How do you adapt in an uncertain world? Lessons from the Thames Estuary 2100 project

World Resources Report Uncertainty Series

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Suggested Citation: Reeder, Tim and Nicola Ranger. "How do you adapt in an uncertain world? Lessons from the Thames Estuary 2100 project." World Resources Report, Washington DC. Available online at http://www.worldresourcesreport.org

INTRODUCTION

As the international debates on appropriate policy responses to climate change carry on, the climate continues to warm and the commitment to further long-term warming grows. The US National Oceanic and Atmospheric Administration (NOAA) recently pronounced that 2010 tied with 2005 as the warmest year globally since records began in the late 19th century[1]. In December 2010, the United Nations Environment Programme (UNEP) released a report that concluded that even if nations meet the pledges made under the Copenhagen Accord for 2020, the world could still be on track to experience a warming of between 2.5 to 5°C above pre-industrial levels by 2100, depending on how quickly greenhouse emissions are reduced post 2020 (UNEP, 2010)[2]. An outcome of the United Nations Framework Convention on Climate Change (UNFCCC) 16th Conference of Parties in Cancun in December 2010 was recognition within the United Nations framework of the goal to maintain global mean temperatures below 2°C.[3]

At the same time, adaptation is rising fast up the domestic policy agenda. For example, the UK Climate Change Act 2008 sets out a legislative framework requiring a Government programme for adaptation, including a 5-yearly National Climate Change Risk Assessment. The uncertainty over long-term mitigation policy creates challenges for adaptation planning; for example, should decision makers be planning to adapt to 1.5°C, 2°C or 5°C? The policy uncertainty is compounded by additional scientific and socioeconomic uncertainties, particularly at a local level. For example, a central projection of a global mean warming of 2°C from climate models today has an uncertainty bound of at least ±0.5°C and different regions will experience

[1] http://www.noaanews.noaa.gov/stories2011/20110112_globalstats.html. Note that other sources using alternate datasets have given 2010 as the second warmest on record.
[2] And to a lesser extent, how the pledges are implemented (UNEP, 2010).

[3] http://unfccc.int/files/meetings/cop_16/application/pdf/cop16_lca.pdf

different levels of warming[4]. Additional, and often unquantifiable, uncertainties are added in estimating the effects of such a warming on local climate-related risks (such as storm surges or droughts), their impacts on the local economy and society and appropriate policy responses. These uncertainties are particularly great in developing countries, where historical meteorological and socioeconomic data, as well as detailed future projections, tend to be scarcer (UNISDR, 2009).

The uncertainties in climate risk projections are particularly problematic for planning large-scale, long-lived and costly adaptation projects, such as public infrastructure and sector-level development programmes. These types of investments tend to be difficult or costly to reverse (i.e. they have high sunk-costs), are high-stakes and their design is dependent on what assumptions are made today about the climate over its lifetime (e.g. the appropriate height of a sea wall will depend on assumptions about sea level rise over the next few decades). This means that if forecasts are incorrect today, the project can become maladapted to climate, exposing society to greater risks, wasted investments or unnecessary retrofit costs.

This paper outlines one approach to tackle this uncertainty that aims to ensure that adaptation decisions made today are resilient to a fast changing and uncertain climate. The approach, based on a developing a simple 'route-map' of adaptation options, has been demonstrated in practice in the Thames Estuary 2100 (TE2100) project for London. The UK Environment Agency's TE2100 project provides a real-life example of adaptation decision making under uncertainty applied to a long-lived infrastructure decision with high sunk-costs. In this paper, we draw on lessons learned during TE2100 to demonstrate how such large-scale decisions can be made robust in the face of deep uncertainty over future climate using a route-map approach.

UNCERTAINTY AND THE THAMES ESTUARY 2100 PROJECT (TE2100)

Decision makers have long called on scientists to provide more quantitative information on the uncertainties in climate projections. In the mid-2000s, scientists began moving from producing scenarios or 'best-guesses' of the future climate to generating the first probabilistic projections, including PDFs (probability density functions, e.g. Murphy et al. 2004). PDFs were seen by some as a good approach to communicating uncertainty that is consistent with standard policy appraisal approaches[5]. However, with climate change, the uncertainties are such that science is not yet able to provide a complete and unique set of probabilities of different outcomes (e.g. Stainforth et al. 2007a, b). That is, probabilistic projections, based on the latest science, are subject to intrinsic, unquantifiable residual uncertainties. Hall (2007) warns that improper consideration of the residual uncertainties of

[4] This 90th percentile uncertainty takes into account only uncertainties that are known.

[5] For example, the findings of the user consultation exercise before the production of the UK Climate Projections 2009 (UKCIP 2006). For an example, the use of probabilistic information in policy appraisal, see the UK HM Treasury Green book approaches on dealing with uncertainty (HM Treasury, 2003)

probabilistic climate information (e.g. omitting them) in adaptation planning could lead to maladaptation.

One strategy to deal with deep uncertainty in long-term decisions is to incorporate flexibility into adaptation measures from the start; for example, this can be achieved by using measures that are suitable over a broad range of possible future climates (e.g. early warning systems have benefit in all climates) or by designing the adaptation measure such that it can be adjusted over time (e.g. building a sea wall with larger foundations so that it can be raised in the future if necessary, rather than replaced) (Fankhauser et al. 1999). However, often incorporating flexibility can mean greater costs (e.g. the larger foundations of the sea wall) or reduced productivity. In many cases, this cost is outweighed by the benefits of flexibility. In a few cases, these approaches to incorporate flexibility are not feasible (or cannot solve the whole problem), either due to cost or other constraints. This situation was faced by the Environment Agency, in the planning of a flood management strategy for London (the TE2100 project).

In such cases, another way of incorporating flexibility is to build it into the adaptation strategy (rather than the individual measures) by sequencing the implementation of different measures over time, such that the system adapts to climate over time, but options are left open to deal with a range of possible different future climates. This was the approach adopted in the TE2100 project and it was facilitated by a simple route-map decision analysis method.

The objective of TE2100[6] was to provide a plan to manage flood risk in London and the Thames Estuary over the next 100 years. Here, we mainly focus on the storm surge component of risk. Today the Thames region is well protected but the impacts of an unmitigated storm surge flood would be disastrous in terms of lives lost, property damaged and economic disruption. Central London is protected by the Thames Barrier, which was opened in the 1980s to protect against at least a 1-in-1000 year return period storm surge. The system was originally designed to provide its design protection up to 2030. The TE2100 project aimed to examine whether and when the system might need to be modified and to provide a forward plan to 2100.

The large-scale (up to £9 billion) and irreversibility of the potential investments, the risks associated with failure, and the long life-times and lead-times of the infrastructure together meant that the investments are likely to be highly sensitive to climate change; the potential for maladaptation is significant. The plan needed to consider not only growing hazards due to climate change, but also the parallel pressures and uncertainties related to ongoing development within the flood plain.

A challenge for the TE2100 project (shared by many other adaptation problems) is the deep uncertainty over

[6] For further information, also see Reeder et al. 2009 and the TE2100 website (http://www.environment-agency.gov.uk/homeandleisure/floods/104695.aspx).

the scale of future climate risks; in this case, increases in extreme water levels in the Estuary. Making predictions of extreme water levels requires modelling processes about which there is much uncertainty; for example, how global warming will affect ice sheets and the North Atlantic storm tracks.

The TE2100 project demonstrates that robust adaptation planning is possible even where dealing with long-lived decisions with high sunk-costs and deep uncertainty over future climate risks. The key lessons learned from the TE2100 project are applicable to many other adaptation problems.

BUILDING UNCERTAINTY INTO THE PLANNING PROCESS

There is now an extensive literature on the theory of how to tackle climate change uncertainties in adaptation planning (e.g. Willows and Connell 2003; Dessai and van der Sluijs 2007; Lempert et al. 2003; Ranger et al. 2010) alongside a growing body of case studies (e.g. Groves et al. 2008). These studies have shown that uncertainty not only has implications for the methods used to appraise different adaptation options (e.g. Ranger et al. 2010), but also for the appropriate approach to adaptation planning (Wilby and Dessai, 2009; Dessai and Hulme, 2007).

The traditional approach to adaptation planning has been ‘science-first’, where the process begins with the generation/interpretation of climate projections, then an analysis of their impacts and finally to the design and assessment of adaptation options to mitigate those impacts (Dessai and Hulme 2007). Some recent studies have suggested that this process should be reversed. An alternative approach is ‘context-first’ (Figure 1).[7]

Figure 1. Example of a ‘context first’ approach from Ranger et al. 2010. Other examples are available, for example, Willows and Connell (2003) and Dessai and Hulme 2007.

Context-first approaches encourage a decision maker to begin at the level of the adaptation problem itself rather than with climate change projections (e.g. the need to maintain food productivity or protect people from

[7] This approach has many different names in the literature, including ‘policy-first’, ‘bottom-up’ and ‘access risk of policy’ (Dessai and Hulme, 2007), (Carter et al. 2007).

flooding), specifying objectives and constraints, identifying appropriate adaptation strategies and only then (if necessary) appraising their desirability against a detailed set of projections and other inputs.

There are several arguments for employing a context-first approach in adaptation planning, particularly where dealing with 'deep uncertainty'. An argument against the science-first approach is that it is much more exposed to 'ballooning of uncertainties' (Carter et al. 2007) meaning that the appraisal of options can become impracticable (Wilby & Dessai, 2009). Context-first approaches can also be less resource and data intense, as they focus on identifying the highest value information at the start and so streamline the analysis. By beginning with the adaptation problem itself, the context-first approach can also encourage a decision maker to think more broadly about the interactions of other risks and priorities with the adaptation problem and seek strategies that have co-benefits with other policy areas.

The TE2100 project is provides a real example where a context-first approach has been applied in practice in policy analysis. The approach built on the framework laid out in Willows and Connell 2003 and was further developed during the project in collaboration with the ESPACE (European Spatial Planning Adapting to Climate Events) initiative.[8] This was a pioneering project that the Environment Agency supported by working with partners in North West Europe including key players in the South East of England. What made the approach context-first is that understanding the vulnerability of the system (in this case, the flood protection system for London) was the first step and core of the adaptation analysis. Of particular importance is identifying key thresholds (i.e. major change points), such as the level of sea level rise at which current sea defences fail and any limits to adaptation. For example, in the case of London a critical engineering limit to adaptation is at 5 meters mean sea level (Reeder et al. 2009). This sets a limit to carrying on with tidal defences in an additive approach and gives a long-term signal that a radical change of direction may be needed in the longer term.

A context-first approach also emphasises "big thinking," concentrating on the adaptation needs in the context of broader policy needs and objectives, rather than focussing unduly on detailed scientific modelling. From here, the adaptation planners could identify a series of adaptation pathways, a route-map, that are appropriate to cope with the plausible range of climatic changes that could be seen by 2100 (described in the following section).

To give an example of how a context-first approach can be applied, below are a series of steps carried out in the TE2100 project:

I. Structuring the problem:

1 Understand current vulnerability of the system. *For example, evaluating the current level of*

[8] http://www.espace-project.org

flood risk and the standards of protection around the Estuary

2 Map future sensitivities to climate change and other risks. *For the Thames Estuary, science and modelling initially suggested a maximum potential increase in extreme water level of 2.7m in 2100. For sensitivity testing, an upper bound of 4.2m was used to represent a catastrophic sea level rise scenario (see Box 1). The upper bound was deliberately pessimistic to take account of most known wild cards.*

3 Assess known (or estimated) key thresholds in between now and this upper-bound figure in terms of vulnerability to impacts. *Key thresholds for sensitivity in the system include: (i) a limit of the present system of walls and embankments is reached;, (ii) the level of sea level rise at which the current Thames Barrier system as designed will fall below the target protection level (1 in 1000); (iii) the engineering limit of the Thames barrier with modifications; and (iv) the limit to adaptation, at 5m it would become difficult to continue to protect London in its current form, potentially requiring some retreat.*

4 Identify feasible adaptation response options (at high level) to cope with these thresholds. *The options identified for TE2100 are shown in Figure 2. Identifying options might involve detailed local studies and or higher level assessments using expert judgement. It is important to assess the lifetime and engineering limits of adaptations and the potential for flexibility (i.e. making adjustments over time). No detailed appraisal of the benefits of options is carried out yet (not until step 7).*

5 Check key interactions with other issues, such as development pressures, at macro level. *For TE2100, some key potential trade-offs involved impacts on ecosystems and pressures from urban development plans.*

6 Assemble high level route maps of response options that will tackle the thresholds. *This could include no regrets measures such as emergency response which will work through the whole range of change.*

II. Appraise Solutions:

7 Compare costs, benefits and other relative criteria (e.g. environmental impact) of each route under the **most likely rate of change in extreme water level**. It would also explore how the costs and benefits vary under different rates of change to gauge the circumstances under which a switch to another route might be desirable. *The exact method of appraisal can vary. In TE2100 a multi criteria approach was taken to assess the cost and benefits of differing routes.*

8 Recommend the preferred route under the most likely rate of change, along with key variables which should be monitored to assess if a switch of route will be needed in the future. *The final recommended plan for TE2100 makes the best use of the existing system and the need to decide on HLO 1 or 3 by 2050.*

III. Implementation:

9 Implement and then monitor so you can bring things forward or put them back or change route *e.g. a significant deviation from the expected rate of sea level rise could significantly delay or accelerate the program, high rates of erosion to the defences in the outer estuary could accelerate the need for upgraded defences.*

An example of these steps taken in TE2100 is described in the next two sections. More detailed information can be accessed on the project website[9].

An advantage of this approach is that it need not take a lot of time or intensive study. For example, an adaptation planner could run through the steps 'back-of-the-envelope' (i.e. a high-level analysis) to get an idea of the nature of the adaptation needs, the types of options that are most relevant, and the information gaps. Then, the planner could repeat the exercise one or more times, with growing detail where necessary, to clarify options and narrow in on the most desired adaptation solution (i.e. a detailed analysis)[10].

Box 1: Developing climate scenarios to inform adaptation planning

TE2100 commissioned work to gain a better understanding of the effects of climate change on storm surge, sea level rise and river flow. This work proceeded as a 'second-track' to the adaptation processes and involved collaborators such as the Met Office Hadley Centre and the Proudman Oceanographic Laboratory.

Given that it was known that sea level rise projections available at the time (from, for example, the IPCC Fourth Assessment Report) were based on modelling that did not include all the necessary processes to provide accurate projections, the project employed the concept of using an extreme but unlikely 'High ++' scenario for sensitive testing the robustness of adaptation decisions to uncertainties.

Initially, the upper bound was set at 4.2m by 2100, based on expert judgement of the maximum plausible increase in water levels from known sources. This value was used in the initial decision appraisal but refined down later to 2.7m based on modelling of the effects of climate change on local sea level rise and storm surge generation alongside a deeper evaluation (incorporating some expert judgement) of the upper and lower bounds of potential sea level during the century (Lowe et al. 2009). The revised figures suggested a most likely level of 90 cm by 2100 and a High ++ scenario of 270cm by 2100 for changes for extreme water levels. These updated numbers refined the TE2100 plan, but the framework was robust enough that they did not change its recommendations for near-term decisions.

[9] http://www.environment-agency.gov.uk/homeandleisure/floods/104695.aspx

[10] Such a 'tiered' analysis was advocated by Willows and Connell, 2003

THE ROUTE-MAP APPROACH

The route-map approach (or *decision pathways* approach[11]) is a method of designing robustness to climate change uncertainties into the adaptation strategy itself. Rather than taking an irreversible decision now about the one or two 'best' adaptation options to cope with climate change (which can lead to maladaptation if the climate scenarios planned for do not emerge), it encourages a decision maker to postulate "what if" outcomes and take a more flexible approach, where decisions are made over time to continuously adapt while maintaining as much flexibility as is desirable about future options. This approach aims to ensure that whatever short- to medium-term plan is adopted, it is set in a framework that will not be maladaptive if climate change progresses at a rate that is different from what is predicted to be "the most probable" today.

TE2100: Developing the route-map

The idea of the route-map is to design 'packages' of adaptation measures that can be implemented over time. Figure 2 shows the route-map generated by TE2100. It identified four different possible packages of measures called 'high-level options' (HLO1, 2, 3a, 3b, and 4). Together, these packages were designed to span the estimated plausible range of increases in extreme water levels in the Thames by 2100 (i.e. up to 4.2m).

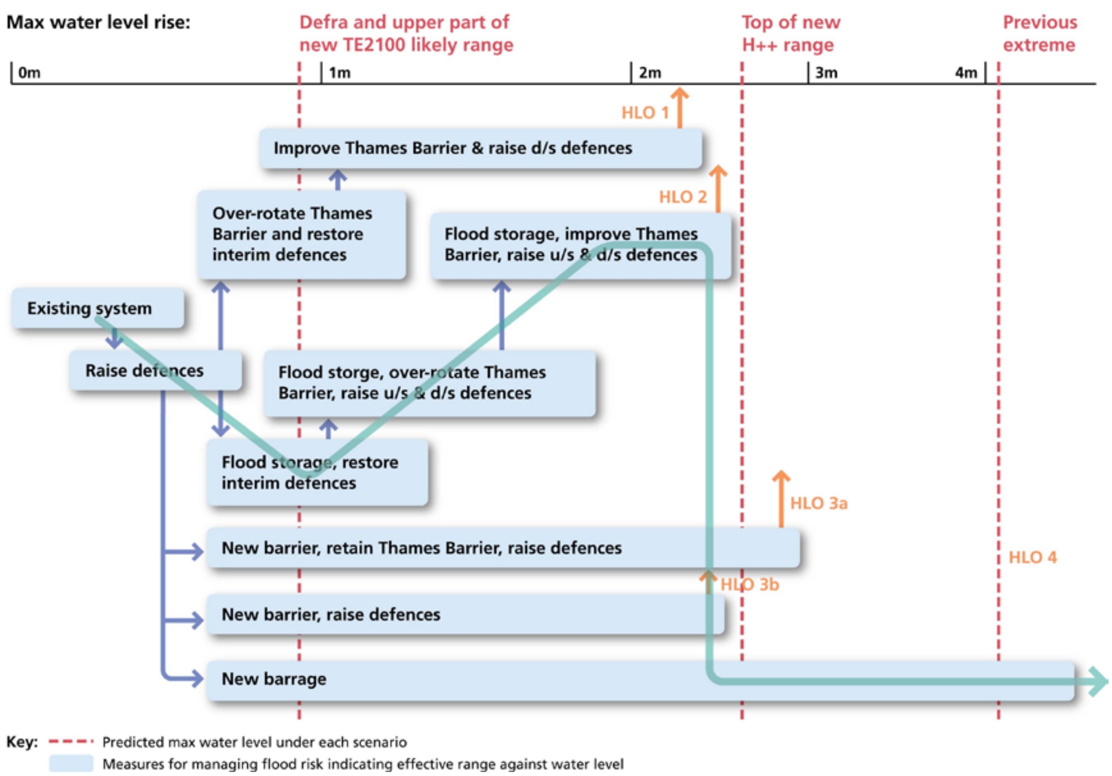

Figure 2. High-level adaptation options and pathways developed by TE2100 (on the y-axis) shown relative to threshold levels increase in extreme water level (on the x-axis). The blue line illustrates a possible 'route' where a decision maker would initially follow HLO 2 then switch to HLO4 if sea level was found to increase faster than predicted.

[11] The approach is based largely on the Risk, Uncertainty and Decision Making Technical Report produced by the Environment Agency for UKCIP (Willows and Connell 2003) and other tools and assessment criteria based on existing and developing guidance.

The decision maker tests the suitability of each package under a range of different scenarios to understand its robustness. For example, HLO1, which culminates in improving the current Thames Barrier, is appropriate for up to around 2.3m of sea level rise. This option would be sufficient given current "most probable" estimates of future sea level rise in the Thames. However, under a "worst-case" scenario of sea level rise, a new barrage would need to be constructed (HLO4). Each HLO consists of a pathway or route through the century that can be adapted to the rate of change that we experience.

Clearly, Figure 2 illustrates that it would be risky to select one pathway based on the projections available today. The choice of adaptation path today is highly sensitive to mean sea level and storm surge projections, which are notoriously uncertain (e.g. Lowe et al. 2009). However, it can be seen that not only are the high level options themselves flexible, but it is possible to move from one adaptation high level option to another depending on the actual rate of change that occurs in reality. For TE2100, the route-map shows that a decision between pathways need only be made in the future (when hopefully there will be better information), as the lifetime of the existing system can be extended by raising other defences around the Thames (i.e. a 'no-regrets' strategy). The High Level Options were produced in 2007 and were the subject of extensive online stakeholder engagement. This engagement was critical throughout the whole TE2100 project (2002 to 2009)

Using the route-map to identify decision points

How can the route-map be used to know when and how a decision should be made? An important advance of the route-map approach is that it is scenario neutral; decisions do not require information about the likelihood of different climate change scenarios. Instead, the strategy sets out a range of 'no-regrets' early actions, such as extending the lifetime of existing infrastructure, as well as a 40-yr investment plan detailing a decision process for upgrading the existing flood management system. Crucially, rather than taking 'inflexible' decisions now, the plan lays out a set of decision points that are conditional on observations of sea level rise.

For each adaptation option, the project assessed: the key threshold of climate change at which that option would be required (e.g. the extreme water level); the lead time needed to implement that option; and therefore, the estimated decision-point to trigger that implementation (in terms of an indicator value, such as the observed extreme water level, with an uncertainty range) (Figure 3).

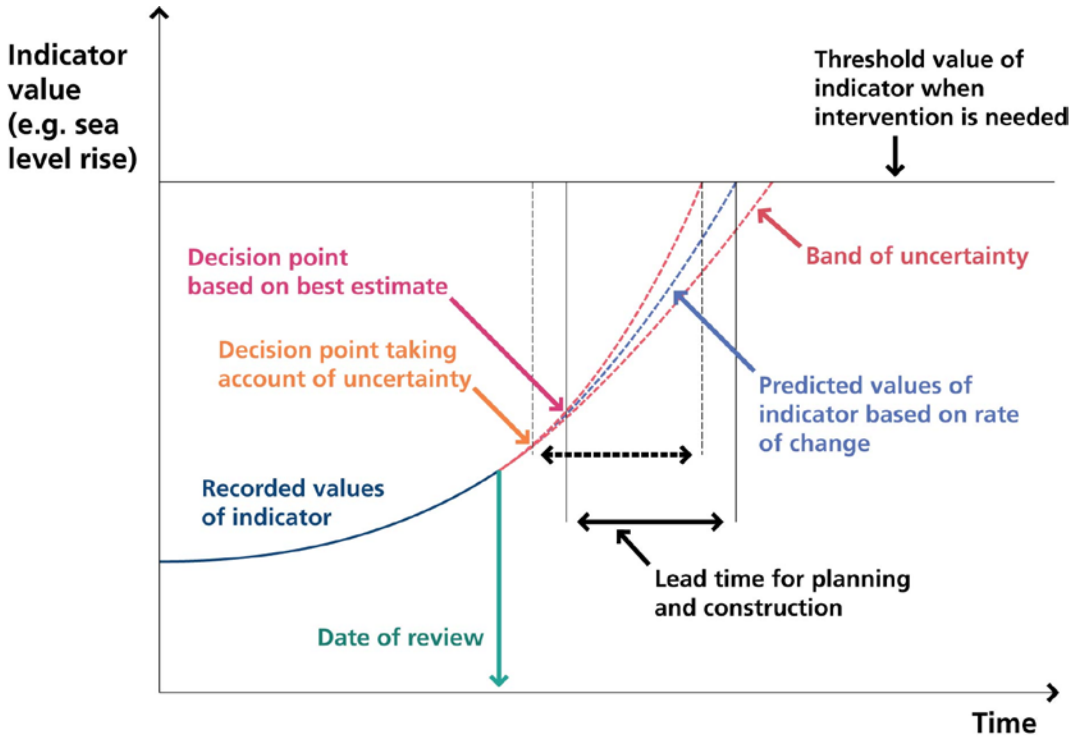

Figure 3. Schematic diagram of the thresholds, lead times and decision points approach from TE2100

On current projections, the initial decision point is expected to come around 2050; at which time decision-makers would choose between the more irreversible options (i.e. the different HLOs), such as upgrading the existing Thames Barrier or building a new Barrage. This decision would be made with the benefit of an additional forty years of knowledge about climate change and sea level rise.

If monitoring reveals that water levels (or another indicator, such as barrier closures) are increasing faster (or slower) than predicted under current projections, decision points may be brought forwards (or put back) to ensure that decisions are made at the right time to allow an effective and cost-beneficial response. This creates an uncertainty on the timing of the decision point that can be estimated based on the range of projections, as shown in Figure 3. The investment plan will contain detailed guidance on how its recommendations should be applied in the event of the more extreme change projections being realized, or a change in socio-economic development, and will show how lead times for major interventions need to take account of any such changes.

The effectiveness of the final plan will depend on a continuing process of regular review. The framework is designed to be robust to uncertainty, but critical to its successful implementation will be the ongoing monitoring and review of decisions through time in light of new observations of sea level rise and updates to projections. The Environment Agency is currently working with the Met Office and others to ensure that this monitoring is in place.

A benefit of the generic route map approach is that it can be relatively quick to complete. A route-map and assessment of decision-points can either come from intensive study, such as in the TE2100 case, or as part of a higher-level initial assessment using expert and stakeholder judgement and input. Its reduced dependence on detailed climate modelling also makes it less information and resource intensive. For this reason, such an approach may be quite favourable to application in developing countries.

Formal options appraisal in TE2100

One potential draw-back with an approach that aims to build flexibility into an adaptation strategy can sometimes lead to greater overall costs. For example, delaying a much-needed public infrastructure project, like a sea defense, could leave people temporarily exposed to storm surges, or (as in the TE2100 case) could mean making costly repairs to older infrastructure to extend its lifetime.

To assess this trade-off, the TE2100 project appraised the different HLOs using multiple decision criteria including the net present value of investments (from cost-benefit analysis) and environmental impact (Haigh and Fisher, 2010)[12]. In this case, the appraisal showed that taking no-regrets measures first would cost-effectively 'buy-time' before it is necessary to make a more irreversible decision (e.g. a new and expensive barrier), thus allowing time to monitor and learn to gain additional information in order to make an improved decision. The TE2100 options development and analysis process has in practice complied closely with a "Real Options" approach, which is recognised as a useful appraisal method in situations of systematic uncertainty (HM Treasury, 2003)[13]

PROGRESSION FROM TE2100

Following on from the approach developed in TE2100, the New York City Panel on Climate Change has recommended flexible pathways or route-maps as a core part of how New York City will approach climate change adaptation (Rosenzweig et al, 2010). The Adaptation Assessment guide book points out how key thresholds and responses should be assessed and once completed fed into capital and maintenance programmes for the City. In the Netherlands, Deltares and others carried an assessment of key thresholds for the Dutch water management system. They have identified key tipping points and developed a route map approach to tackle this (Haasnoot et al, *forthcoming*). Such an approach has also been applied to managing risks from sea level rise in the Netherlands (Kwadijk et al. 2010). This work is a fundamental part of the 2011 Delta Programme "Working on the Delta", which will see the Netherland taking a holistic approach to adaptation for the whole country. This will ensure that adaptation actions are set in a longer-term context. It is perhaps the leading example of an integrated approach at a national level, which is appropriate given the scale of the

[12] A challenge of this type of formal decision analyses is that it can be resource intensive. However, where the stakes are high, this type of careful, substantive and clear appraisal, with a full assessment of sensitivities and uncertainties, is often justified.

[13] HM Treasury (2003) definition: Real option theory [or analysis] presumes that decision making is sequential and that decision makers may benefit from choosing options that may seem sub optimal today but which increase flexibility at later times, leading to better decision making when more is known about the project. Real-options analysis is one approach to informing decision making under uncertainty. It is designed to help a decision maker to evaluate where an investment should be placed (or in this case, which high-level option) and importantly, when the investment should be made, given a set of criteria. It was a useful tool in this case as it allowed decision makers to assess whether a decision over the irreversible investment in a new barrier should be made now, or delayed until there is more information available about long-term sea level rise (Haigh and Fisher, 2010).

challenge for the Dutch nation. TE2100 has also worked with partners in the Netherlands, Germany and Belgium in the ESPACE Project to develop and refine transnational methods.

APPLICATION TO DEVELOPING COUNTRIES

The advantages of this methodology for making uncertainties created by a lack of information make it particularly relevant to planners in developing countries. The route-map approach is relevant where it is known that climate change is likely to affect the decision and uncertainties mean that it is difficult to select between adaptation options. This will usually be the case when dealing with long-term decisions, involving high sunk costs, but could also be relevant for shorter-term decisions that have far-reaching implications, such as sectoral planning, for example when considering how to best to invest on food supply chains or import facilities (which will need to factor in changing availability of home grown or imported supplies). Resource-light tools are available to help identify where climate factors and uncertainties are important in a decision.[14]

The route-map approach is complemented by making best use of no-regrets and win-win solutions such as emergency planning or climate-resilient development. These types of measures can be incorporated into the route-map to gain a holistic robust strategy.

Challenges to using this approach could be centred on a perceived need for detailed knowledge and information. Also the need for known thresholds could be a problem if there is insufficient understanding or they are unknown. For example, a challenge faced in TE2100 was to establish thresholds for damages to local ecosystems at risk. However, by going through the process, key thresholds can be postulated and challenged. For example in TE2100 critical success thresholds for flood storage were assumed and then subject to more detailed modelling, which eventually led to a decision not to adopt the flood storage route. If a potential threshold is found to be critical it can be monitored and researched further so that the route map can be adjusted through time. It is recognised that this will be difficult for some issues as ecosystems. However as long as the route map approach is aware of surprises, allowances for adjustment can be planned in. The susceptibility of decisions to ‘surprises’ can be tackled through building resilience and reducing risk using shorter term reactive and anticipatory adaptive measures, which can be included in the route map such as emergency planning, maintaining existing infrastructure well or better warning systems.

A key to the success of this approach is the building of long-term records of climate and relevant information so that change can be detected and any necessary alterations to plans put in place given sufficient time. We

[14] The ESPACE project developed a high level vulnerability assessment tool that could be relevant to planning at national, regional or local scales. This sets out that the large key thresholds given longer-term change must be factored into devising adaptation strategies that will be resilient to larger change in the longer term (http://www.espace-project.org/part1/publications/pdf20.pdf).

suggest that this be a key priority for investments in improved information.

CONCLUSIONS

This paper tries to point a way forward to tackling decision making given large uncertainty. Societies and decision makers have always had to confront making decisions given imperfect knowledge. Climate change adds an additional factor or dimension to this in that the scale of change is uncertain and could eventually put the context of decisions well beyond that which could be informed by historical experience.

The TE2100 project has developed and applied a framework for adaptation planning that aims to ensure adaptation strategies cost-effectively reduce risk while being flexible and adaptable to an uncertain future. The route-map approach developed has a number of benefits in this context: firstly, it is easy to apply and can be carried out quickly at a high level; secondly, it reduces the dependence of a decision on any one climate change scenario and so can lead to robust planning; and thirdly; it encourages an adaptive and resilient approach which is cost effective and avoids early maladaptation.

For TE2100, the outcome of this approach is an adaptation plan that focuses on sequencing a suite of measures in order to cost-effectively manage current risk while maintaining the flexibility to cope with the range of possible future sea level rise.

Acknowledgements

We wish to thank Kelly Levin, Nick Haigh and Jason Lowe for their helpful comments and suggestions. The authors also wish to thank for the World Resources Institute for their support in writing this paper. Dr Ranger's research was also supported through the Centre for Climate Change Economics and Policy by the UK Economic and Social Research Council (ESRC) and Munich Re. The views, opinions, findings and conclusions or recommendations expressed in this paper are strictly those of the authors and do not necessarily represent, and should not be reported as, those of the Environment Agency.

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