Climate and Development
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/tcld20

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John Jacob Nay[a], Mark Abkowitz[b], Eric Chu[c], Daniel Gallagher[d] & Helena Wright[e]

[a] Program in Integrated Computational Decision Science and Institute for Energy and Environment, Vanderbilt University, PMB 407702, 2301 Vanderbilt Place, Nashville TN 37240-7702, USA

[b] Department of Civil and Environmental Engineering, Vanderbilt University, PMB 351831, 2301 Vanderbilt Place, Nashville TN 37235, USA

[c] Department of Urban Studies and Planning, Massachusetts Institute of Technology, 77 Massachusetts Avenue, Room 9-316, Cambridge, MA 02139, USA

[d] Adaptation Fund Board secretariat, Mailstop P4-400, 1818 H Street, NW, Washington, DC 20433, USA

[e] Centre for Environmental Policy, Imperial College, London, UK

Published online: 28 Apr 2014.

Climate and Development, 2014
Vol. 6, No. 4, 357–367, http://dx.doi.org/10.1080/17565529.2014.912196

climate and development

REVIEW ARTICLE

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John Jacob Nay[a*], Mark Abkowitz[b], Eric Chu[c], Daniel Gallagher[d] and Helena Wright[e]

[a]*Program in Integrated Computational Decision Science and Institute for Energy and Environment, Vanderbilt University, PMB 407702, 2301 Vanderbilt Place, Nashville TN 37240-7702, USA;* [b]*Department of Civil and Environmental Engineering, Vanderbilt University, PMB 351831, 2301 Vanderbilt Place, Nashville TN 37235, USA;* [c]*Department of Urban Studies and Planning, Massachusetts Institute of Technology, 77 Massachusetts Avenue, Room 9-316, Cambridge, MA 02139, USA;* [d]*Adaptation Fund Board secretariat, Mailstop P4-400, 1818 H Street, NW, Washington, DC 20433, USA;* [e]*Centre for Environmental Policy, Imperial College, London, UK*

(*Received 21 September 2013; final version received 10 February 2014*)

In order to increase adaptive capacity and empower people to cope with their changing environment, it is imperative to develop decision-support tools that help people understand and respond to challenges and opportunities. Some such tools have emerged in response to social and economic shifts in light of anticipated climatic change. Climate change will play out at the local level, and adaptive behaviours will be influenced by local resources and knowledge. Community-based insights are essential building blocks for effective planning. However, in order to mainstream and scale up adaptation, it is useful to have mechanisms for evaluating the benefits and costs of candidate adaptation strategies. This article reviews relevant literature and presents an argument in favour of using various modelling tools directed at these considerations. The authors also provide evidence for the balancing of qualitative and quantitative elements in assessments of programme proposals considered for financing through mechanisms that have the potential to scale up effective adaptation, such as the Adaptation Fund under the Kyoto Protocol. The article concludes that it is important that researchers and practitioners maintain flexibility in their analyses, so that they are themselves adaptable, to allow communities to best manage the emerging challenges of climate change and the long-standing challenges of development.

Keywords: simulation modelling; agent-based; cost–benefit analysis; GIS; decision-support

1. Introduction

For a number of reasons, climate change poses additional negative implications for developing countries as well as poverty-affected communities residing anywhere (Stern, 2006). Poverty is associated with less economic, political, and organizational capacity to adapt, which makes individuals and communities more vulnerable to economic and climate shocks (Dodman & Satterthwaite, 2008). Moreover, poverty-affected communities may live in more vulnerable areas because these are historically the more marginalized areas, which are often the by-products of informal land tenure, a lack of public services, and exposure to natural hazards. Developing economies depend more on climate-sensitive activities, such as rain-fed agriculture, that are more impacted by climate variability (Hertel & Rosch, 2010). Financially constrained governments are less able to devote significant amounts of capital to "climate-proof" infrastructure and improve weather forecasting. Equity concerns such as these must serve as a backdrop for climate adaptation policy (Parks & Roberts, 2010; Shepard & Corbin-Mark, 2009).

Proposed adaptation interventions may generate benefits independent of climate change concerns (Carter et al., 2007). The Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2007) concluded that planned adaptations to climate risks are "most likely to be implemented when they are developed as components of (or as modifications to) existing resource management programs or as part of national or regional strategies for sustainable development." Many general development activities, such as creating more effective and equitable agricultural markets or diversifying livelihood options beyond rain-fed cultivation, can simultaneously improve the lives of the poor and reduce climatic risks.

Climate adaptation mainstreamed into development planning can address pressing global issues such as inequality and natural resource mismanagement through streamlining and supporting existing decision-making

*Corresponding author. Email: john.j.nay@vanderbilt.edu

processes across different sectors (Halsnæs & Traerup, 2009; Huq & Reid, 2004). "Community-based adaptation" can be interpreted as a field of research and a community of practice rooted in the notion that improving livelihoods and reducing poverty are primary aims, and that adapting to climate change is a means to those ends. Climate change adaptation is "mainstreamed" into development planning to the extent that development plans are predicted to be robust to current climate variability and expected climate change stressors, such as more variable and extreme droughts and floods (Carmin, Dodman, & Chu, 2013).

Recognition of the links between climate change and development has led to the emergence of tools to integrate climate change adaptation into development planning (OECD, 2009; Olhoff & Schaer, 2010; UNDP/UNEP, 2011). The IPCC has called upon researchers to provide "effective approaches for identifying and evaluating both existing and prospective adaptation measures and strategies" (Carter et al., 2007). The need to examine policies has also been highlighted (OECD, 2009) in light of the close links between adaptation and development. Decision-support tools are important for prioritizing adaptation activities that should be scaled up. However, some tools offer limited guidance on the integration of adaptation into planning (Olhoff & Schaer, 2010) and on how local adaptation needs can be matched by international funders. This article intends to support the effort to identify useful tools by reviewing modelling methods, the importance of community engagement and the assessment of costs and benefits, and to shed light on how international financial mechanisms, such as the Adaptation Fund, can benefit from employing such decision-support tools to inform their own funding portfolios. The ultimate goal is to more effectively determine which (if any) development interventions are most likely to improve communities' welfare in light of the expected climatic change.

2. Balancing community input and technical tools

A conceptual issue at the core of this article is a tension between technical tools and community engagement. There is no "one-size fits all" tool or public policy solution. As Ostrom (2007) argued, there are no panaceas for predicting or governing social–ecological systems.

To effectively allocate public expenditures, estimates of costs and benefits, or at least cost-effectiveness, are useful. At the same time, there are examples of capital-intensive projects that may have been technically justified through economic analyses that, in retrospect, have done more harm than good because decision-makers did not understand local realities (Gilligan, Ackerly, & Goodbred, 2013; Haque, 2013). In these cases, if the respective communities had been engaged during the design and review phases, these projects may have been designed differently or abandoned altogether. For example, in the development of National Environmental Action Plans in Cote D'Ivoire, top-down processes resulted in misidentification of problems and could have wasted limited resources (Ayers, 2011; Bassett & Zuéli, 2000).

Social vulnerability to climate change is a socially constructed phenomenon affected by inequitable resource availability and the entitlements of individuals or groups to call on these resources, including institutional and economic dynamics (Adger & Kelly, 1999). For instance, women's limited access to resources, restricted rights, limited mobility and voice in community, and household decision-making can make them particularly vulnerable to the effects of climate change (Wright & Chandani, 2014). Most technical accounts of "problems" and "solutions" do not take the socially constructed nature of vulnerability into account (Sultana, 2013). Cost-effectiveness measures are not designed to account for non-quantifiable benefits or the issue of *who* benefits. Therefore, researchers, planners, and policy-makers should consider how to strike a balance between fully addressing stated needs of the beneficiaries of an intervention *and* seeking to maximize the intervention's technically derived net benefits or cost-effectiveness.

To assist in assessing future benefits, researchers should develop and utilize tools that facilitate forecasting social, economic and environmental change, and anticipating challenges that may be amenable to intervention from government or civil society. In this article, we call tools of this environmental-economic nature "integrative models." The successful application of integrative models to development planning is to a large extent dependent on the extent to which they are bottom-up. Community input can increase legitimacy of planning and allow the planner to make better predictions. This may ultimately result in more effective interventions.

Before discussing the respective characteristics and relative merits of various types of models and tools, we review two themes important to any approach to mainstreaming adaptation: (1) community participation and engagement and (2) approaching the community or region of interest as a coupled human-natural-engineered complex system.

3. Participation and engagement

Climate adaptation strategies must be implemented at the local level. As a result, community-identified activities are integral to planning. Facilitating public participation and stakeholder engagement is critical to defining climate impacts, understanding local implications, and prioritizing responses. Stakeholder engagement in the design, implementation, and monitoring of interventions is important because the potential impacts of climate change and the actions to reduce these impacts are ultimately interwoven with specific populations and regional vulnerabilities

(Ebi, 2009). Similarly, an area's cultural and local institutional contexts strongly determine the kinds of adaptive strategies people utilize (Adger, Barnett, Brown, Marshall, & O'Brien, 2012; Crate, 2011).

Public participation and engagement processes can strengthen the knowledge and awareness necessary to achieve a sense of citizenship. The idea of citizenship influences the practice and efficacy of participation, the transfer of skills across issues and arenas, and the thickening of alliances and networks (Gaventa & Barrett, 2012). This can also contribute to a broader sense of inclusion of previously marginalized groups within society and potentially increase social cohesion (Gaventa & Barrett, 2012). In this sense, different classes, genders, and cultures play an important role in stakeholder engagement processes (Smith, Vogel, & Cromwell, 2009) and, therefore, also in selecting adaptation strategies (Nielsen & Reenberg, 2010).

If citizen discourse and deliberation play central roles in helping to define impacts and prioritize responses, it must be acknowledged that public discourse and participation in a decentralized political sphere are messy, driven by dynamic, and often contentious, streams of local knowledge (Cheema, 2007), which can all be striving to simultaneously influence institutional change (Hobson & Niemeyer, 2011). Despite this, community-generated knowledge, because of the deliberative processes involved in its creation, can ultimately increase legitimacy of decisions and the likelihood of achieving locally appropriate outcomes (Pringle & Conway, 2012).

Community participation and stakeholder engagement are also keys to facilitating the integration of adaptation and development planning (Halsnæs & Traerup, 2009; Huq & Reid, 2004). The rationale is that adaptation, when addressed simultaneously with other local socioeconomic priorities, can contribute to the livelihoods of people and make improvements in their capacity to deal with climatic change (Halsnæs & Traerup, 2009; Saito, 2012). Local ownership over processes of mainstreaming adaptation into local development can facilitate these programmes' effectiveness (Shaw, 2006), increase their chances for more equitable and just outcomes (Ebi, 2009), and provide opportunities for local innovation (Rodima-Taylor, 2012).

4. Integrative systems approach

In order to understand climatic and non-climatic changes and inform adaptation and development strategies, one must understand the relevant social-ecological systems, as well as their potential critical feedbacks and nonlinear changes (Ostrom, 2009). Human communities and biophysical environments are complex systems with processes operating at nested spatial scales – social units have boundaries such as individual, household, community, and region, whereas biophysical units have boundaries such as patches, stands, forests, watersheds, and biomes (Holling, 2001). Components of both human and biophysical systems are subject to cross-scale interactions and abrupt change (Gunderson, 2010). Communities are characterized by co-evolving social, engineered, and natural systems dynamically affecting one another (Gilligan, Ackerly, & Goodbred, 2013).

Social, natural, and engineered systems co-evolve by interacting in specific places (Gunderson, 2010), for example, infrastructure siting and land-use decisions result in modified physical landscapes. Understanding the dynamics that give rise to effective adaptation requires recognizing how people interact with their environment. A bottom-up analysis of this nature is data hungry (and computationally intensive if modelling and simulation methods are used) and has the difficult task of moving from micro-level details to macro-level patterns and policy recommendations. More top-down methods offer less understanding of the dynamics of coupled systems and are less able to identify how co-evolving factors can determine outcomes (Gilligan, Ackerly, & Goodbred, 2013; Ostrom, 2009). Considering adaptation problems from a social–ecological systems standpoint offers a powerful perspective on the complexity of adaptation, but there are trade-offs in the use of various modelling approaches that explore and simplify this complexity. Various modelling options are, therefore, explored in the following section to present insights into the trade-offs facing decision-makers and researchers.

5. Modelling tools

In the discussion below, we outline a distinction between conceptual and formal models before dividing formal models into those that are equation-based, agent-based, geographic-based, and participation-based. These categories should not be interpreted as rigid or mutually exclusive. Rather, the distinctions are intended to serve as a guide to thinking about general (and compatible) *approaches* to modelling in the adaptation context. We describe these model types abstractly herein; additional detail on each model type and how they are applied in case studies can be found in cited literature.

Models can be used to forecast, illuminate uncertainties, demonstrate trade-offs, and inform policy and planning (Epstein, 2008). Assumptions about important variables of a system and their relationships should be established in any model formulation. This process requires researchers and analysts to test the consistency of (often) previously implicit models and allows the resulting model to be replicated, which facilitates a process of incremental scientific and social learning (Epstein, 2008). We first divide models into those that are more conceptual in nature and those that have a more formalized structure.

5.1. *Conceptual model*

Figure 1 illustrates a broad *conceptual model* for thinking about coupled systems.

This shows the combined social (e.g. economic, regulatory, and informal norms), environmental (e.g. flooding severity and variability), and engineering (e.g. water infrastructure) factors that might lead to unsustainable communities. The conceptual model in Figure 1 focuses on understanding coupled system dynamics by incorporating social and engineering factors. The model is interested in capturing how people adapt to environmental changes under particular institutional and biophysical regimes. It is designed to focus on the complex community or regional system with extant infrastructure and social coping and response mechanisms, and then to investigate possible adaptations.

5.2. *Formal model*

Formal models, which are necessary for more rigorous analyses of conceptual models, can be divided into equation-, agent-, geographic-, and participation-based categories.

5.2.1. Equation-based

Both equation-based models (EBM) and agent-based models (ABM) can be deterministic or stochastic, simulate feedback effects, and make extensive use of equations (Bonabeau, 2002). The fundamental difference is that an EBM starts with a set of equations that describes relationships among variables of a system, whereas an ABM starts with behaviours of constituent agents of a system (Parunak, Savit, & Riolo, 1998; Patt & Siebenhuner, 2005). ABMs often have higher computational requirements, which may increase the effort required for sensitivity analyses and calibration. However, EBM approaches may not as sufficiently account for the dynamic processes that can produce macro-level phenomena such as the effect of social norms on individual decision-making, social networks, and heterogeneity in agents' information or control in strategic interactions (Parunak et al., 1998).

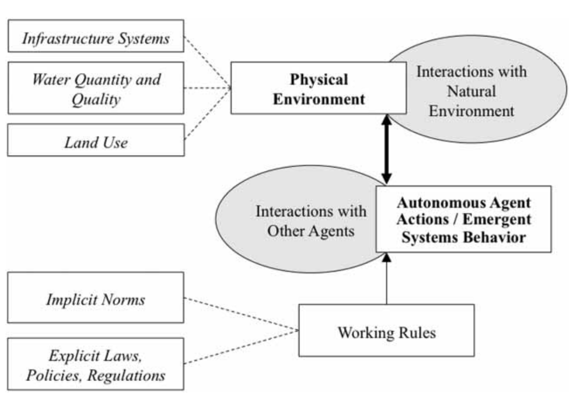

Figure 1. Conceptual model of the integrated system.

EBM adopts a more top-down modelling approach, whereas ABM operates from a bottom-up perspective (Bonabeau, 2002). The top-down approach is often more amenable to making precise predictions and has less parameters to estimate. The bottom-up approach affords flexibility to relax the strong behavioural assumptions of neoclassical economic theory and introduce bounded rationality, social influence, and heterogeneity within a population of simulated economic agents (Filatova, 2009). In many conditions of less than competitive markets where an effective price system is lacking, these additions to micro-behavioural characterizations may allow greater understanding of macro-phenomena than traditional economic models (Poteete, Janssen, & Ostrom, 2010).

Figure 2 illustrates an integrated economic EBM of adaptation to environmental change (based on Fisher-Vanden, Wing, Lanzi, & Popp (2013) integrated assessment model of climate adaptation). The red factors represent exogenous change and the blue factors represent endogenous change. This demonstrates a general practice applicable to all types of formal models: specifying which factors are exogenous and endogenous. *Protective adaptation* (similar to "planned adaptation") shields sectors from impacts, that is, reduces sectors' exposure by reducing the marginal effects of environmental impacts on productivity. Examples of protective adaptation are flood mitigation infrastructure. *Adaptive coping* (similar to "autonomous adaptation") lessens losses that arise once impacts actually affect the sectors in question, that is, increases resilience by lowering the marginal effects of productivity shocks on economic losses. Examples of adaptive coping include migration and changing crop technology. *General equilibrium effects* include relative price changes and substitution responses (Sterner & Persson, 2008). Transformative adaptation, a complete revamp of a social–ecological system in order to become adaptive, would be incorporated in this model as either adaptive coping or protective adaptation. The model moves from conceptual to formal when equations are specified that govern the relationships of the variables connected by arrows.

5.2.2. Agent-based

"Agents" in computational ABMs are autonomous decision algorithms that interact with other agents and their environment. Agents can have heterogeneous procedures such as decision-making or learning processes and heterogeneous static (e.g. gender) or dynamic (e.g. wealth and social network) attributes. Social and psychological constraints

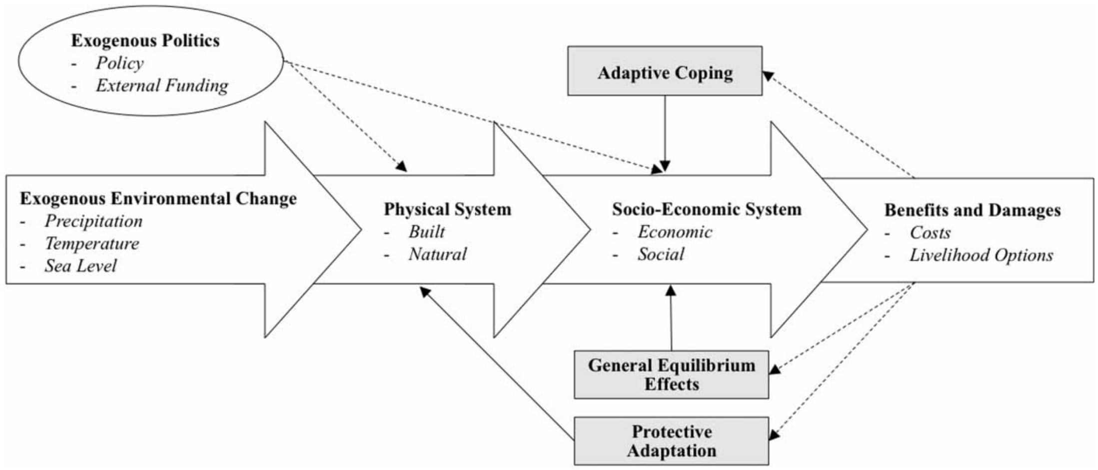

Figure 2. Integrated EBM of adaptation to exogenous change.

can be modelled to affect behaviour. Agent behaviours are actions executed during simulation to achieve some objective(s).

ABMs can be used as tools to explore a range of "what–if" scenarios (Carley, 2002; Lempert, 2002); evaluate how well competing models of human behaviour account for empirical observation (Robinson et al., 2007; An, 2012); better understand potential causal dynamics behind case studies or sequences of events (Janssen & Ostrom, 2006); simulate individuals adapting to changing environments (Balbi & Giupponi, 2009; Patt & Siebenhuner, 2005); and simulate economic, social, and biophysical factors in one integrative model (Schreinemachers & Berger, 2011).

In Patt and Siebenhuner's (2005) review of ABM applied to climate adaptation problems, they note that adaptive capacity is an emergent social phenomenon generated by interaction effects between individuals. They argue that ABM is a suitable tool for understanding adaptive capacity because:

> adaptive capacity arises from a complex system, in which many actions are taken in response to the actions of others. Second, adaptive capacity presents us with a puzzle – maladaptation – that conventional modeling seems unable to solve. Third, it ought to be possible to gather … data necessary to construct valid agent based models of adaptive capacity. Fourth, given the lack of a feasible alternative, ABM may be the only way to predict the success of policy interventions. (p 317)

Community-based adaptation research is focused on agents' adjustments in the face of uncertain change, diffusion of adaptive technologies or behaviours, and decentralized coordination and collective action issues – all phenomena where ABMs have been fruitfully applied (Berger, 2001; Patt & Siebenhuner, 2005). ABMs can represent dynamics in unpredictable systems (Lempert, 2002) and, uniquely, they can formally accommodate actors' heterogeneity (Abdou, Hamill, & Gilbert, 2001).

No model can consistently predict the behaviour of complex adaptive systems such as coupled social–environmental-engineered community systems (Bradbury, 2002), but ABMs can offer insights into a range of future responses to change and the elements that are most sensitive to those changes. ABM is useful under three conditions (outlined in Patt & Siebenhuner, 2005). First, agent interactions are important for system outcomes, for example, nonlinear changes in system outcomes may result from small changes in agent behaviour. Second, a simpler and more clearly predictive EBM is inadequate (if it is a yet to be experienced phenomenon, such as extreme climate change scenarios, then it might be too difficult to specify the equations that an EBM requires). Third, there are data about agents (EBM does not require micro-level data about agents). The first two conditions hold for most problems of climate adaptation and the third depends on the amount of community participation, relevant theory, and empirical research.

To develop an ABM, one should first select simple attributes of agents and their environments based on existing social science or decision science theory (Cioffi-Revilla, 2010). After adding any necessary complexity in subsequent iterations, one should then look for empirical fit between simulations and the observable system. Sensitivity analyses should be conducted to help find the simplest model that still captures the processes of interest. Grimm et al.'s (2005) "pattern-oriented modelling" approach emphasizes including key structural elements of the real system that are posited to produce characteristic patterns of that system at multiple scales. If the model is designed to replicate just one empirical pattern, it is often too easy to generate that pattern without the model generating it for the *right* reasons. Replicating multiple patterns mitigates the risk of developing a structurally unrealistic model (Railsback & Grimm, 2012).

One of the most difficult issues of any modelling endeavour, agent-based or otherwise, is finding a desirable level of complexity. If a model is too complex, its analysis may become too difficult or there will be so many parameters that it might be fitted to match existing data even when its structure is an invalid representation of the real system. Conversely, if a model is too simple, it might not capture enough detail to improve understanding of any real system. Pattern-oriented modelling, using patterns at the micro-, meso-, and macro-scale of a system, is a strategy to help guide model development to an appropriate level of complexity (Grimm et al., 2005).

Computational simulation methods, which can include EBM and ABM, are most useful – compared to traditional policy modelling techniques – when there are high levels of uncertainty about a system; but predictions are not reliable under these circumstances (Lempert, 2002; Moss, 2002). Traditional policy analysis might involve defining only a few scenarios. If, on the other hand, we have a large number of relevant future scenarios, we should compare policy options across scenarios and evaluate them according to their "robustness," that is, how well they perform across a wide range of scenarios (Lempert, 2002). ABM and EBM simulations can facilitate this process.

5.2.3. Geographic-based

Geographic information systems (GIS) enable spatial information from a variety of sources to be manipulated in a common projection format such that spatial relationships can be analysed and visualized. Examples of information relevant to climate adaptation for which GIS is an invaluable resource include political boundaries, demographics, infrastructure, weather, response assets, environmentally sensitive areas, hydrology, soil properties, and natural hazards. Government agencies, civil society, and businesses alike, have shifted their practices to collect data in GIS-compatible formats and have created large repositories of relevant spatial information. Moreover, advances in data collection technology are enabling such information to be obtained through a variety of means, including satellites and mobile phones.

Adding to the power of GIS is the ability to store considerable information associated with any point (site) or polygon (area). These attributes provide an opportunity to associate location-specific characteristics with each GIS record. For example, flood mitigation infrastructure that has been assigned geographic coordinates can have information stored behind it that describes its type, age, condition, and use. Similarly, a GIS record for a response asset, such as a disaster aid organization, might contain attributes describing the number of volunteers and their level of training, as well as available supplies. A GIS demographic layer typically contains attributes characterizing population demographics.

These capabilities relate to climate adaptation policy in a variety of ways. For instance, in order to understand the implications of natural hazards, it is important to consider potential extreme weather event scenarios, superimpose the impact area and intensity of these events, and estimate the loss and damage that may subsequently occur, both immediately and in the long-term. GIS is ideally suited for this purpose (Alam & Mqadi, 2006).

ABMs are useful for representing processes and causal mechanisms underlying, and *generating*, system behaviour. On the other hand, geographic-based models (GBM) represent detailed spatial patterns and facilitate visualization, but are not as adept at representing dynamic heterogeneous processes. Combining ABM and GBM tools allows for a rich understanding of both behavioural *process* and resulting spatial *pattern* (Abdou et al., 2001). For instance, GBM allows us to take into account how changes to spatial representations of an environment – for example, land-use, salinity ingress, and infrastructure systems – might impact agents' opportunities and thus their actions, their interactions with other agents, and the overall system behaviour. For coupled systems, combined GBMs and ABMs are effective tools for integrating disparate types of data (Crooks & Castle, 2012).

5.2.4. Participation-based

Stakeholders will likely view computer-based tools as "black boxes, which raises the issue of their legitimacy and acceptability" (Barreteau & Abrami, 2007). Role-play games (RPGs) may be useful in explaining an ABM or GBM (Barreteau, Bousquet, & Attonaty, 2001). RPGs are used by the Red Cross/Red Crescent Climate Centre to assist researchers and practitioners to better understand climate risks, explore a range of plausible futures, and improve decisions related to mainstreaming climate adaptation into development planning (Mendler de Suarez et al., 2012). Role-play simulations conducted in communities can help to create local climate adaptation plans that have the necessary political momentum to be implemented (Susskind, 2010). RPGs and ABMs have the same conceptual structure (autonomous agents interacting dynamically in a shared environment), allowing them to be combined into a hybrid tool (Barreteau & Abrami, 2007). RPGs can be used to gain understanding of a social system for input into an ABM – information about interactions among actors and their institutions – and to convey an ABM to stakeholders, whereas an ABM can be used to repeat RPGs and explore outside their parameter space (Barreteau et al., 2001).

RPGs, ABMs, and GBMs can be integrated. Knowledge about a physical system is used to populate a GBM and knowledge about a social system is used to characterize agents and their behavioural processes, which together comprise a spatially explicit ABM (Guyot & Honiden, 2006). The RPG – consisting of stakeholders acting with a simplified representation (computational, paper, blackboard, etc.) of the GIS – and the ABM iteratively inform one another, partly by the RPG feeding back into improved behavioural models (Castella, Trung, & Boissau, 2005). The ABM will likely need to be reduced and simplified for conversion into an RPG. Simplifying the ABM and identifying aspects of utmost interest may be done with the assistance of stakeholders (Guyot & Honiden, 2006). Involving stakeholders in co-constructing ABMs and RPGs is often referred to as "companion modelling" (Barreteau et al., 2001). The game is created to observe particular decisions of participants (Castillo, Bousquet, Janssen, Worrapimphong, & Cardenas, 2011). Debriefing sessions – where participants provide feedback on the game – can improve characterizations of agents in the ABM (Bousquet, 2001; Castillo et al., 2011). Stakeholders may not understand the link between their decisions and the larger consequences of those decisions. Participatory modelling can help stakeholders make these connections in an iterative process of describing the environment, their decisions, and running the model (see D'Aquino et al., 2002 for a review of case studies). Developing and validating ABMs with stakeholder input, regardless of whether an RPG is used, can be part of adaptively managing a dynamic, coupled system (Moss, Pahl-wostl, & Downing, 2001).

With the realization that cost–benefit techniques, broadly defined, will often be used for decisions regarding which adaptation projects and policies to implement at scale, we argue for improving the process with the modelling options outlined and community engagement. The process and outputs of formal modelling can illuminate uncertainties and demonstrate the many trade-offs involved under adaptation alternatives. Outputs of models that explore a range of plausible scenarios can inform a cost–benefit analysis, and will ideally incorporate community participation and engagement at both model building and cost–benefit analysis stages.

6. Demonstrating cost-effectiveness and community benefit

The ensuing discussion offers pragmatic context to our review of models and tools, on the understanding that decision-makers share a common goal of ensuring that adaptation interventions seek benefits for the most climate-vulnerable communities. These examples showcase the variability in how decision-support models and approaches are being used by a number of international actors to assess, prioritize, and implement adaptation options at the local level.

There remains significant uncertainty surrounding downscaled climate forecasts, which, along with issues of choosing an appropriate discount rate and valuation technique, complicates any analysis of adaptation projects designed to deliver benefits that may extend decades into the future. The significant uncertainty in the future behaviour of coupled systems regardless of climate uncertainty, further supports our argument for utilizing empirically grounded simulations to better understand change and the potential implications of adaptation options. Cost–benefit analysis, broadly defined, can be an effective, complementary tool for assessing adaptation options and mainstreaming such options into development (Agrawala & Fankhauser, 2008; Stage, 2010).

A range of approaches has proven to be valuable in the assessment of the costs and benefits of proposed adaptation interventions. These include cost–benefit analysis, which has been most widely applied in adaptation cost considerations to date (Berger & Chambwera, 2010), cost-effectiveness analysis, and multi-criteria analysis. The merits of these and other approaches are explored in detail under the Economics of Climate Adaptation working group (2009) and Nairobi Work Programme (UNFCCC, 2011). In contemplating the quantification of costs and benefits of proposed adaptation measures at the local level, it is important to acknowledge several considerations that arise relating to valuation and equity.

Research on the use of cost–benefit analysis for evaluating adaptation in developing countries has highlighted challenges associated with monetizing the costs or benefits associated with issues such as environmental goods and services, social, or cultural values (Chambwera et al., 2011; UNFCCC, 2011). Furthermore, it is important to consider the distribution of costs and benefits, that is, considerations of who benefits from adaptation interventions (UNFCCC, 2011), especially since poorer groups are most vulnerable to climate impacts. Assigning costs and benefits to potential interventions must extend beyond those aspects that can be easily assigned monetary value (such as changes in output of productive systems linked to formal markets) to those that cannot be easily monetized (such as improvements in human well-being and ecosystem services). In local contexts, the social value that disparate groups of individuals place on community assets poses challenges to a traditional cost–benefit approach. For example, in the case of a participatory cost–benefit analysis of drip irrigation in Morocco, non-monetary benefits, including cross-sectoral benefits, were ranked more highly by stakeholders than the monetary benefits (Chambwera et al., 2011). Furthermore, issues relating to the definition of a time horizon and whether to deal with single or multiple baselines are contentious (Chambwera et al., 2011). A decisive variable in most cost–benefit analyses is the discount rate, which, in climate adaptation considerations, Stern (2006) suggests must be lower than in conventional analyses and Broome (2008) believes should be removed from the equation entirely to uphold the principle of inter-generational equity that is central to sustainable development.

Beyond the debates over the variables that contribute to a formal analysis are value judgments that many analyses fail to capture. Of key importance to considerations at the community-level, for example, is failure to capture the distribution of costs and benefits between stakeholder groups (Kennedy, 1981) without using subjective weightings for value judgments (UNFCCC, 2011). These challenges highlight how conventional approaches to assessing costs and benefits must be re-thought in many adaptation-mainstreaming cases. Participatory cost–benefit analysis uses participatory research appraisal methods to ensure all financial, social, and environmental costs and benefits are identified. Piloting this tool in five countries highlighted that not all benefits can be monetized, and it is important not to compare strategies in purely economic terms as this may lead to important benefits being overlooked (Chambwera et al., 2011). An example from Khulna, Bangladesh, showed that the approach can be used to complement quantitative analyses and may even reduce the cost of adaptation by requiring a balancing of benefits across stakeholders (Haque, 2013). The value of adopting a stakeholder-focused approach also lies in facilitating dialogue among stakeholders who may not otherwise interact, as they seek solutions to address their diverse needs (Chambwera et al., 2011). Ultimately, quantitative assessments of costs and benefits should be used not as reductionist simplifications of complex issues, but as decision-support tools in seeking transparent and cost-effective solutions to reducing climate impacts. In considering the pursuit of effective adaptation at scale, it is instructive to examine the extent to which these issues have been reflected to date in decision-making processes in the allocation of international climate finance.

Many adaptation decision frameworks tend to use a form of multi-criteria analysis (MCA) as the basis for decision-making on adaptation strategies, as suggested by UNFCCC (2011). At the adaptation planning level, it is notable that MCA was used to develop National Adaptation Programmes of Action and featured in recent guidance for National Adaptation Plans (NAPs). Some form of MCA is used widely in community-based adaptation; for example, CARE's toolkit suggests prioritization of adaptation strategies based on a set of agreed upon criteria. In selecting a decision-support tool, practitioners must consider the resources required for the analyses, a particularly salient consideration at local levels. For simplicity and ease of use, it is important that the tool is appropriate to the context and purpose.

The entity charged with financing interventions that addresses the needs of the most vulnerable countries and communities is the Adaptation Fund under the Kyoto Protocol. In seeking grant financing from the fund for adaptation interventions in developing countries, proponents must demonstrate that proposals are "cost-effective" and "justified on the full-cost of adaptation reasoning" (Adaptation Fund, 2012). The instructions provided to proponents states that cost-effectiveness is assessed based on a provision of a description of alternative options to the proposed measures and that quantitative assessments of cost-effectiveness are only to be provided where feasible and useful. A review of the technical reviews of proposals (Adaptation Fund, 2013) shows that the assessment of this criterion is undertaken on a qualitative basis in nearly all cases. The remaining criteria applied in the assessment of proposals are predominantly qualitative in nature, with the exception of the assessment of a detailed budget. This practice demonstrates that quantitative modelling and assessment of costs and benefits is not a requirement to obtain funds from the Adaptation Fund, but rather an optional tool that proponents can use to demonstrate that proposed interventions are indeed cost-effective. This flexibility could be perceived as, on the one hand, a lack of support in articulating clear expectations of the review process. On the other hand, in not prescribing the use of quantitative tools, such an approach may benefit community-based adaptation by allowing proponents the flexibility of using the tools best suited to particular local circumstances.

It is expected that the quantitative assessment of costs and benefits will continue to dominate adaptation discussions at the macro-level, where they have proven useful in informing global discourse and choices (Parry et al., 2009; Stern, 2006). At the level of community-based and sub-national interventions, however, issues of valuation, equity, and complexity demonstrate the need for a combined qualitative and quantitative approach, such as the modelling options described herein, to demonstrate how local adaptation needs can most effectively be addressed.

7. Conclusion

Community-based adaptation seeks to incorporate current and future climatic risks into the design of interventions that are key for local economies and overall well-being (Dumaru, 2010; Rojas Blanco, 2006). While communities have extensive knowledge of local environmental changes, they often have limited knowledge of the causes and effects of exogenous change. Building and utilizing integrative models may, in some circumstances, help evaluate and manage trade-offs inherent in local adaptation options. This article has reviewed some tools and techniques available for this purpose.

The uncertainty of projections and lack of understanding of local dynamics means technical data needs to be supplemented with local knowledge (Lunduka et al., 2013). The participation-based models of the type described herein may provide one avenue to achieve this integration.

It is crucial that tools selected for use are appropriate to the situation, remaining cognizant of the resources available for conducting the effort. Under some circumstances, a stakeholder-focused approach to cost–benefit analysis has been deployed, which enables stakeholders to reach an informed consensus based on analyses that take account of both monetary and non-monetary benefits (Lunduka et al., 2013). Whether qualitative or quantitative in nature, however, model and cost–benefit analyses outputs should be seen as decision-support tools rather than as definitive justifications for particular interventions (or for any intervention).

The example illustrating how the Adaptation Fund reviews proposed adaptation options serves to demonstrate how climate finance is attempting to manage these trade-offs and make itself amenable to a variety of approaches and tools. As climate impacts become more severe, it is important that climate adaptation researchers and practitioners, as well as entities charged with the governance of climate finance, maintain this type of flexibility in their analyses and operations to be adaptable themselves to allowing communities to best manage the emerging challenges of climate change and the long-standing challenges of development.

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