrupted or rendered problematic by stresses and shocks in different ways. This means that some 'framings' will be forced 'open' (destabilised) by events at different times (and places) more easily than other framings. For example, dynamic events in the global food system will be more disruptive of the more situated 'system framings' of local farmers (who occupy a more limited and vulnerable system, and may experience system properties and uncertain dynamics in particular ways) than say of the higher-level view of global capital (who might see dynamism - like crop failures or shifts in relative commodity prices - as a source of profit-making within a larger, more stable system). Thus some framings are more robust than others, and in the contested negotiation of sustainability pathways, the power relations between different framing assumptions, and the 'objectification' of such framings is key.

Negotiating Sustainability is therefore necessarily a political process, informed by scientific analyses of contexts, systems and their properties, but one that fundamentally requires an opening up of debate, through a diversification of knowledge bases, processes of inclusive deliberation at all steps, supported by reflexive institutional frameworks and governance systems, requiring perhaps above all an increased humility and attention to power relations in processes of appraisal and decision-making.

6. CONCLUSION

Just how this might come about – both in terms of wider governance issues and particular appraisal designs – is the subject of other papers in this series - in particular, STEPS Working Papers 2 and 3 on Governance and Designs. This paper has offered a route towards these wider goals by offering a heuristic approach to thinking about complex, dynamic systems in ways that elaborate and extend a range of bodies of work concerned with how to respond to complexity, variability and rapid change in highly dynamic contexts. Debates about the general property of sustainability (and particularly the normative quality of Sustainability) have highlighted how important it is to be reflexively aware of diverse framings of system structures and functions, and of how trade-offs between system properties are ultimately guided by such normative and political choice in the quest for sustainability.

A new science for Sustainability thus requires a joining together of now well elaborated non-equilibrium perspectives from the natural sciences with constructivist social science perspectives in an integrated manner. With Holling (1998) we agree that a positivist, sometimes reductionist, analytic is needed alongside more integrative, holistic sciences. This requires greater dialogue and interaction across disciplines, sectors and policy debates. As Holling (1998: 5) notes “Those more comfortable in exercising only one of these have the responsibility to understand the other”. Figure 4 offers a preliminary, schematic and highly simplified typology of these different streams of debate.

Figure 4: Approaches to understanding sustainability: a very tentative schema

	A 'Equilibrium' approaches	B 'Non-equilibrium', 'complex systems' approaches	C The reflexive turn: pathways to sustainability
Key features	Linearity, predictability, homogeneity, simplification	Non-linearity, complexity, heterogeneity, uncertainty, ambiguity, ignorance, surprise	Multiple possible framings/ constructions of the 'system'
System organisation	Single level, social dimensions separable – closed, 'hard' systems	Multiple scales, hierarchy, interaction, integration	Multiple framings of system and contexts
Models and methods	Equilibrium models, normal distribution based statistics, controlled experimentation, valuation/audit/ CBA	Open experimentation, interactive modelling, adaptive learning, trial-and-error, non-standard distributions and statistics, open-ended appraisal	Scenarios, multi-criteria mapping, pathways analysis
Management implications	Command-and-control, top-down, prescriptive, instrumental – single 'optimal' solution	Adaptive, responsive, context- and scale-dependent	Multi-scale, multi-level participative, deliberative negotiations around multiple solutions, trajectories, pathways
Intervention principles	Expert based – often quantitative, singular metrics (carrying capacity, sound science, probabilistic risk etc.)	Adaptive management and learning	Deliberative, inclusive, negotiated, performative – diverse knowledges needed; reflexivity/ normativity/ politics key
Social science engagements	(Much of) mainstream applied social science engagement in development.	(Parts of) anthropology, (political) sociology, ecological economics, science and technology studies, political ecology, organisation/ institutional studies, and especially resilience studies and sustainability science	An agenda for the STEPS Centre?

In this paper we have argued that the move from 'equilibrium approaches' to 'non-equilibrium complex systems' understandings has been significant across a wide span of natural and social science enquiry, as a response to the practical and intellectual challenges of dealing with complexity. Echoing Holling, we agree this is not an either/or dichotomy – elements of different traditions can interact productively with each other, as long as mutual appreciation and understanding is at the core, and institutional and political motivations do not preclude one perspective from view; a feature, as we have seen, which too often happens in development.

However, there is a further move – what we have called the reflexive turn in this paper – which is also critical. This is because the debates between equilibrium and non-equilibrium perspectives are not simply resolvable in debates about the contested idea of Sustainability. This requires the incorporation of a further step – one not often fully accommodated in the existing literatures on complexity and dynamics beyond a few wise words about participation, inclusion and deliberation. It derives from a constructivist position on understanding systems, their structures, properties and functions, centered on normative/political understandings of Sustainability.

Any negotiation of 'pathways to Sustainability' in dynamic complex systems must therefore be centrally about:

- Focusing on framings – of contexts, of systems and their properties - recognising divergent epistemological and ontological positions, associated with different actors and interests.
- Recursively negotiating the trade-offs across diverse pathways (actual, potential and imagined) in relation to the political-normative positions of diverse actors.
- Examining processes across scales and over time, being attentive to the cross-scale system interactions of dynamics, power relations and institutional/governance arrangements, as well as ensuring longitudinal analyses of change processes (cf. Gibson et al, 2000; Ostrom 2007).
- Integrating understandings of dynamics into the overall governance of appraisal, decision-making and policy processes, avoiding simplistic, blueprint, managerial responses to complex and uncertainty settings, and emphasizing diversity in institutional and policy options (Stirling, 2007).

Creating the space – which is sufficiently open but also well-informed – to have such deliberation about pathways to Sustainability is a critical challenge for development policy and practice. The simple heuristic approach presented in this paper, together with the justification for its need and a review of some of the diverse antecedent literatures, is a first attempt by the STEPS Centre to offer a way forward in this challenging, but vitally important, area.

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