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Challenges in using a Robust Decision Making approach to guide climate change adaptation in South Africa

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Abstract Conventional forecast driven approaches to climate change adaptation create a cascade of uncertainties that can overwhelm decision makers and delay proactive adaptation responses. Robust Decision Making inverts the analytical steps associated with forecast-led methodologies, reframing adaptation in the context of a specific decision maker's capacities and vulnerabilities. In adopting this bottom-up approach, the aim is to determine adaptation solutions which are insensitive to uncertainty. Yet despite the increased use of the approach in large-scale adaptation projects in developed countries, there is little empirical evidence to test whether or not it can be successfully applied in developing countries. The complex realities of decision making processes, the need to combine quantitative data with qualitative understanding and competing environmental, socio-economic and political factors all pose significant obstacles to adaptation. In developing countries, these considerations are particularly relevant and additional pressures exist which may limit the uptake and utility of the Robust Decision Making approach. In this paper, we investigate the claim that the approach can be deemed valuable in developing countries. Challenges and opportunities associated with Robust Decision Making, as a heuristic decision framework, are discussed with insights from a case study of adapting coastal infrastructure to changing environmental risks in South Africa. Lessons are extracted about the ability of this framework to improve the handling of uncertainty in adaptation decisions in developing countries.

Keywords complexity · uncertainty · decision frameworks · developing countries

1 Introduction

Climate change adaptation decisions are being made with incomplete system understanding and imperfect knowledge about the consequences of implementing different adaptation options. Furthermore, decision makers are required to make trade-offs based on conflicting personal, institutional and stakeholder values. The combination of competing objectives and questionable assumptions about the nature of climatic and societal uncertainties creates a

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complex decision space. How then do we make adaptation decisions that are rational and scientifically defensible?

Adaptation scientists and practitioners typically adopt a "predict-then-act" framing of climate risk, with the aim of characterizing and ultimately reducing uncertainties to establish the most likely climate outcomes (Dessai and Wilby 2011). Yet in combining information about global and regional climate changes with local environmental and socio-economic factors, a cascade of uncertainty is created that can overwhelm decision makers (New and Hulme 2000). To reduce the risks of maladaptation, and assess the suitability of different adaptation options in the context of deep uncertainty, it is prudent to consider alternative framings and approaches. Robust Decision Making (RDM) (Lempert and Schlesinger 2000; Lempert et al 2004) is consistent with an "assess-risk-of-policy" framing, inverting the analytical steps to determine those decision strategies that perform well under a wide range of plausible futures. In this paper, we investigate how the RDM approach might be applied in a developing country context. Key challenges that are likely to arise are discussed with insight from a case study of coastal adaptation in South Africa, where the analysis commissioned to date has been within a predict-then-act framing but where the uncertainty and broader issues involved might warrant an RDM approach.

Global Climate Model (GCM) output and downscaled regional output suffer from model inadequacies (Christensen et al 2007). Impact models propagate these imperfections producing information that is highly conditional on embedded assumptions. Despite the complex physical processes incorporated in these models, the additional complexities of the social, economic, cultural and political dimensions of climate change adaptation are usually considered separately. While some modeling approaches, such as Integrated Assessment Models, combine physical and socio-economic variables to assess climate change mitigation policies (Weyant and et al 1996; Parson and Fisher-Vanden 1997), their formulation is ill-suited to guide climate change adaptation at the local scale. Combining multiple decision drivers within a single decision-theoretic approach is challenging but treating each driver separately eliminates the possibility of exploring the true complexities of the decision process.

An assess-risk-of-policy framing has been considered both more useful and valuable than a predict-then-act framing (Lempert et al 2004; Lempert and Kalra 2011). Yet it is necessary to make a distinction. A tool or approach may be considered *useful* if it can or will be used. However, to have *value* there need to be tangible benefits for the user. Here we differentiate between the value of a particular adaptation strategy and the value of the methodology by which adaptation strategies are considered. While many studies have investigated the value of climate information (e.g. Johnson and Holt 1986; Williamson et al 2002; Luseno et al 2003), relatively few studies have assessed the value of adopting different approaches to consider climate information and inform adaptation (Hallegate et al 2012; Weaver et al 2013).

In developing countries, adaptation and development are intrinsically linked (Halsns and Verhagen 2007) and successfully implementing adaptation decisions requires decision making tools that are appropriate in this context. In a series of papers published in the 2011 World Resources Report, robust adaptation approaches were advocated for use in developing countries (Brown 2011; Dessai and Wilby 2011; Ranger and Garbett-Shiels 2011; Reeder and Ranger 2011). This paper examines whether or not RDM might improve the treatment of climatic uncertainties in developing country adaptation decisions and provides insights from a case study to help assess the claim of Lempert and Kalra (2011):

> "The approach may prove at least as valuable in developing countries as it has proven elsewhere."

Lempert and Kalra (2011) describe a hypothetical developing country adaptation decision. While it is conceptually attractive to consider hypothetical examples, unless the RDM method is understood in the context of real decisions, we cannot expect to fully learn about the benefits and limitations of the approach. Therefore, this paper examines how the approach might be applied for an adaptation decision being made in South Africa. Section 2 outlines the RDM approach in more detail and section 3 provides the results of the South African case study. The wider challenges of adopting the RDM approach in developing countries are discussed in section 4 using insight from the case study. Finally, section 5 concludes the paper, commenting on whether or not RDM, as a heuristic framework, provides value for adaptation decision makers in a developing country context.

2 The "heuristic" RDM approach

Moss and Schneider (2004) describe three conditions under which RDM might be deemed appropriate to guide adaptation decisions. Firstly, when uncertainty is deep as opposed to well-characterized; secondly, when there are a rich number of possible decision options; and thirdly, when the decision space is sufficiently complex to justify the use of simulation models. Though many developing country adaptation decisions satisfy these criteria, running simulation models can be prohibitively expensive. Lempert and Kalra (2011) distinguish between a "full" and a "heuristic" RDM approach. In full RDM, a large ensemble of computer simulations explores the decision space and help to assess the performance of alternative strategies under different future climate scenarios. In this study the aim is to assess the value of the RDM approach as a heuristic framework where the analytical steps are the same but the use of computer simulations is omitted. Therefore, the approach is less likely to generate quantitative decision support but may still provide valuable qualitative guidance.

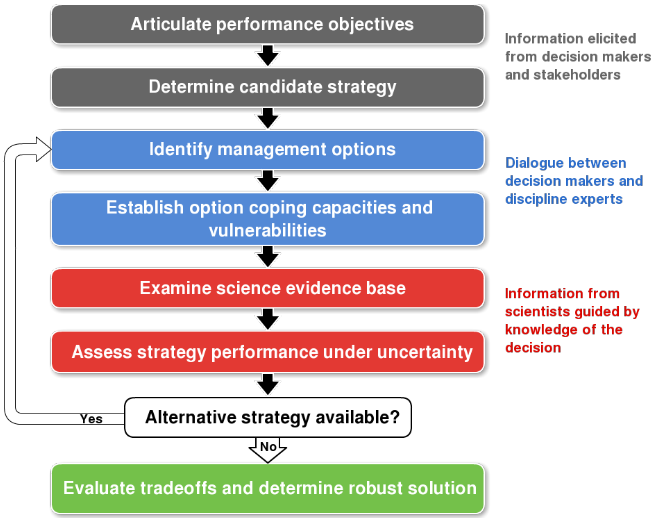

Fig. 1 The sequence of analytical steps in the heuristic Robust Decision Making approach.

Fig. 1 shows the sequence of steps associated with the heuristic RDM approach. The process begins with establishing the performance objectives of the decision makers, identifying the relevant stakeholders, determining the planning time horizons and constraining the problem statement by deciding on the relevant uncertain variables to which the adaptation strategy must be deemed robust. The next step is to articulate the candidate strategy; in the first iteration this will be the strategy that does not incorporate new information about future climate change. The next phase of the process (blue steps), sometimes referred to as "scenario discovery" (Lempert et al 2004), involves assessing the coping capacities and the vulnerabilities of the available adaptation options under different future scenarios. The subsequent phase (red steps) encourages exploration of the broader scientific evidence base about future risks (which would desirably include, where available, appropriate model projections) followed by an assessment of the strategy's performance under the range of uncertainties. These steps consider changes to relevant climatic and non-climatic variables; only at this point would probability distributions of these variables (if available) be used in the analysis (Hallegate et al 2012). Using an iterative process, the decision makers and disciplinary experts then consider alternative strategies to deliver the same performance objectives. The final step is to evaluate trade-offs among the options and strategies to determine robust strategies which perform well across a wide range of possible future scenarios. In the next section, the application of heuristic RDM framework outlined here is presented for a real-world case study of coastal adaptation in South Africa.

3 Case Study: Protecting railway infrastructure at Glencairn, Cape Town

3.1 Background of case study

The City of Cape Town (CoCT) municipality is responsible for managing public assets along 240 km of coastline which are becoming increasingly exposed to environmental change. Infrastructure on the South Peninsula Transport Corridor (SPTC), located between Muizenberg and Cape Point (see Fig. S1), is particularly vulnerable to sea level rise, changes in the frequency and intensity of storm surges as well as dynamic coastal processes such as erosion and migrating dunes (City of Cape Town 2005; Cartwright 2008; Cartwright et al 2008). At specific locations along the SPTC, such as Glencairn (superimposed on Fig. S1), the railway line is in need of urgent interventions to reduce these vulnerabilities. In August 2012 the CoCT announced a call for tenders to conduct a modelling study to assess the beach dynamics at Glencairn and coastal processes across False Bay (Cape Times 2012). In December 2012 the tendering process was completed and the successful consultancy began work on the study in early 2013 (Worley Parsons 2013). The study was completed in November 2013 and recommendations on remedial interventions to protect the SPTC railway have been provided.

The study was conducted in two phases. The first phase focused on data collection and the use of model simulations to predict future changes along the coastline. This process incorporated a range of climate model projections for changes in wind speed and sea level. The projections were subsequently used to construct error bars on best estimates but could have formed part of an uncertainty exploration to facilitate a RDM analysis. In light of these predictions, the second phase examined the suitability of different adaptation options, drawing on results from a formal elicitation of stakeholder preferences (using a multi-criteria evaluation matrix) to find an optimal solution. The study can therefore be conceptually associated with a conventional top-down approach resulting from a predict-then-act framing, which differs to the bottom-up approach and assess-risk-of-policy framing consistent with RDM:

1. Seek optimal solution → Predict-then-act framing → top-down approach
2. Seek robust solution → Assess-risk-of-policy framing → bottom-up approach

The beaches along the SPTC coastline are subject to a seasonal cycle of accretion during winter, associated with cyclone-driven westerly winds, and erosion during summer, associated with persistent south-easterly winds (Colenbrander et al 2012). Significant erosion events are therefore more likely in the summer when the south-easterly winds are particularly strong and persistent (see Fig. S2) but they can also occur in winter as a result of storm surges associated with intense cold fronts. The possible impacts of sustained erosion on the SPTC railway include: direct expenses from structural damage; degradation of natural coastal defences that protect the railway; major disruption for commuters and tourists from rail closures and ongoing maintenance; economic impacts for local businesses dependent on the functioning of the railway; depreciation of the value of nearby assets and properties; and health and safety implications for communities who utilize the coastline.

A number of studies have investigated the impacts of climate variability and climate change on key sectors in Cape Town and its surrounding areas (Johnston et al 2007; Mukheibir and Ziervogel 2007; Ziervogel et al 2010). The CoCT is therefore relatively well equipped to consider the impacts of climate change when compared to urban areas in other developing countries. Moreover, Cape Town and other South African coastal cities are unusual in that many of their most exposed areas, including sections of the SPTC, are home to wealthier populations. However, some of the issues that need to be addressed are relevant to urban and coastal adaptation in other developing countries: notably, high rates of rural-to-urban migration (Africa 2013) that places increasing pressure on the infrastructure; social equity issues as the poorer communities largely rely on public transport while wealthier communities primarily utilise private vehicles; and highly constrained financial resources to invest in the long term resilience of coastal infrastructure. Furthermore, the SPTC study will influence how future decisions are made along the rest of the Cape Town coastline, impacting many more communities, including those living in the Cape Flats (an area housing many of Cape Town's poorer communities) which are particularly vulnerable to flooding events that are expected to worsen under climate change. It is in this context that we investigate the potential value of the RDM approach as an alternative to the predict-then-act approach being applied in the SPTC study.

The data and insights shared in this paper are drawn from continued engagement with the project management team and the contracted consultancy over the duration of project, from July 2012 to November 2013; the data in fig.2 and fig. 3 were not incorporated into the SPTC project and are only present in this study. The engagement consisted of attendance at project meetings, interviews with members of the project management team and further informal discussions with the project manager.

3.2 Application of the RDM approach

An interview with Darryl Colenbrander (SPTC project manager at the CoCT) was conducted to establish the nature of the decision problem being investigated in the study. The main aim of the interview was therefore to elicit the *performance objectives* and *candidate strategy* from the decision maker's perspective, constituting the first two steps in the RDM analysis (Fig. 1). Questions related to the other steps in the RDM process were also asked where possible (see *supplementary materials*). In the interview, three key project objectives were articulated:

1. To understand the beach dynamics along the SPTC, specifically at Glencairn, and determine how any observed trends might evolve in the future.
2. To gather data to inform the most appropriate remedial interventions.
3. To determine how best to use that information in shaping decisions that promote sustainability along the entire Cape Town coastline.

These project objectives provide the context for the ultimate outcome objective of the SPTC study: to design and implement a remedial intervention(s) to protect the railway and supporting infrastructure from environmental risks along vulnerable stretches of the SPTC, while limiting any adverse environmental and social impacts. Within the scope of the SPTC study, the current strategy is to preserve and protect the existing railway by implementing soft or hard defensive engineering solutions. The decision time horizon is 25 years but protection of the railway over the next five years is considered a priority. Data from interviews with other members of the project management team reveal ancillary performance objectives. All stakeholders agree on the need to protect the railway but some members are particularly concerned about the environment impacts of any intervention while others stress the importance of selecting options that do not require ongoing maintenance. The views of local residents have not been explicitly included in defining the performance objectives as these communities are to be consulted at a later stage in the decision process.

Given the historic exposure of the SPTC railway to coastal processes, a number of climate variables have previously been identified which affect the vulnerability of the railway (CSIR 1987). Of key concern is the height of sea level in False Bay, the storm surge associated with intense cyclonic systems and the strength of the prevailing winds. Sea level rise and an increase in the frequency and/or magnitude of south-easterly driven wave chop (rapid short, steep motion of breaking waves) could significantly impact the railway at Glencairn and elsewhere along the SPTC. Evidence from past events can be used to better understand the current vulnerability of the railway. For example, in summer 2011 a significant erosion event occurred at Glencairn, when waves came to within 50 cm of the railway resulting in the temporary closure of the line. Ad-hoc solutions were subsequently implemented to protect the railway from further erosion (Fig. S3). The railway is also exposed to a build-up of wind-blown sand on the track. When the prevailing south-easterly wind persists for three or more days, workers are employed to clear sand so the line can remain open.

Socio-economic and political factors also need to be acknowledged within the decision process. The CoCT prides itself on the accessibility and visual appearance of the coastline and decision makers acknowledge that local communities will want to preserve the aesthetic value and maintain access to the beaches for recreation. The railway also supports tourism and maintaining regular services will feedback into the local economy (Burns et al 1993). These factors need to be considered when determining robustness criteria to assess the possible interventions. How RDM accounts for these aspects is discussed in more detail in section 4.

The third step of the RDM process (Fig. 1) identifies the possible adaptation options consistent with the candidate strategy. A series of meetings and a site visit were attended at which possible options were discussed. Table 1 lists some of the main remedial interventions that were considered by the CoCT; the list does not document combinations of options that may prove to be more effective and appropriate. In step four of the RDM approach (Fig. 1), the coping capacities of the options are established for each of the uncertain variables. Some options (e.g. beach nourishment) will only protect the railway for small changes in

Table 1 Possible remedial interventions to reduce the vulnerability of the SPTC railway at Glencairn.

Intervention	Description
Groyne	A hydraulic structure (above water or submerged) extending from the coastline perpendicular to the shore: designed to prevent longshore drift.
Gabion mattress	Stacked free-draining wire-mesh units, filled with stone/rock, lining the beach.
Rock revetment	Sloping rock structure placed on coast to absorb the energy of incoming water.
Geofabric revetment	As above but using elongated ecologically sustainable cloth bags or tubes, filled with sand; a form of semi-hard coastal engineering.
Breakwater	Shore-connected or detached coast-parallel structure close to the surf-zone.
Dune creation	Artificial dune construction and rehabilitation using beach compatible sand.
Beach drainage	Artificial lowering of the groundwater table, with a drainage system.
Beach re-profiling	Re-designing the beach profile to alter the vertical slope.
Beach nourishment	Importing sand to replace sand lost from erosion and restoring existing dunes.
Sea wall	Vertical engineering solution typically made of concrete, boulders or steel.

the relevant climatic variables. In addition, other non-climatic variables, such as rural-to-urban migration, may place further stresses on rail services in the future impacting the life-span of certain remedial interventions. If the RDM approach had been adopted in the SPTC study then the specific coping capacities and vulnerabilities of the options would have been identified. Conversely the predict-then-act approach only yields information on the drivers of vulnerability; the vulnerabilities of the options in the candidate strategy remain unexplored.

The next stage of the RDM process is to examine the scientific evidence base, assessing the range of uncertainties, and establishing a large number of plausible future climate scenarios. According to NOAA, mean sea level at Simon's Bay increased at 1.82 mm/year between 1957 and 2010 with a 95% confidence level ± 0.28 mm/year (NOAA 2012b). This broadly agrees with a 1.95 mm/year increase calculated from PSMSL (Permanent Service for Mean Sea Level) data (black line, Fig. 2). Given the absence of likelihood statements in the Intergovernmental Panel on Climate Change (IPCC) fourth assessment report (AR4), Brundrit (2008) argues that it is prudent to restrict decadal projections of sea level rise in False Bay to extrapolations of current trends. Fig. 2 shows the increase in monthly mean tidal gauge data for Simon's Town from 1957 to 2011 (some data is missing due to a lack of continuous observations). Although a crude method for estimating future sea level rise, a linear extrapolation of the NOAA trend over the next 25 years results in 4.55 cm of sea level rise (green scenario, Fig. 2). However, the trend from 2001 to 2011 shows an acceleration of the rise in sea level at Simon's Town to 7.72 mm/year. Using this trend, a much higher increase of 19.3 cm is projected (red scenario, Fig.2).

While acknowledging that linear interpolation of sea level rise projections is highly questionable, the range of global sea level projection anomalies provided in the IPCC AR4 and AR5 reports are interpolated for the year 2037 (IPCC 2007, 2013). The AR4 projections (blue line, Fig. 2) range from no sea level to the upper red scenario while the AR5 projections (grey line, Fig. 2), which account for contributions from ice sheets, show a greater range with a maximum of 40 cm of sea level rise by 2037. All values within these ranges might be considered plausible in the absence of further information. However, these scenarios do not bound the uncertainty and higher/lower trends cannot be ruled out. Other contributing factors may lead to larger sea level rises (Nicholls et al 2011; NOAA 2012a; Rahmstorf et al 2012; Rahmstorf 2012) making the robustness requirements more stringent.

The erosion at Glencairn beach, and the secondary problem of wind-blown sand on the railway line, are particularly sensitive to strong persistent south-easterly winds. Fig. 3 shows

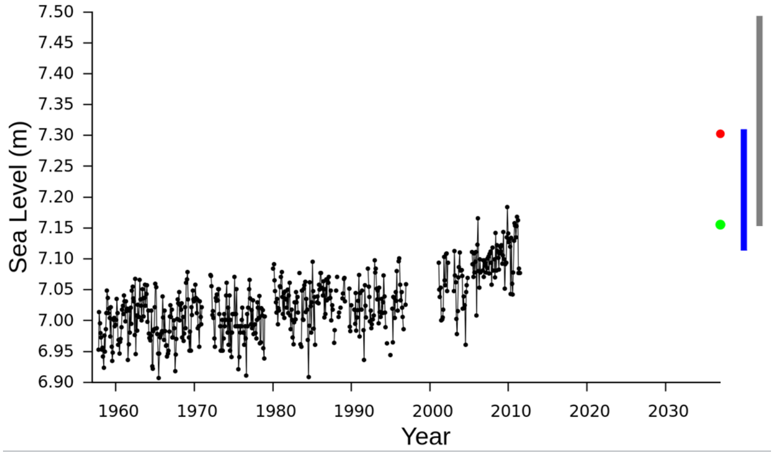

Fig. 2 Monthly mean tidal gauge data for Simons Town (black), two scenarios of future values based on extrapolation with a trend of 1.82 mm/year (green) and 7.72 mm/year (red) and the IPCC AR4 (blue) and AR5 (grey) range of sea level projections interpolated for 2037 based on the 2080-2099 projection anomalies from 1980-1999 and 1986-2005 respectively. Observed data available at psmsl.org/data/obtaining/stations/826.php.

that even with a limited dataset it is possible to detect inter-annual variability in the most damaging winds; between 40% and 50% of winds are south-easterly at $\geq$ 5 m/s. Climate change may impact the frequency and magnitude of south-easterly winds in False Bay but in the absence of reliable model simulations of regional scale surface wind changes, it is prudent to consider adaptation options that can cope with both an increased and decreased frequency and intensity of damaging winds.

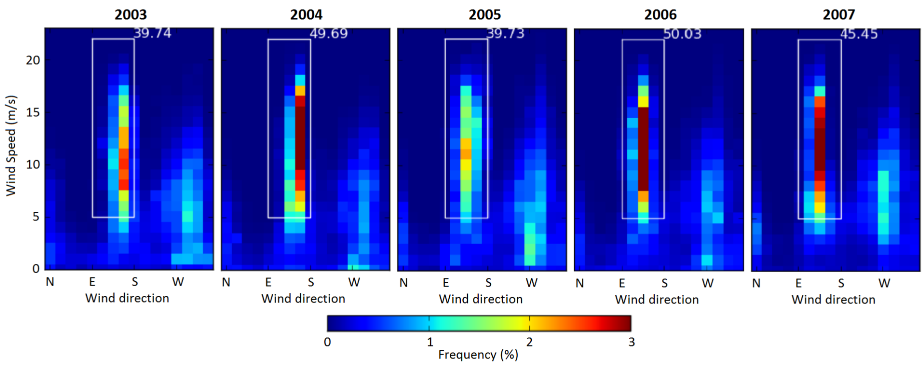

Fig. 3 Wind squares for Roman Rock weather station 2km south-east of Glencarin. The two-dimensional frequency plots show the percentage of winds occurring for given directions and windspeeds within each year. White boxes, and the corresponding number, show the percentage of winds $\geq 5m/s$ from an E to S direction.

The interventions listed in table 1 are consistent with the candidate strategy. However, the RDM approach explicitly encourages the consideration of alternative strategies. Possible alternative strategies include: (1) a phased retreat of the railway and surrounding assets; (2) re-routing the line at a higher elevation or greater distance from the coast; (3) building a promenade along the coast and re-constructing the railway line along the promenade[1]; or (4) abandoning the railway line at Glencairn and terminating the line at a more northerly station. Consistent with the framing of the SPTC study in the stated objectives, the CoCT has been clear since the project's inception (Worley Parsons 2013) that the candidate strategy of protecting the existing railway is the only viable strategy in the short to medium-term. Yet, to ensure the long-term sustainability of coastal management activities, decision makers might be impelled to investigate the possibility of these other more radical, potentially more robust, strategies. This illustrates that adopting a RDM approach and considering alternative strategies might be more appropriate if the planning time horizon was longer and the decision framing allowed for consideration of a wider range of strategies.

The final stage of the RDM process assesses which combination of options and strategies are robust to a wide range of futures. This step involves evaluating the trade-offs between different options. Based on the evidence of sea level rise in False Bay presented here, any options which fail to protect the railway for a 40 cm mean sea level rise cannot be deemed robust over the planning time horizon. Crucially however, to address non-climatic factors, decision makers also need to determine which options are robust to other environmental risks (e.g. dune degradation), socio-economic variables (e.g. local acceptability) and the broader stakeholder values. While the consultants on the SPTC study have made recommendations on the appropriate adaptation strategy, based on the modelling study and the views represented in the project management team, the CoCT still need to complete an Environmental Impact Assessment (EIA) to assess the wider impacts of the proposed intervention. It is therefore not yet possible to disclose the recommended solution, and without consideration of non-climatic factors it is not possible to determine whether this option is robust to a wide range of possible futures.

4 Assessing the value of the RDM Approach

4.1 Handling uncertainty

> "Uncertainty is key in how we make decisions"
>
> – Darryl Colenbrander, The City of Cape Town

RDM seeks to find decision strategies that perform well across a wide range of possible future scenarios. There is no requirement to determine the precise probability of each future climate scenario but there must be sufficient reason to believe each scenario is plausible. Consequently, a binary assessment of likelihood (plausible or *im*plausible) is necessary. How to ascribe this form of likelihood to different scenarios is non-trivial.

In the SPTC study, a 50 cm sea level rise in 25 years would require significant remedial interventions. While this scenario may be improbable, it might be considered plausible given evidence of rapid sea level rise in the past (Clark et al 2004). However, if model projections (e.g. those used in the IPCC AR5) are unable to produce a 50 cm sea level rise on this timescale, should this scenario be excluded from the planning process? By doing so, it means that we place confidence in the ability of our models to represent the evolution of the real system. If we think it unwise to dismiss a 50 cm sea level rise, despite the inability of the

[1] Similar to a recent construction in Umhlanga, Durban: http://www.umhlangatourism.co.za/promenade.php.

models to produce such a change, then our models are assumed unfit to determine what is and isn't plausible and are of little use in an RDM analysis. Here lies the dilemma. In choosing to follow the heuristic RDM approach, and considering multiple lines of evidence, a more nuanced, less tractable "model" is created to determine what is and isn't plausible. In this sense, the decision will be neither robust to all possible future change nor to the future changes exhibited within a particular (climate) model. Rather, a robust decision, determined in this way, performs well only within the range of uncertainty considered in the scope of the analysis. This scope is defined as much by the problem framing and objectives as it is by any methodological choices, but it is nevertheless critical to be explicit about what the scope is and detail the relevant assumptions. The danger is that by adopting "robust" measures decision makers are fooled into thinking that their decisions are insensitive to the full range of *real-world* uncertainties.

In developing country adaptation decisions, the use of full RDM, described in 2, is likely to be minimal see discussion in section 4.3. The process of scenario discovery using heuristic RDM is unlikely to be based on simulation models but rather a variety of sources from scientific reports, anecdotal data and subjective input from disciplinary experts. Admittedly, it is the problem framing that primarily constrains the scope of the analysis and the information required may not differ substantially between top-down and bottom-up approaches. However, the way in which the information is used in the decision making process is likely to differ. Hulme and Dessai (2008) note that climate scenarios create a constructive tension as they operate both as products and as processes; as decision makers work with scenarios (as products) they enter a learning process and begin to appreciate their limitations. Through engaging in this learning process, decision makers are then empowered to use the scenarios to facilitate robust decision making. It is therefore important that the application of heuristic RDM preserves this learning process and enables decision makers to appreciate the assumptions that go into determining the range of plausible future scenarios. It is also worth highlighting that in adopting the principles of RDM, one needn't preclude the strengths of a top-down approach and there is an emerging view that an integration of both top-down and bottom-up approaches is potentially more useful (Brown 2011).

4.2 Addressing non-climatic factors

In the case study presented, the analysis in section 3.2 is focused on climatic factors. Yet there is a need to ensure salience and legitimacy in any decision process (Cash et al 2002); information must be relevant to the decision and explicitly consider the values and perspectives of different stakeholders. In the current approach, the CoCT will explicitly incorporate the views of local residents in the next phase of the project through a formal public participation and EIA process. While the timing of stakeholder engagement is independent of the decision methodology applied, adopting the RDM approach in the SPTC study would have encouraged decision makers to consult all stakeholders prior to the scoping of remedial interventions, helping to improve salience and legitimacy. Indeed, Weaver et al (2013) state that robust decision frameworks can confer greater credibility, salience and legitimacy by adopting bottom-up articulations of adaptation contexts.

With a climate change adaptation lens, there is often a one dimensional view of what is considered optimal. To an engineer an optimal solution might be one that best protects the asset, while to a city planner the optimal solution may be that which yields the least amount of social unrest. It follows that an optimal decision in the context of multiple competing, highly uncertain, factors may well be sub-optimal from any one perspective. Similarly, a decision which is robust to climatic uncertainties may be less robust in the wider decision context. Lempert and Collins (2007) show that RDM preserves the advantages of using a precautionary approach while minimizing the potential for maladaptation that might result from an optimal-decision based approach. Yet ignoring the values and preferences of those affected, and prioritizing environmental risks can be similarly maladaptive; there may be a high social and cultural cost associated with protecting a system or asset at risk from climate change, such as the SPTC railway, which may outweigh the gains in reduced environmental risks. Adaptation is complicated by the need to accommodate social and cultural preferences but these preferences need not be seen as obstacles to overcome but rather the goals and objectives to be met.

The RDM process explicitly allows for the consideration of trade-offs between multiple factors and this may well result in trading off robustness to climatic uncertainties in favour of options which are more robust to other environmental, socio-economic and political uncertainties. Such trade-offs are often negotiated in other approaches but RDM is particularly well suited to address these trade-offs as they are presented in the context of all available strategies; a result of inverting the decision steps.

4.3 Application of the RDM approach to developing countries

While it is somewhat incongruous to generalize about adaptation decisions, which are highly location and context dependent, it is important to highlight the different factors which affect adaptation in developing countries. Ziervogel et al (2010) comment that developing nations are "burdened with meeting numerous development challenges" and with a lack of sufficient human and economic resources, coupled with weak and inefficient institutions, effectively engaging in adaptation is difficult. In South Africa, and other developing countries, the widespread uptake of full RDM is therefore unlikely and the heuristic RDM approach will only be adopted if it can be shown to provide value, delivering tangible benefits to decision makers and the beneficiaries of adaptation decisions.

Developing countries are often limited by poor availability of and access to reliable data. While full RDM is data intensive, the heuristic RDM approach can make use of stakeholder-led elicitations of vulnerabilities. RDM can therefore improve on predict-then-act approaches that rely on data-driven analyses of risk. In addition, engagement in the SPTC study suggests that RDM could improve salience and legitimacy in the decision process; of particular relevance to developing nations where issues of trust and governance can be significant barriers to adaptation (Ziervogel and Zermoglio 2009). However, other potential barriers could limit the successful uptake of the RDM approach.

Perhaps the most limiting factor relates to the very notion of adopting "robust" versus "optimal" decisions. In developing countries, where resources are highly constrained and maximizing development gains remains a priority, choosing options that are considered sub-optimal may be politically and economically unattractive. In the SPTC study decision makers are wary of implementing costly solutions which may be robust to uncertainties but divert resources away from other pressing infrastructure and development issues, such as poverty, crime and the provision of affordable housing.

Another key issue that limits the relevance of RDM in developing countries is the planning time horizon. RDM is best suited to address those decisions which have long time horizons. Short- and long-term perspectives can be complimentary but this requires a formal assessment of the long term impacts of interventions; a decision considered robust in the short-term might not be robust in the longer-term. Because of the urgent need to address existing, unacceptable risks to the railway at Glencairn, short-term remedial interventions have been prioritized. This situation is likely to be mirrored in other developing countries which are burdened by an existing adaptation deficit (the separation between the desired and actual level of current climate risk); in a development context, adaptation often focusses on reducing current, as opposed to future, levels of risk. It could be argued that the study selected here is not well suited to assess the value of RDM because of its 25 year planning horizon but there are few adaptation decisions in developing countries with planning horizons beyond two or three decades. A key element of a robust adaptation strategy is the ability to incorporate adaptive capacity (Smit and Wandel 2006; Ranger and Garbett-Shiels 2011; Reeder and Ranger 2011); the capability to modify plans in light of new evidence or changing risks. However, short planning time horizons mean that adaptive capacity is often considered less of a priority when compared to factors such as the cost of capital, effectiveness and social acceptability.

The starting point for RDM is the articulation of performance objectives (see Fig. 1) but in many developing countries, vastly competing world-views and attitudes to risk can cause significant disagreement about what those objectives should be. In the SPTC study, decision makers identified coastal erosion as a major problem requiring urgent intervention but the objective to prioritise protection of the railway, as opposed to other assets and values, may not necessarily be shared by all stakeholders. This raises complex governance issues related to authority, social justice and equity, which are particularly pertinent in a South African context. This consideration need not necessarily prevent the uptake of RDM but it does mean that the initial engagement in a RDM process requires a concerted effort to ensure representation in the articulation of performance objectives.

On a practical level, informing adaptation decisions in developing countries raises further issues relevant to RDM. Institutions and decision processes are often less developed making it difficult to sustain engagement with stakeholders. Also, climate researchers and adaptation experts are rarely based close to vulnerable communities so bringing scientists, practitioners and communities together introduces significant expenses and time commitments. Finally, translation of information into local languages and dialects can be a necessity in some areas. These present real non-negligible problems in successfully applying any approach, including RDM, in developing countries.

5 Concluding Remarks

Does RDM improve the handling of uncertainty in decision making processes? Based on insights from engagement in the SPTC study it appears that RDM can improve on predict-then-act approaches in helping to better identify those uncertainties which are important to a specific decision, removing unnecessary analysis of irrelevant variables. Adopting the RDM approach should also reduce the risk implementing decision strategies that are prone to projection errors. However, it is crucial to be clear about the scope of the analysis and the process of scenario discovery to ensure that the decision makers are not complacent about the robustness of solutions. Also, combining quantifiable with unquantifiable uncertainties, associated with multiple stressors, remains problematic but the RDM approach at least encourages decision makers to confront this challenge.

Are adaptation decisions in developing countries aided by a RDM approach? All developing countries have specific challenges to overcome and South Africa has its own unique history which continues to shape its future. Moreover, adaptation decisions are entrenched in societal norms, cultural beliefs, stakeholder attitudes to risk and, perhaps most significantly, political and economic realities. Using "full" RDM to support developing country adaptation decisions seems unlikely at present but irrespective of the resources required to engage in RDM, the decision to implement potentially more costly, albeit robust, solutions may be unattractive to decision makers wary of diverting resources away from other pressing infrastructure and development issues. Also, the need to address existing vulnerabilities and the prevalence of short planning time horizons may reduce the uptake of the RDM approach. However, RDM does encourage decision makers to address non-climatic factors, which are often the main drivers of vulnerability in developing countries, throughout the process.

Whilst the case study explore here cannot provide conclusive evidence regarding the value of adopting the RDM approach in developing countries, the study suggests that there is a need to consider alternative adaptation decision making approaches to those currently being employed in developing countries. Nevertheless, the RDM approach is not a panacea for climate change adaptation and it is important to recognize the complex nature of decision making in any formal decision methodology.

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References

Africa SS (2013) Statistical release, P0302: Mid-year population estimates. Available at http://www.statssa.gov.za/publications/P0302/P03022013.pdf

Brown C (2011) Decision-scaling for robust planning and policy under climate uncertainty. World Resources Report Uncertainty Series. Available at http://www.worldresourcesreport.org/

Brundrit G (2008) Global Climate Change and Adaptation: A Sea-Level Rise Risk Assessment. Phase one: Sea Level Rise Model

Burns MER, Barwell L, Heinecken TJE (1993) Analysis of critical coastal processes affecting recreation and tourism development opportunities along the South-Western cape Coastline. In P.P. Wong (ed), Tourism vs. Environment: the case of coastal areas, The Geo Journal Library, Kluwer Academic Publishers, Boston, USA, pp 19–32

Cape Times (2012) Municipal Notices: Invitation to tender. Published August 10. Tender No: 47C/2012/13: provision of professional services to model sediment dynamics in False Bay and to provide recommendations for remedial options for the Glencairn railway line.

Cartwright A (2008) Global Climate Change and Adaptation. Phase three: Final Report, A Sea-Level Rise Risk Assessment for the City of Cape Town

Cartwright A, Brundrit G, Fairhurst L (2008) Global Climate Change and Adaptation. Phase four: Final Report, Sea-Level Rise Adaptation and risk mitigation measures for the City of Cape Town

Cash D, Clark W, Alcock F, Dickson N, Eckley N, Jger J (2002) Salience, credibility, legitimacy and boundaries: linking research, assessment and decision making. John F. Kennedy School of Government Harvard University Faculty Research Working Papers Series

Christensen et al JH (2007) Regional Climate Projections. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA

City of Cape Town (2005) City of Cape Town's coastal zone management strategy, coastal zone management review and state of the coast Year two: Nov 2004 - Oct 2005. Summary Report. Prepared by the Environmental Resource Management Department

Clark PU, Marshall McCabe A, Mix AC, Weaver AJ (2004) Rapid rise of sea level 19,000 years ago and its global implications. Science 304(5674):1141–1144

Colenbrander D, Sutherland C, Oelofse G, Gold H, Tsotsobe S (2012) Reducing the pathology of risk: developing an integrated municipal coastal protection zone for the City of Cape Town. In: Climate Change at the City Scale, Routledge, Earthscan, chap 10, pp 182–201

CSIR (1987) Glencairn Beach Management Plan. Tech. Rep. OX/C/CSW2/2

Dessai S, Wilby R (2011) How Can Developing Country Decision Makers Incorporate Uncertainty about Climate Risks into Existing Planning and Policymaking Processes? World Resources Report Uncertainty Series. Available at http://www.worldresourcesreport.org/

Hallegate S, Shah A, Lempert R, Brown C, Gill S (2012) Investment decision making under deep uncertainty: application to climate change. Policy Research Working Paper 6193, The World Bank, Sustainable Development Network, Office of the Chief Economist

Halsns K, Verhagen J (2007) Development based climate change adaptation and mitigation - conceptual issues and lessons learned in studies in developing countries. Mitigation and Adaptation Strategies for Global Change 12(5):665–684

Hulme M, Dessai S (2008) Predicting, deciding, learning: can one evaluate the 'success' of national climate scenarios? Environ Res Lett 3:045,013

IPCC (2007) Climate Change 2007: The Physical Science Basis, Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA

IPCC (2013) Summary for Policymakers. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S. K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA

Johnson SR, Holt MT (1986) The Value of Climate Information. Center for Agricultural and Rural Development, Iowa State University. Staff Report 86-SR 6

Johnston P, Ziervogel G, Matthew M (2007) The uptake and usefulness of weather and climate forecast information among water resource managers in the SW Cape region of South Africa. Papers of the Applied Geography Conferences 30:380–389

Lempert R, Collins M (2007) Managing the risk of uncertain threshold responses: comparison of robust, optimum, and precautionary approaches. Risk Analysis 27(4):1009–1026

Lempert R, Kalra N (2011) Managing Climate Risks in Developing Countries with Robust Decision Making. World Resources Report Uncertainty Series. Available at http://www.worldresourcesreport.org/

Lempert R, Schlesinger M (2000) Robust strategies for abating climate change. Climatic Change 45:387–401

Lempert R, Nakicenovic N, Sarewitz D, Schlesinger M (2004) Characterising climate-change uncertainties for decision-makers. Climatic Change 65:1–9

Luseno WK, McPeak JG, Barrett CB, Little PD, Gebru G (2003) Assessing the Value of Climate Forecast Information for Pastoralists: Evidence from Southern Ethiopia and Northern Kenya. World Development 31(9):1477–1494

Moss RH, Schneider SH (2004) Climate Scenarios and Projections: The known, the unknown, and the unknowable as applied to California. Prepared for the Aspen Global Change Institute by Susanne C. Moser

Mukheibir P, Ziervogel G (2007) Developing a municipal adaptation plan (MAP) for climate change: the City of Cape Town. Environment and Urbanisation 19:143–158

New M, Hulme M (2000) Representing uncertainty in climate change scenarios: a Monte-Carlo approach. Integrated Assessment 1(3):203–213

Nicholls RJ, Marinova N, Lowe JA, Brown S, Vellinga P, de Gusmao D, Hinkel J, Tol RSJ (2011) Sea-level rise and its possible impacts given a 'beyond 4°C world' in the twenty-first century. Phil Trans R Soc A 369(1934):161–181

NOAA (2012a) Global Sea Level Rise Scenarios for the United States National Climate Assessment. Technical Report OAR CPO-1, available at http://cpo.noaa.gov/sites/cpo/Reports/2012/NOAA_SLR_r3.pdf

NOAA (2012b) Tides and Currents: Sea Levels Online. Accessed 5 September 2012, available at http://tidesandcurrents.noaa.gov/sltrends/sltrends.shtml.

Parson EA, Fisher-Vanden K (1997) Integrated Assessment Models of Global Climate Change. Annu Rev Energy Environ 22:589–628

Rahmstorf S (2012) Modeling Sea Level Rise. Nature Education Knowledge 3(10):4

Rahmstorf S, Foster G, Cazenave A (2012) Comparing climate projections to observations up to 2011. Environ Res Lett 7(4), 044035

Ranger N, Garbett-Shiels SL (2011) How can decision-makers in developing countries incorporate uncertainty about future climate risks into existing planning and policy-making processes? Policy paper. Centre for Climate Change Economics and Policy and the Grantham Research Institute on Climate Change and the Environment in collaboration with the World Resources Report

Reeder T, Ranger N (2011) How do you adapt in an uncertain world? Lessons from the Thames Estuary 2100 project. World Resources Report Uncertainty Series. Available at http://www.worldresourcesreport.org/

Smit B, Wandel J (2006) Adaptation, adaptive capacity, and vulnerability. Global Environmental Change 16:282–292

Weaver CP, Lempert RJ, Brown C, Hall JA, Revell D, Sarewitz D (2013) Improving the contribution of climate model information to decision making: the value and demands of robust decision frameworks. WIREs Clim Change 4:39–60

Weyant J, et al (1996) Integrated Assessment of Climate Change: An Overview and Comparison of Approaches and Results. In: Bruce JP, Lee HL, Haites EF (eds) Climate Change 1995: Economic and Social Dimensions of Climate Change, Contribution of Working Group III to the Second Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, pp 367–396

Williamson RA, Hertzfeld HR, Cordes J (2002) The Socio-Economic Value of Improved Weather and Climate Information. Space Policy Institute, The George Washington University, Washington, DC 20052

Worley Parsons (2013) Provision of professional services to model sediment dynamics in False Bay and to provide recommendations for the remedial options for the Glencairn railway line. Tech. rep., 269990-00-CS-REP-0001

Ziervogel G, Zermoglio F (2009) Climate change scenarios and the development of adaptation strategies in Africa: challenges and opportunities. Clim Res 40:133–146

Ziervogel G, Shale M, Du M (2010) Climate change adaptation in a developing country context: the case of urban water supply in Cape Town. Climate and Development 2:94–110