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Barriers and opportunities for robust decision making approaches to support climate change adaptation in the developing world

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ABSTRACT

Climate change adaptation is unavoidable, particularly in developing countries where the adaptation deficit is often larger than in developed countries. Robust Decision Making (RDM) approaches are considered useful for supporting adaptation decision making, yet case study applications in developing countries are rare. This review paper examines the potential to expand the geographical and sectoral foci of RDM as part of the repertoire of approaches to support adaptation. We review adaptation decision problems hitherto relatively unexplored, for which RDM approaches may have value. We discuss the strengths and weaknesses of different approaches, suggest potential sectors for application and comment on future directions. We identify that data requirements, lack of examples of RDM in actual decision-making, limited applicability for surprise events, and resource constraints are likely to constrain successful application of RDM approaches in developing countries. We discuss opportunities for RDM approaches to address decision problems associated with urban socio-environmental and water-energy-food nexus issues, forest resources management, disaster risk management and conservation management issues. We examine potential entry points for RDM approaches through Environmental Impact Assessments and Strategic Environmental Assessments, which are relatively well established in decision making processes in many developing countries. We conclude that despite some barriers, and with modification, RDM approaches show potential for wider application in developing country contexts.

Contents

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Introduction

Adapting societies to climate variability and change is one of the greatest challenges the world faces. The challenge is greater for developing countries because of higher biophysical vulnerability and dependence on climate sensitive sectors like agriculture, and lower adaptive capacity (Millner and Dietz, 2015). Developing countries already face considerable risks due to current climate variability. Poverty alleviation and development in the developing world are both intrinsically linked with climate, and there is a recognized need for addressing them in an integrated manner (Hallegatte et al., 2015). However, deep uncertainty about future socio-economic and climatic changes and their associated impacts makes it difficult to identify adaptation requirements and strategies (Dessai et al., 2007; Brown, 2011; Refsgaard et al., 2013) which can be a barrier to implementation. Nevertheless, adaptation planning is important to avoid potentially dangerous maladaptation, minimise negative consequences and maximise opportunities of a changing climate (Dessai et al., 2009; Dessai and Wilby, 2011).

In the absence of perfect foresight or reliable information about probabilities of different outcomes due to climate change, established statistical and optimization techniques are not helpful for informing decisions (Stainforth et al., 2007; Lempert and Collins, 2007; Lempert et al., 2009). Uncertainty in climatic conditions has traditionally received little attention in decision making, but it is so large in the future that traditional approaches to infrastructure design for long term assets and investments is inadequate (Hallegatte, 2009). In such situations, a growing body of literature indicates that Robust Decision Making (RDM) approaches or Decision Making Under Uncertainty (DMUU) approaches provide value by helping identify individual or portfolios of adaptation strategies that work reasonably well across large ranges of uncertain future climatic conditions. There is a family of approaches incorporated within RDM or DMUU including, but not limited to, information-gap decision theory, decision scaling and dynamic adaptive pathways; they all aim to address uncertainty/severe uncertainty/deep uncertainty in future conditions. In this review, we use the umbrella term 'RDM approaches' to refer to this range of methods and their variants. The underlying rationale of these approaches is that decision makers face important long-term planning issues with deep uncertainties which cannot be reduced by gathering more information, but can be addressed by moving from predict-then-act approaches to assess-risk-of-policy approaches (Lempert et al., 2006; Walker et al., 2013; Weaver et al., 2013).

Typically, RDM approaches involve a combination of top-down and bottom-up approaches, wherein quantitative modelling methods are informed by stakeholder driven processes (Hallegatte, 2014). RDM approaches recognize that policy makers face many issues related to social, economic, environmental and technological changes. While decisions are influenced by policy, science should assist in tackling these issues effectively (Schenkel, 2010). Hence RDM relies on engaging decision makers and stakeholders to elicit their priorities, preferences and performance criteria for adaptation strategies, followed by modelling assessments across a large range of potential future conditions, including climatic, socio-economic and landuse changes. Robust strategies are understood as those which satisfy performance criteria against most sets of future conditions (Walker et al., 2013; Hinkel and Bisaro, 2014). Such strategies have a greater chance of garnering political support than strategies with large or irreversible consequences (Moser and Ekstrom, 2010). When several potential strategies are identified for specific decision contexts, such robust strategies are often available; thereby assisting decision makers to choose strategies with lower regret (Ranger et al., 2010).

Decision makers in developing countries may often have over-riding priorities like poverty alleviation, economic growth and improving living standards which draw their attention for planning and investment. Neglecting long-term risk from climate change in current planning, however, could reduce the useful lifetime and value from investment, while potentially committing societies or countries to more vulnerable or maladaptive development pathways (Ranger and Garbett-Shields, 2011; Jones et al., 2015). This means that long-term climate change adaptation needs to jointly address pressing day-to-day challenges in developing countries for greater acceptability (Patt and Schröter, 2008; Conway and Mustelin, 2014).

Adaptation policy and planning are increasingly influential processes in many developing countries and feature strongly in development actor programmes. An important example has been the Least Developed Countries' National Adaptation Programmes of Action (NAPA) which aim to integrate responses to climate change impacts (Kalame et al., 2011). The NAPA process acknowledges the need for adaptation plans to identify and prioritize options for both the short-term and the long-term as well as the need to integrate them with existing national development plans. However, these efforts have not been entirely successful. Reasons vary from lack of multi-stakeholder engagement to over-focus on narrow project aims to the

detriment of achieving lasting impact (McGray et al., 2007; Hardee and Mutunga, 2010). NAPAs have also been found to address to a limited extent the root causes of vulnerability, the adaptive capacity needs of local agencies and the need to undertake system-wide transformations (Kuruppu and Willie, 2015). Stakeholder engagement, including vulnerable groups and high-level policy makers, and collaboration between different ministries, is critical to the success of NAPAs (Huq et al., 2004; Kalame et al., 2011). Such initiatives represent an important process for long-term adaptation in LDCs and for stimulating the application of innovative decision making approaches such as RDM.

The rationale and usefulness of RDM approaches for developed countries is well established and their usefulness in developing countries is recognized, especially because of significant investment in infrastructure projects for water, energy, transport and flood mitigation (Dessai and Wilby, 2010; Ranger et al., 2010; Lempert and Kalra, 2011; Walker et al., 2013; Kalra et al., 2014). This review examines the potential for wider application of RDM approaches in developing country contexts. While the need is recognized we are aware of just two practical examples; in Ho Chi Minh City, Vietnam (Lempert, 2013) and in Lima, Peru (Kalra et al., 2015). We first describe various decision problems for which RDM approaches may have value and identify barriers to their application in developing country contexts. We then consider the relevance of RDM in sectors which to date have received less attention in the RDM literature. Finally we present Environmental Impact Assessment (EIA) and Strategic Environmental Assessment (SEA) as possible entry points for embedding RDM approaches in climate change adaptation and draw overall conclusions.

Methodology

We used as a starting point recent RDM related reviews (Walker et al., 2013; National Academies Press, 2013; Eisenack et al., 2014; Kalra et al., 2014 and Watkiss et al., 2014) to identify conceptual papers and case studies in academic journals and grey literature. The reviewed literature highlights the characteristics, strengths and limitations of different approaches and to a lesser extent provides case study applications. While most case studies focus on water resources, other focal sectors include energy, transport, infrastructure, natural resource management and disaster management (S1 presents a full list of articles). From this literature we extracted information about two aspects of RDM; anything relating to barriers to applying RDM approaches in developing countries and examples of potential decision problems relevant for RDM approaches. The information on barriers was then classified into four main sets of limitations to structure the review (‘*Barriers to application of RDM in developing countries*’). Potential decision problems were identified based on two criteria (a) existing applications in developed countries but not in developing countries, and (b) those proposed in the literature for developing countries. We then augmented the review by searching Google Scholar for each barrier or decision problem with the keywords ‘barrier/decision problem’, ‘uncertainty’ and ‘decision making’. A snow-balling method was used to capture all relevant studies cited in the bibliographies of the identified literature (Atkinson and Delamont, 2010). All reviewed literature is provided in Supplementary information 1.

Barriers to application of RDM in developing countries

From descriptions in the literature of the limitations of RDM approaches, we identify four main barriers to the application of such approaches in developing countries. This section presents various arguments made as to how, under what circumstances and for what reasons such barriers could limit applicability.

Data requirements

RDM approaches adopt the philosophy that it is better to be roughly right than precisely wrong, by working with relatively fast and simple models or fit for purpose models (Haasnoot et al., 2014) and avoiding complex and detailed modelling processes (Walker et al., 2013). An example of such an approach is expert judgment which does not rely on intensive quantitative data analysis. However, for analysing potential consequences of a large number of scenarios, correspondingly large data requirements, computational capability, model simulation and visualization, becomes necessary (Lempert and Collins, 2007; Mahmoud et al., 2009; National Academies Press, 2013). Scenario driven RDM assessments for future climate change typically involve analysis of historical/observed climate, future projections and impacts (Groves et al., 2008; Brown, 2011; Lempert and Groves, 2010). Data are often collated from diverse sources for sectors such as water, agriculture and land use, transport, infrastructure, energy and natural resources, which are sometimes coupled with economic cost-benefit analyses of candidate strategies. Detailed information of this sort is more readily available and accessible in developed countries compared to developing countries. Conflicts between sub-national administrative entities like states and provinces with shared resources such as water, can also make data collection more challenging. In many cases more observations, better data quality (integrity) and increased data accessibility is necessary, but insufficient in itself, to support effective research and practice in developing countries. Opportunities exist to customise large scale published scenarios which could generate cost-effective approaches for developing decision relevant scenarios. This could be crucial in developing countries which also face significant financial constraints and human resource capacity constraints. It has also been argued that robustness can be assessed in a less data-intensive manner (Ranger and Garbett-Shields, 2011). Indeed using stakeholder perceptions and expert judgment Bhave et al. (2014) were able to identify no-regret adaptation strategies for water resources management

in a mesoscale river basin in India. Moreover, Lempert (2013) after undertaking a data-intensive RDM analysis in Ho Chi Minh City, Vietnam, observe that data requirements for RDM analyses are less than for conventional detailed assessments. Nevertheless, location specific characteristics such as political/social contexts and spatio-temporal heterogeneity also need to be resolved for successful customization. Overall, while robust strategies may be identified and RDM analyses conducted in a resource light manner, modelling itself requires observed data which are often unavailable at a decision relevant resolution in developing countries.

Limited applicability for actual decision-making

Hallegatte (2014) asks a critical question; 'when considering no-regret strategies, it is critical to investigate why they have not been already implemented' (pg. 186). He points to institutional and legal constraints, lack of information, transactional costs and financial and technological constraints; the last of these is particularly relevant to developing countries. Moreover, behavioural and cognitive aspects, lack of human capital and political leadership, institutional and planning issues, financial and data constraints, historical context and the widening science-policy gap associated with wicked problems, are known barriers affecting implementation of climate change adaptation strategies (Wise et al., 2014). Therefore, although RDM approaches may benefit from greater credibility, legitimacy and decision maker relevant analysis, other factors may typically play a more important role in actual decisions made in developing countries.

The success of RDM approaches also depends on the availability of a sufficiently rich decision space (number of options) from which robust strategies may be determined (Lempert and Collins, 2007; Lempert et al., 2009). Because RDM approaches are scenario driven and the identified strategies have to be robust against worst case scenarios, the solutions often tend to be conservative. It may also be that robust strategies, which perform well across a range of scenarios, may not be available for several decision contexts (National Academies Press, 2013). Ranger et al. (2010), however, argue that low regret strategies are indeed often available to decision makers. There are clearly divergent views on this issue. Ideally RDM should identify realistic options which are available. However, this may not be the case in practice and some factors in developing (resources, technology, capacity to implement etc.) may mean that this is more often the case. More real-world applications are required for improved clarity on this issue.

Climate change adaptation decision making has been described as a 'super wicked' problem because of its characteristics of severe uncertainty, divergent stakeholder understanding and interests, dynamic socio-environmental interactions and limited understanding of natural and societal responses to future climatic changes (Lazarus, 2009; Mearns, 2010; Levin et al., 2012; Head, 2014). They are also influenced by issues, impacts and solutions at a range of spatial scales (Head, 2014) which limits the feasibility or acceptability of solutions, thus reducing the decision space. Different perspectives, multiple actors with varying preferences and uncertainty in organizational and regulatory regimes make decision making for wicked problems highly complex (Head, 2014). Finding solutions to wicked problems generally entails relying on political judgments in addition to or other than scientific analysis (Rittel and Webber, 1973), which can include RDM approaches as they can provide robust options or pathways to address some of the aspects of wicked problems (Kwakkel et al., 2016). However, they 'may be politically and economically unattractive', if found to be sub-optimal from input resource and development perspectives (Daron, 2014). RDM approaches may also struggle to maintain relevance for wicked problems which dynamically evolve with solutions proposed or implemented (Kwakkel et al., 2016).

Another critical issue is the involvement of stakeholders and decision makers in the RDM approach. Stakeholder consultation, although difficult, can (i) increase the commonality of understanding through access to information, (ii) build problem-solving capacity at multiple scales and (iii) address insecurities regarding uncertain, complex and divergent factors (Brugnach and Ingram, 2012; de Boer et al., 2010; Bommert, 2010). However, under conditions of deep uncertainty, differences in stakeholder opinion and political opposition to action, often lead to policy paralysis (Hallegatte, 2014). Stakeholder/s may capture a consultation process and delay decision making while decision makers may be reluctant to make decisions on high profile or contested issues. Moreover, stakeholder based articulation of performance objectives, a central theme in RDM approaches, may be problematic in developing countries because of vastly different risk perceptions and attitudes about such objectives (Daron, 2014), and sometimes, stakeholder fatigue (Conway and Mustelin, 2014). Multi-level stakeholder consultations can also be challenging because diverse groups have conflicting demands, local politics, different expectations from consultations, busy schedules and limited cross-stakeholder communication (Few et al., 2007; Bhave et al., 2015). Cultural and political transferability of western approaches to participation and decision-making are therefore unlikely to be straightforward in many developing countries with markedly different socio-cultural and political settings.

Limited applicability for surprise events

Unknown unknowns constitute a part of the uncertainty domain beyond current understanding. Black swan events lie in this uncertainty domain. They are characterized as outliers because no events in the past can point to their possibility and yet they can have massive impacts (Taleb, 2007). Such events pose a challenge to conventional decision making approaches, since they may not specifically account for such radically diverse scenarios of future conditions, across both natural and human systems. While most conventional planning approaches face challenges in addressing surprise events, RDM approaches have been found to be useful in identifying and characterizing flexible and adaptive strategies, especially for climate change adaptation. The process of scenario development and exploration inherent to RDM affords it the ability to factor

in surprises or 'wild cards', which, although hard to envisage, can be included as surprise scenarios in the planning process (Dessai and Wilby, 2011). However, static robust policies may not perform as well when confronted with black swan events, which are beyond the realm of our current understanding (Walker et al., 2010). Adaptation decision making frameworks try to address this by incorporating known/expected thresholds/triggers/signposts using adaptive decision making frameworks (Hamarat et al., 2013, 2014; Haasnoot et al., 2015). However, the need for establishing such thresholds may be a problem, particularly if they are unknown/poorly understood or unquantifiable (Reeder and Ranger, 2010). Moreover, while RDM approaches can be useful to support decisions regarding implementation timelines, they do not solve the problem of managing extreme events (Mens and Klijn, 2015) and are potentially sensitive to worst-case scenarios (Hallegatte et al., 2012). This challenge is particularly relevant for climate change adaptation decision making because of the non-linear nature of projected changes in climatic extremes in a changing climate.

Resource constraints

Short-term planning horizons, less developed institutions, communications and decision processes, are some of the challenges to RDM approaches in developing countries (Conway and Schipper, 2011; Daron, 2014). Financial constraints also limit monitoring of social and environmental change and reduced institutional capacity hampers coordination and implementation of new management practices (Conway and Mustelin, 2014; Shackleton et al., 2015). Some studies (McDaniels et al., 2012; Haasnoot et al., 2013) have demonstrated how resource light methods using expert judgment can help fine tune the decision problem in a relatively short time, thus aiding adaptation decision making. A major research challenge therefore is to customize methods, which are not financially and computationally resource intensive, for adaptation decision making in developing countries, taking into account the institutional and human resource constraints while maintaining rigour and credibility with decision makers.

Issues of conflicting timescales, institutional fragmentation and inadequate inter-agency cooperation may be more severe in developing countries (Eisenack et al., 2014; Lehmann et al., 2015). Daron (2014) emphasizes the increased salience and legitimacy that RDM approaches afford, especially because adaptation strategies are place and context specific. However, a trade-off exists between increased legitimacy and salience (Cash et al., 2002). Inclusion of more stakeholders may be problematic because social power dimensions of participatory processes can cause tension between the principles of stakeholder involvement and inclusive climate change adaptation. Such participatory processes may also not produce consensus on adaptation strategies which have long-term benefits, and may lead to reduced salience for decision making (Few et al., 2007)

Opportunities for application of RDM in developing countries

Literature review revealed potential decision problems for the application of RDM approaches. In this section we elaborate on each decision problem and its relevance to developing country contexts.

Urbanization, the Water Energy Food nexus and transformative adaptation

RDM approaches have traditionally assessed urban infrastructural options, particularly water resources management and transport management options, for their robustness under changing socio-economic and climatic factors (Walker et al., 2013). Rapid and often unplanned urbanization in developing countries is a major socio-environmental and infrastructural challenge, particularly because climate change may exacerbate the vulnerability of the urban poor in fundamentally uncertain ways (Hallegatte and Corfee-Morlot, 2011). Managing rapid urbanization, the increasingly interconnected nature of infrastructure, suburban infrastructure planning and issues related to peri-urban sprawl in developing countries also present a pressing challenge (Chappin and van der Lei, 2014), where RDM approaches could be used. In Water-Energy-Food (WEF) nexus literature, a comprehensive but location specific framework for integrated assessment of WEF nexus issues exists (Bizikova et al., 2013). This framework includes several elements which fit with RDM approaches; stakeholder involvement for understanding past stresses, current trends and future risks, critical uncertainties, scenario analysis for devising long term adaptation strategies and adaptive management. Such a framework could therefore provide a suitable entry point for RDM approaches to study WEF nexus problems (Ringler et al., 2013).

Transformational adaptation, a more systemic form of planned adaptation, is increasingly discussed in the literature (e.g. Wise et al., 2014) and may offer potential for RDM approaches. Greater focus on understanding the historical context and pathways of the socio-ecological system, along with a more explicit analysis of the ability of organizations and governance systems to adapt will likely increase the relevance of RDM approaches to current research needs. RDM approaches could focus explicitly on options that include institutional changes and coordination or better operational management, to capture more transformative governance-like changes. The governance aspect is critical because the ability of cross-sectoral adaptation is influenced by legal, political and institutional responses (Dovers and Hezri, 2010). Relatively resource-light qualitative analyses, as shown by McDaniels et al. (2012), may be used as a thought experiment to reveal and test such options. Another aspect which needs further research is the analysis of institutional and socio-cultural conditions which influence the feasibility of identified adaptation strategies or pathways (van der Brugge and Roosjen, 2015). Although this added research

focus presents an opportunity, determining what institutional arrangements are necessary and implementing the relevant adaptive policies remains a major challenge (Walker et al., 2010).

Forest resources management

Historically, forest management practices benefitted from the relatively stable climatic conditions of the 20th century, but there is a growing need to take decisions under uncertainty which necessitates changes in conventional management of forest resources (West et al., 2012; Yousefpour et al., 2012; Keenan, 2015; Yousefpour and Hanewinkel, 2016). Keenan (2015) suggests that many forest managers prefer a 'wait and see' approach because future conditions are too uncertain to decide strategies. However, he argues that the use of RDM approaches for devising robust strategies is preferable because optimal management strategies provide limited benefit under deep uncertainty in climate change impacts. Uncertainties in biophysical relationships, ecosystem response, feedbacks among system components, the impact of past decisions and decisions which need to be taken in the near future, all add to the challenge of effective decision-making in forest resources management (Polasky et al., 2011). McDaniels et al. (2012) explore robust forest management strategies using expert judgment and describe the benefits of shifting the focus from uncertainty characterization to understanding uncertainty in the context of flexible management strategies. Socio-economic linkages of local communities with ecosystems add an important dimension to their vulnerability and adaptive capacity, which need to be taken into account in decision making processes (Adenle et al., 2015; Folke et al., 2005). RDM approaches benefit from location and context specific analysis and the inclusion of multiple perspectives through stakeholder engagement, which makes their application in such situations potentially useful.

Disaster risk management

Along with severe uncertainties decision makers are often confronted with decisions involving potentially dangerous risks, consider difficult trade-offs and manage systems with non-linear processes and unknown thresholds (Lempert and Collins, 2007). Disaster risk management exemplifies such situations, especially because global multi-hazard hotspots indicate significantly high mortality and high economic risks (Lerner-Lam, 2007). Climate change adaptation and disaster risk management, despite the different time horizons, have substantial overlap in terms of their core objective of reducing vulnerability and risk. Developing countries face enormous challenges for disaster risk reduction in a changing climate and ex-ante responses for risk reduction and increasing resilience should be supported by timely decision making (Seneviratne et al., 2012). Since RDM approaches can include multiple performance metrics of failure or success for a robust strategy, strategies which provide value for multiple hazards for a range of future scenarios can be devised. Additionally the focus on flexibility can prevent lock-in effects of management strategies and reduce risk of potentially expensive and/or catastrophic maladaptation in undesirable albeit unlikely scenarios (Ranger and Garbett-Shiels, 2010; Hallegatte, 2014). Although disaster management authorities are usually involved in decision making, RDM approaches could facilitate the inclusion of stakeholders across hazards, build constructive dialogue and help create consensus (Hallegatte, 2014).

Conservation management

The world's biodiversity is concentrated in developing countries and traditionally systematic conservation planning has been used for national and regional conservation management. However, observed climate change impacts on biodiversity distribution and abundance and uncertain future climate impacts require a revised approach (Game et al., 2011). Conventionally, conservation planners had to consider the fulfilment of specific objectives, which were often short-term and locally relevant. However, now they have to consider impacts of environmental change and the effect of their decisions on future resources in highly dynamic situations, despite the uncertainty involved (Williams and Johnson, 2013). RDM approaches have been suggested as potentially useful for decision making in ecosystem and natural resources management (Lempert et al., 2006; Polasky et al., 2011; Rowland et al., 2011) and have been applied to conservation management case studies. Examples include translocation strategies (Haight et al., 2000), invasive species risk assessment (Johnson et al., 2001), species management (Peterman and Anderson, 1999), and reserve and habitat management (Haight et al., 2002). Regan et al. (2005) argue that RDM approaches identify flexible strategies which provide value under deep uncertainty and which will increase the reliability of conservation management decisions.

An entry point for RDM: Environmental Impact Assessment and Strategic Environmental Assessment

Widespread adoption of RDM approaches in developing countries will be hampered by various institutional constraints noted earlier. Environmental Impact Assessment (EIA) processes, however, are already embedded in the institutional structures of many developing countries and are widely used for environmental management. These assessments are based on the precautionary principle and involve suggesting actions for nullifying the potential adverse impact of anthropogenic activities before project implementation (Pavlickova and Vyskupova, 2015). EIAs therefore represent a potential route to introduce some or all aspects of RDM without needing to design completely new institutional structures and staff capacity. Uncertainty management is already a feature of such assessments, including, identifying options and criteria, choosing

options and criteria, and identifying and implementing management options. Since many infrastructure projects have long lifetimes it is essential to consider the impact of future climate change. Moreover, for greater decision making relevance and to avoid overconfidence in such assessments, identification, communication and consideration of uncertainties is necessary; indeed issues with uncertainty are being regularly highlighted (Leung et al., 2015; Jiricka et al., 2016). Cardenas and Halman (2016) analysed EIA guidelines in Colombia and propose using RDM approaches for increasing the relevance and robustness of environmental decisions under deep uncertainty. RDM approaches implicitly embed the precautionary principle, because they highlight future scenarios in which a decision today could cause harm, thereby providing decision makers with a chance to re-evaluate options (Lempert and Collins, 2007). The need to include climate change uncertainties along with environmental impact uncertainties of anthropogenic development means that integration of RDM within EIA could benefit decision making processes in environmental management.

Strategic Environmental Assessment (SEA), a tool with roots in EIA, (Lobos and Partidario, 2014), is applied at upstream decision making levels for systematic consideration of environmental impacts of polices, plans and programmes (Nilsson and Dalkmann, 2001; Finnveden et al., 2003). SEA not only assesses the impact of a plan or project on the environment but also of the environment on the plan or project (Larsen and Kørnøv, 2009). Active linking of SEA with development cooperation by donor agencies and international organizations has helped build capacity and promote stakeholder involvement in developing countries. Better integration of SEA with adaptation decision making could be valuable because of complementarities in objectives and approaches (Fundingsland Tetlow and Hanusch, 2012). The European Commission (2013) has suggested using risk based approaches, together with the precautionary principle, to develop robust and adaptive strategies which take into account systemic thresholds and critical interdependencies of natural and human systems. Severe uncertainty is also associated with SEA, but, where considered, uncertainty is approached with more data collection and better modelling (Zhu et al., 2011; Larsen et al., 2013). However, deep uncertainty associated with climate change and adaptation issues, necessitates cognizance and a move towards creating adaptive policies, plans and programmes that explicitly incorporate learning and experiences (Larsen et al., 2013; Lobos and Partidario, 2014). Integration of adaptation decision making with SEA and the use of RDM approaches can therefore be useful in two ways. Firstly, assessing impacts of projects/plans on the environment and identifying strategies, under deep uncertainty, for nullifying the impacts. Secondly, assessing climate change impacts on the projects/plans and identifying adaptation strategies for minimising the impacts. Since EIA and SEA are an established part of existing decision making processes, applications in this domain could provide an effective entry point for mainstreaming RDM approaches in decision making processes in developing countries.

Conclusions and future directions

The limited application of RDM approaches in developing countries restricts the evidence base for analysing their effectiveness or identifying practical lessons. Adaptation decision making in developing countries has its own set of challenges, both for identifying robust strategies and for implementing them. Nevertheless, RDM approaches can help engage stakeholders, improve understanding of shared risks and help forge partnerships. These approaches can also reveal synergies, highlight potentially beneficial options and reveal scenarios where limits to adaptation are crossed. In this review we identify the following four barriers to their application in developing countries; data requirements, limited applicability in actual decision making, limited applicability for surprise events and resource constraints. We find opportunities for RDM approaches for less explored sectors and decision problems; urban socio-environmental and Water Energy Food nexus issues, forest resources management, disaster risk management, and conservation management. We identify EIA and SEA as potential entry points for integrating climate change adaptation and RDM approaches.

Existing developmental priorities for decision makers in developing countries may lead to passive consideration of future oriented adaptation decision making (Daron, 2014). RDM approaches do not always explicitly consider current vulnerabilities or developmental priorities, although where they are applied effectively they should do so implicitly. More explicit consideration through stakeholder engagement may help leverage buy-in from decision makers. While short-term decision making remains a predominant motivation, a change of framing of the decision problem may help increase the relevance of RDM approaches. Moving from a ‘managing future uncertainties’ framing to ‘reducing future vulnerabilities’ framing (Conway, 2011) may resonate better with decision makers. Linking urgent priorities with long-term adaptation requirements, which is also in accordance with the NAPA process objectives, may also effectively support adaptation decision making. The relevant spatial and temporal scales for RDM studies will also need to be explicitly considered because the meaning of short-term or long-term and the suitable spatial scale will also vary for different sectors, governance scales, decision contexts, locational characteristics and stakeholder priorities in developing countries.

The wide-ranging scenarios approach in RDM methods could help reveal limits to adaptation, thus highlighting the need to avoid certain development pathways and aid decision makers in charting a more sustainable pathway and avoiding maladaptation. Developing demonstration projects parallel to an organization’s planning activities could also help decision makers incorporate RDM approaches into regular planning mechanisms (Lempert, 2013). RDM approaches may also be helpful in operationalizing adaptation decision making through the development of adaptive institutions and stakeholder involvement in developing countries, which is crucial for enabling implementation. This is because RDM approaches can highlight the need for adaptive institutions which need to be applied in a flexible and adaptive manner due to the dynamic and uncertain

future socio-economic and climatic conditions. A potential way forward, therefore, is to develop RDM frameworks and methods which can reveal and evaluate institutional, legal or administrative responses along with modelling relevant options.

Customization of existing RDM approaches will be necessary to increase their relevance for developing country contexts. Future research directions need to consider real-world cases and to unravel some of the political economy of the decision making space within which RDM sits. Apart from applications focussing on sectors for which case studies in developed countries already exist, it may be useful to direct efforts towards less explored sectors and decision problems discussed here; urban socio-environmental and water-energy-food nexus issues, forest resources management, disaster risk management and conservation management. In conclusion, we encourage researchers and practitioners to expand their geographical and sectoral foci with regards to the application of RDM approaches.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.crm.2016.09.004.

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