CONTESTED MODELLING

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ABSTRACT

We suggest that the role and function of expert computational modelling in real-world decision-making needs scrutiny and practices need to change. We discuss some empirical and theory-based improvements to the coupling of the modelling process and the real world, including social and behavioural processes, which we have expressed as a set of questions that we believe need to be answered by all projects engaged in such modelling. These are based on a systems analysis of four research initiatives, covering different scales and timeframes, and addressing the complexity of intervention in a sustainability context. Our proposed improvements require new approaches for analysing the relationship between a project's models and its publics. They reflect what we believe is a necessary and beneficial dialogue between the realms of expert scientific modelling and systems thinking. This paper is an attempt to start that process, itself reflecting a robust dialogue between two practitioners sat within differing traditions, puzzling how to integrate perspectives and achieve wider participation in researching this problem space.

Keywords: systems thinking; systems practice; expert modelling; scientific modelling; ontology; praxis; purpose

INTRODUCTION

Computational models are widespread and increasingly becoming indispensable in decision-making about complex systems at a wide range of temporal and spatial scales. With the wider recognition of the complexity of contemporary sustainability challenges, society increasingly – and mostly unknowingly – relies on models for analysis and future projections. Enormous investments are made in the development of models of social-environmental and social-technological systems of escalating size and complication via the agency of government and industry funded research (e.g., Future Earth, 2012; WCRP, 2009; Balaji et al., 2004). These models by nature are simplifications, structural representations of an *organic*, dynamic and complex reality. Yet their content and structure are increasingly opaque, even to other expert modellers (e.g. Anderson, 2010; Lenhard and Winsberg, 2010).

Contested Modelling

At the same time, the role of models in decision-making is changing. We have observed that the representation of complex systems in models collapses all too easily to their conceptualisation as complicated-but-predictable systems, like machines, resulting in idea of *optimising* the world, at all scales from individual businesses up to the whole planet, based on the outputs of models. Overpowering other representations and narratives, instrumental rationality is pervading society (Sanderson, 2006, Kelly, 2003). As the purpose of models moves from being about "advancing knowledge" to "informing action", reflection becomes immanently important, on the modelling process (Helgeson et al., 2012; Boyd and Richerson, 2005) and across the methodology spectrum, from idiographic to nomothetic (Gilbert and Arhweiler, 2009).

However, the purpose of a model is rarely stated and often blurred, as the projects reviewed in this paper indicate. It can range from objectivist prediction (as if the model sits within a control loop) to subjectivist elicitation of mental models, exploration of "what if" questions, and reflection (Pidd, 2004). Assessments of the confidence that can be held in the predictive power of models can verge on the arcane and are often methodologically incoherent (as discussed in Stainforth et al., 2007 and Keenan et al., 2011), but still have a powerful draw for the users of the output (e.g. IPCC 2007). Their philosophical basis is rarely interrogated; plausibly realistic model output is confused with reality. This "*unreasonable effectiveness of mathematics*" (Anderson, 2010) can be interpreted as the possibility that modelling leads us to make abductive fallacies (Lorenz, 2009, Schwaninger and Hamann, 2005) – i.e. applying inadequate simulation techniques to a simulation task and obtaining the *"right output behaviour for the* wrong *reasons*[1]*"* (c.f. Barlas, 1996).

In the light of these issues, this paper reviews the modelling processes from four research projects ranging from local to global scale, in which modelling is being performed with a broad goal of informing experts and/or society generally about sustainability options.

METHOD

The theoretical lens for this paper has been chosen on the basis of its discriminating power to address issues of ontology and praxis. Our first dimension of analysis revolves around the problem of ontology. We make use of Geel's work in analysing socio-technical transitions towards sustainability against seven social-science ontologies (rational choice, evolutionary theory, structuralism, interpretivism, functionalism, conflict and power struggle, and relationism) to formulate a key question (Geels, 2010). The modelling activities in these projects extend to real-world interventions, and therefore our second dimension is focused on praxis, by which we mean the way in which the theoretical knowledge of the expert modeller is enacted through intervention. By definition, we refer to the people conducting the modelling in these projects as expert modellers. Our third dimension of analysis takes a reflexive perspective, drawing on

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[1] Barlas said *"right output behaviour for the* right *reasons"*

(Romm, 1998, Macnaghten, Kearnes and Wynne, 2005, Doubleday, 2007) who have translated the ideas of reflexivity from general social theory into the context of environmental governance. For us, reflexivity involves sensitivity to inputs from diverse perspectives, consciously recognising that there are alternative ways of seeing issues of concern. It involves a deliberate consideration of whether all the necessary voices are present, and are being listened to. These three perspectives or dimensions of analysis have led us to propose the following questions which we believe need to be clearly addressed by any project in which modelling forms the underpinning of its methodology:

1. **Ontology**: What is the underpinning ontology for the project's methodology? Is there diversity in underpinning ontology? Is ontology made explicit, or self evident from the mode of writing or journals used to communicate results?

2. **Praxis and the purpose of modelling**: What is the (stated) purpose of modelling in the project? How best should the model purpose be expressed? Is it to constrain uncertainty, or at least better characterise the boundaries of uncertainty? Is modelling designed to guide action, or merely to "predict", where action is beyond project scope? If modelling is directed towards action, how does it relate to an explicit process of action research?

3. **Reflexivity**: How does modelling support reflexivity and stakeholder engagement? What is the process of engagement with stakeholders? Does engagement persist beyond a project lifetime?

PROJECT ANALYSIS

We have reviewed the modelling approaches taken in four projects. These projects aim to develop and use models to inform decision-making in either a social or business context, and develop phenomenological descriptions of themes that arise. The authors have been involved as research co-investigators or research student supervisors in these projects. The project details are summarised in Table 1 and Figure 1.

Sympact – Exploring the environmental impact of digital transformation

The Sympact project is funded by a grant under the UK Engineering and Physical Science Research Council (EPSRC) Transforming Energy Demand through Digital Innovation (TEDDI) programme in partnership between the University of Bristol, Guardian News and Media (GNM) and the University of Surrey Centre for Environmental Strategy. The purpose of its modelling activity is to evaluate different future scenarios of how the news industry might look as a result of digital technology innovations, with a view to informing sustainability strategies. The approach adopted integrates environmental life-cycle assessment (LCA) techniques (Schien, Preist, Yearworth and Shabajee, 2012) into systems modelling approaches (Yearworth, Schien, Preist and Shabajee, 2011). This allows quantitative energy and emissions analyses to be combined with more speculative models of technological and behavioural change, such as models of the uptake of electronic reader devices.

Contested Modelling

The underpinning ontology for the models developed in Sympact is clearly functionalist. The project has developed a system dynamics model that shows dynamic behaviour of a system comprising a producer and consumers of digital news media presented as a set of scenarios over a period of 10 years. The project has also had to deal with modelling 'at the next level down'; hence its use of detailed LCA in order to answer questions about an appropriate functional unit for analysis. For example, the geographic location of consumption has emerged as a significant factor in determining energy footprint and emissions (Schien, Preist, Yearworth and Shabajee, 2012). The purpose of Sympact's system dynamics model is to support attempts to understand what factors are likely to influence the evolution of this system and to make predictions about greenhouse gas emission trends in the digital news media industry.

The involvement of a major news industry player in the project is indicative of its emphasis on praxis, in terms of enabling advice on business strategy by addressing such questions as the impact of future carbon pricing.

Despite the co-development of the research with the prime user of its outputs, reflexivity has not been addressed in the project's publications, and the role of stakeholders and their engagement is not clear in its documentation. However, co-author Yearworth's role as a co-investigator in the project means that it is possible to state that future work will involve investigating a way of presenting the models developed so far in a web-based framework that will enable a wider stakeholder group to use them in developing their own scenarios about the evolution of energy use and emissions in this market.

HalSTAR – the Halcrow Sustainability Toolkit and Rating System

HalSTAR was developed by the consultancy company Halcrow, now part of CH2M HILL, with the stated purpose of achieving a grounded, holistic approach to assessing sustainability (Pearce et al., 2011). It is designed as a flexible appraisal framework that ensures that a wide range of sustainability issues and options are considered in client consultations and with broader stakeholder groups as part of project planning, design and management.

HalSTAR's framework is based on Forum for the Future's five capitals model[2] (natural←human and social←financial and manufactured). Its underpinning knowledge base is populated with concepts drawn from a qualitative data analysis of an extensive body of relevant literature, ranging from formal guidelines and regulations through to current scientific publications on sustainability concerns, issues and requirements. Within the 'five capitals', HalSTAR further groups these concepts by stakeholder viewpoint ranging from client to project, end-user, local, regional and global. This framework was designed to allow for flexibility in use according to client needs, from detailed issues within schemes or projects to overall performance summaries. The current development of HalSTAR involves linking the diverse concepts within the framework, through the

[2] http://www.forumforthefuture.org/project/five-capitals/overview

development of causal loop diagrams with the purpose of identifying potentially important feedback loops which could have an impact on the dynamic behaviour of solutions proposed through the use of the framework (Montgomery, 2012).

Although the initial elicitation of concepts from the literature was conducted through a process of qualitative analysis, their clustering into needs or capitals and grouping into stakeholder viewpoints produces a structural arrangement. This, coupled with the use of causal loop diagrams, suggests that the prevailing ontology for the project is functionalist.

The praxis is clearly about stakeholder engagement in the exploration of sustainability options. HalSTAR has in effect *digested* a vast range of literature and presented it in a framework that makes it easier for stakeholders to engage with the material. Whilst the framework is still owned by the expert modellers in Halcrow, the engagement process is clearly intended to enact a change in behaviours with the clients. This method of engagement mediated through expert-owned models suggests a useful way forward that potentially offers a high degree of reflexivity.

The framework is being used to surface issues at different levels of concern to stakeholders but is not a methodology as such for reconciling conflicting stakeholder views. The ongoing development of the causal loop diagrams could be used as a basis for group model-building activities, and thus approaches a more interpretivist stance (Montgomery, 2012). The latter may also go some way towards improving reflexivity, with both stakeholders and expert modellers learning more about sustainability issues through engagement over shared models of causal relationships derived from the original HalSTAR framework.

CONVERGE – Rethinking globalisation in the light of Contraction and Convergence.

CONVERGE is a European Commission FP7 research project, involving academic and non-governmental organisation partners from five countries. Its focus is on global sustainability, seeking to conceptualise equity for human societies within Earth's natural biophysical limits. It also aims to promote social learning and action, drawing lessons from existing sustainability activities at the community level in the partner nations.

In the project, system dynamics models are developed through consultation with community groups, integrating various measures of sustainability across scales and in different contexts. The stated purpose of these models is to investigate and promote adaptive management approaches (CONVERGE 2009). Other project documents refer to the value of models for supporting communication within the stakeholder communities and improving understanding of the complex system (e.g. Koca et al. 2010). Yet at the same time, the project's approach involves taking models developed through these engagement events and applying them in other contexts (e.g. Kristinsdóttir et al. 2011).

Thus several underpinning ontologies are apparent in CONVERGE's methodology and praxis. Ideas on interpretivism and power/conflict resolution were invoked in providing the rationale for the modelling consultation approach but have faded into the background as the project has developed. The ways in which the expert modellers actually develop the models are strongly functionalist; and structuralism is evident from the assumption that models developed about a particular issue or in a given community can be scaled up to the global or applied universally. The models are explicitly intended to guide action towards sustainable practices, and action research approaches are explicitly mentioned in the project workplan. The plurality of ontologies and model purposes has been recognised, and indeed the project includes a specific work-package to reflect upon and address interdisciplinary challenges such as this.

We, the authors, are research advisors to CONVERGE (co-author Cornell was previously an investigator within the project). In this capacity, we have focused on issues of reflexivity in the project team's modes of working. There are two strands of research in the project involving engagement with community stakeholders – the more interpretivist analysis of cases of local sustainability initiatives, and the process of system dynamics model building. In the former, the engagement generally has involved a long-term relationship between researchers and communities (initiatives pre-dated the project and will continue beyond its life). In the latter, stakeholder engagement is much more ad hoc. The project team have noted some conceptual and practical tensions between these two distinct strands, but the research is not yet advanced enough to draw robust lessons about the extent to which the modelling supports more reflexive processes in stakeholder engagement and shifts towards more sustainable practices.

IHOPE – Integrated History and future of People on Earth

IHOPE is a profoundly interdisciplinary research project linking social and environmental sciences to understand human-environment interactions over multiple timescales. It began at a Dahlem expert discussion workshop in 2005 (Costanza et al., 2006), evolving into an international collaborative project supported by a network of institutions and global change research programs within the Earth System Science Partnership[3]. IHOPE's stated goals, as outlined in the research plan (Hibbard et al., 2010) are to:

- map the global integrated record of human and biophysical change;
- test social-environmental system models to understand the dynamics of those system/s; and
- project options for the future of humanity.

Much of the formal documentation of this project strongly implies a functionalist ontology, but there is some dissent and discussion about the nature and role of models and the modelling process in the project (Cornell, 2010 and Cornell et al. 2010). Dearing et al. (2010) and Sörlin (2011) have reflected in depth upon the rationale for looking at the past in this way, and provide a nuanced analysis that addresses the functionalist/structuralist limitations and deterministic implications.

[3] http://www.essp.org

Contested Modelling

At present, the modelling effort in the project is still piecemeal – to date, the main focus of the initiative has been to gather a suitable database of examples of human-environment interactions. However, the focus has recently returned to modelling, first because it offers a way to identify and systematise "suitable examples" for expansion of the evidence base, and also because the project leadership recognises the need to engage with a wider group of knowledge communities in the social sciences and humanities. At present, the research plan text suggests that the end-goal for all our effort is to "improve quantitative models". At the very least, it needs now to be developed further to say what these models might be for, and explain what kinds of processes the models will be deployed in. Above all, the research plan should recognise that new knowledge inputs they may actually transform, not merely slot into, the current functionalist content and procedures of Earth System modelling.

Project	Description	Funding Body	Project URL (short)	Indicative References
SYMPACT	Tools for assessing the systemic impact of technology deployments on energy use and climate emissions, in conjunction with the UK newspaper *The Guardian*. The research aims to develop methods and tools that would enable collaborative model building to take place at scale to enable shared learning over large sets of stakeholders, and to trial this with a user community associated with the technological transformation of the news publishing industry towards online media.	UK EPSRC (EP/I000151/1)	http://goo.gl/XNvxk	(Yearworth, Schien, Preist and Shabajee, 2011, Schien, Preist, Yearworth and Shabajee, 2012)
HalSTAR	A pre-sales engagement tool for structuring conversations between Halcrow, an environmental consultancy business, and its clients, in order to elicit requirements and design appropriate solutions within a multi-criteria sustainability framework.	Halcrow Ltd Private Venture (PV)	http://goo.gl/bCoIu	(Pearce and Murry, 2010, Pearce, Murry and Broyd, 2012)
CONVERGE	An action-oriented project with a multi-scale focus, involving community engagement on global sustainability issues. "*CONVERGE recognises the deep-rooted interconnections of environmental and socio-economic systems. A variety of systems thinking methods will be used to 're-conceptualise' the ingredients and processes that produce the phenomena of globalization, in order to move towards a more sustainable and equitable path for the world's inhabitants*." (CONVERGE Description of Works, 2009)	European Commission (FP7-ENV-2008-1, project 227030)	http://goo.gl/zzp1e	(Fortnam, Cornell, Parker and CONVERGE_Project_Team, 2010)
IHOPE	A global research network, sponsored by International Human Dimensions Programme for Global Environmental Change and the International Geosphere-Biosphere Programme and linked projects. Global-scale, multi-timeframe analysis of dynamics of human-environment interactions, drawing on contemporary Earth observation and socio-economic analysis, and historic, palaeoenvironmental and archaeological studies.	Consortium support[4]	http://goo.gl/JnMGR	(Costanza et al., 2012)

Table 1: Summary descriptions of four projects applying systems modelling approaches to sustainability challenges

[4] The main contributors to date are: the University of Uppsala (where the international project office is now hosted), Stockholm Resilience Center, US National Center for Ecological Analysis and Synthesis, the UK Natural Environment Research Council's QUEST program, Arizona State University, the Institute for Sustainable Solutions at Portland State University, the Australian National University's Climate Change Institute, the Dahlem Foundation, the US National Center for Atmospheric Research and the Pacific Northwest National Laboratory.

DISCUSSION AND CONCLUSIONS

Modelling has become a specialised scientific endeavour largely disconnected from social processes, while holding the potential to shape society through its outputs. These four projects have the explicit aim of informing interventions in society, and thus need to face up to the intensive mathematisation of modelling and its associated simulation techniques, which tend to exclude narrative concepts and representations. While they address different scales, contexts and objectives, the modelling paradigm adopted by all four projects analysed is apparently functionalist and deterministic – that is, equations are being solved, and loops being closed (Geels, 2010). Such modelling easily becomes essentially black-box in nature, with the process and results owned by experts.

The functionalist/structural account of complexity and associated need for modelling and simulation approaches to explore dynamic behaviour (Fararo and Butts, 1999) mean that the expert modeller plays an essential role in bringing these models into existence and in their on-going ownership and control. It is this ownership and control that puts the models outside processes that would make them *debatable*. However, we believe that the expert modelling community needs to assume *a priori* that its models will be *contested*, both in the narrow scientific sense of falsifiable, but also as part of the wider social context in which the models' purpose is being enacted. The latter perhaps represents a Popperian ideal; expert models, ranging in scale from the specialised models developed by the projects discussed in this paper through to full-complexity Earth system models, are not just about making sense of "laboratory science", they are becoming a necessary component of intervention in the social world.

We propose that questions should be asked of the relation between the expert modelling within a project and its prevailing paradigm. Starting with functionalism, the most prominent paradigm in our four projects, we suggest these could include:

- Is functionalism the only approach suitable for dealing with coupled socio-technical or socio-environmental or "socio-*x*" problems?
- Does functionalism imply determinism and deny voluntarism/agency (Lane, 2001b, Lane, 2001a)?
- Do expert modellers inevitably tend to accounts of system behaviour based on dynamic interaction between system elements?
- How does functionalism confine or liberate expert modellers' perceptions of the world?
- Is a functionalist account of complexity any more or less believable, by stakeholders, than other possible accounts?

We also note that these projects grapple to different extents with issues of explanation, causality and supervenience. Questions that can help illuminate those issues include:

- Are projects modelling a complex system's behaviour at the level of the behaviour (i.e. black box modelling), or seeking to capture properties and behaviour the next level down?

Contested Modelling

- Is there evidence of any thinking with respect to supervenience – is it muddled, clear, absent?

The organizational cybernetics community already recognises the notion of second-order systems (self-aware, self adaptive) and understands the relationship to the social world, notably through the work of (Luhmann, 1995). Their modelling is structural but not deterministic. Other examples exist: economic modelling around information asymmetries to understand emergent behaviours such as perverse incentives and moral hazard also give us structural but non-deterministic models (as discussed in Hansen 2010). The work of Habermas (notably ideas of communicative action; Habermas, 1986), is little known by the expert modeller community, but its emphasis on ensuring that citizens involved in public decision-making have capacities for engaging in informed debate resonates with sustainability concerns and has implications for modelling processes intended to inform sustainability decisions.

However, by what mechanisms can this wider stakeholder engagement and debate come about? Methods based on argumentation (De Liddo, 2010), participatory action learning (Perkons and Brown, 2010), Issue Based Information Systems (IBIS) (Buckingham Shum, 2006, Conklin, 2003), and social learning (Senge, 2005) all offer possible solutions, either singly or in combination.

Ultimately it is the questions about modelling purpose and praxis that are most important. In the context of sustainability, the intended outcome of much modelling is behaviour change – but is this a function of the model's predictive accuracy or the method of coupling the modelling process to social change? It could be argued that the latter is more important than the former, although some level of accuracy is required. However, the balance of these options can never be tested if changes are modifying the system all the while. Answering these questions requires healthy and reflexive attitudes in the expert modeller community towards building models that are fit for purpose, rather than "right" (Sterman, 2002, Box and Draper, 1987). For example, what is the purpose of climate modelling? It is the largest social experiment based on modelling ever attempted – predictive mathematical models injected into the sightline of powerful decision-makers. Yet the climate modellers' prevailing functionalist worldview can make them unfortunate bedfellows with policy makers. Who has the view of the *real world*? Many of these experts hold onto the idea of being "*not policy prescriptive*" (e.g., IPCC 2010), but given knowledge derived from numerical predictions emitted by their models, intervention then becomes a moral question that cannot be avoided. The *system* that is the *object* of expert modellers' attention is not "*out there'* and disconnected from the experts: they too are the system and their actions are not independent of it.

This raises questions of reflexivity and scrutiny. Who owns the knowledge derived from stakeholder-engaged, use-oriented modelling, and how is it to be applied? Unfortunately most expert modeller approaches often seem stubbornly opaque. This can be due to the difficulty of creating suitable engagement processes, although HalSTAR suggests a way forward in an industry setting. To all intents and purposes, without appropriate stakeholder engagement, models become black-boxes that emit predictions but are not open to internal structural, or white-box, validation (Barlas, 1996). Attention then focuses on seeking "agreement between models", rather than agreement on process that meets purpose. The paradigmatic expert modeller, constructing models to satisfy a narrow set of "scientific" criteria, denies a wider role for the modeller in the social processes that must mirror the very changes these models seek to explain. Where there is debate about models, this is likely to be around black-box predictive accuracy rather than informed white-box debate, *sensu* Barlas, in which model validation involves evaluation in a "*continuum of usefulness*". It is notoriously difficult for the non-scientific public to understand the distinctions between ignorance, uncertainty and contingent findings, expressed as testable hypotheses (Spiegelhalter et al., 2011). These factors stultify engagement, interventions and effectiveness of societal or behaviour change. By over-attention to "being scientific" we paradoxically close avenues for scientifically informed but *systemic* solutions.

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