Identifying constraining and enabling factors to the uptake of medium- and long-term climate information in decision making

Working Paper No. 113

CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS)

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Abstract

We apply a systematic review of peer-reviewed literature to assess constraining and enabling factors to the uptake of medium- to long-term climate information in a wide range of sectoral investment and planning decisions. Common applications of climate information are shown to relate to adaptation of environmental policy and planning, urban planning and infrastructure, as well as flood and coastal management. Analysis of identified literature highlights five categories of enablers to the uptake of medium- to long-term climate information in decision-making, the most of frequent of which relates to greater collaboration and bridging between producers and users of climate information. Five categories of constraints are also identified, the largest comprising of scientific and technical limitations associated with available medium- to long-term climate information. We highlight that not every decision requires long-term climate information to be taken into account for successful outcomes to be achieved. This is particularly the case in the context of developing countries, where the immediacy of development challenges means that decision-makers often prioritize short-term interventions. Care should therefore be taken to ensure that information is targeted towards investments and planning decisions that are relevant to longer-term timescales.

Keywords

Climate services; Climate change adaptation; Climate Science; Decision Making; Climate information uptake

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Contents

Introduction

Climate change poses considerable challenges to the management of socio-political, economic and ecological systems (Lemos et al., 2012). Decision makers are increasingly pressured by international, national and local stakeholders to ensure that long-term climate risks are factored into investment and planning decisions (Dilling and Lemos, 2011). The push for inclusion of medium- to long-term climate information in decision making is largely founded on the notion that understanding changing risk profiles and their potential impact on investments can help to guide and support anticipatory action and adaptation (Barnett and O'Neill, 2010).

Given the length of timescales involved, medium- to long-term climate information is typically associated with investments and planning decisions that have long time horizons such as large infrastructure and national development plans. Failure to consider the implications of climate change and ensure adaptive management within these types of investments can increase the risk of maladaptation and lock-in of irreversible or costly future development trajectories (Ranger and Garbett-Shiels, 2012). Though considerable progress has been made in incorporating weather, seasonal and short-term climate information into decision making (Pozzi et al., 2013; Tall et al., 2012; Thomson et al., 2006), the uptake and use of medium to longer-term climate information lags behind the pace of recent scientific developments (Kirchhoff et al., 2013b; Wilby et al., 2009). In this paper, we seek to better understand the reasons for this shortfall.

Through a systematic review of available peer-reviewed literature, we assess constraining and enabling factors for the uptake of medium- to long-term climate information in decision making. To date, a number of reviews have assessed constraints to the use of weather and short-term climate information in decision making (Dilling and Lemos, 2011; Hansen et al., 2011; Marshall et al., 2011; Mase and Prokopy, 2013; Vogel and O'Brien, 2006; Ziervogel and Calder, 2003). Our review takes a novel approach, focusing solely on medium- to long-term climate information, associated with inter-annual to multi-decadal timescales.
In critically assessing and synthesizing lessons learned from across a wide range of peer-reviewed literature, this systematic literature review answers two targeted research questions: 1: How is medium- to long-term climate information being used in decision making; and 2: What are the main constraints and enablers to the uptake of medium- to long-term climate information in decision making?

Data and Methods

Following approaches used by several related studies (Berrang-Ford et al., 2011; Delaney et al., 2014; Ford and Pearce, 2010), we adopted a systematic literature review methodology to identify and analyse literature pertaining to the uptake of medium- to long-term climate information in decision making. Here we define medium- to long-term climate information as ranging from inter-annual and decadal to centennial timescales (most commonly associated with initialised decadal forecasts and multi-decadal climate projections).

In the context of this paper, climate information refers to a broad range of data, including: historical observations (used to establish baseline of past and current climate); future projections over multiple timescales (typically achieved through climate and earth system models); and climate impact, vulnerability and adaptation analysis (requiring information and analysis from various sectoral disciplines spanning economic, environmental, social and political sciences) (Jones et al., 2015). We adapt Moser and Ekstrom's (2010) definition of "barriers" to describe obstacles to improved uptake of climate information in decision making that can be overcome with concerted effort. Within this study, "barriers" are used interchangeably with "constraints". We recognise "limits" as obstacles that tend to be absolute in a real sense (Moser and Ekstrom, 2010). Finally, we refer to "enablers" as factors that have been found to be associated with improved uptake of climate information in decision making.

The Scopus database was selected for the review, as the largest abstract and citation database of peer-reviewed literature. Literature was screened to ensure that papers examining the use of weather and short-term climate information (defined here as those associated with sub-annual timescales, such as seasonal climate and weather forecasting) were excluded. Our search strategy deliberately targeted empirical case studies and conceptual articles that documented and/or explicitly discussed the uptake of climate information in investment decisions, planning processes and institutional responses (see Appendix 1 for further details).

The systematic review targeted English-language peer-reviewed literature from natural and social science published between January 2006 and October 2014. The choice of 2006 relates to the cut-off date for inclusion within the IPCC's Fourth Assessment Report. We excluded grey literature due to three factors: the inability to set matching search criteria between Scopus and Google Scholar; documented weaknesses of using Google Scholar's algorithms and database coverage in conducting systematic reviews (Giustini and Boulos, 2013); and the relative abundance of available peer-reviewed literature on the topic area. We also excluded studies on short-term climate information operating on monthly and seasonal time scales (up to 90 days) (Lemos et al., 2012; Siregar and Crane, 2011; Vogel and O'Brien, 2006; Ziervogel and Calder, 2003). The predominant entry point for the use of medium- to long-term climate information is national and regional decision making bodies or organisations; consequently we excluded household-level decision making in this review (the latter typically associated with weather and seasonal forecasting).

Table 1: *Broad inclusion and exclusion criteria for the literature search*

Included	Excluded
Sources published between January 2006 and October 2014	Sources published before 2006
Peer-reviewed literature (Scopus database)	Grey literature
Literature in English	Literature in languages other than English
Medium- (90 days, up to 10 years in length) to long-term (10 years +) climate information	Weather forecasts (days – weeks) and seasonal climate forecasts (up to 90 days in length)
Use in investment decisions, planning processes and institutional responses	Use in individual or household decision-making

Our search string consisted of the following terms:
"climat* change" OR "climat* variability" OR "global warming"
AND
"climate information" OR scenario* OR projection* OR "climate science"
AND
"decision mak*" OR plan* OR communicat* OR polic* OR uptake OR adapt*
AND
Obstacle* OR limit* OR constrain* OR hinder* OR prevent* OR fail* OR barrier* OR opportunit* OR success* OR enabl* OR progress* OR benefit* OR accomplish* OR achiev*

The initial search yielded a total of 2530 publications (**Figure 2**). Articles subsequently underwent a two-stage screening process by two independent review teams, consisting of: 1) title and abstract screening, with 110 articles progressing; and 2) full text screening, with 44 articles going forward to full data extraction. Kappa scores between the two review teams for the full-text screening were 0.916. A full list of literature identified under Stage 1 and 2 can be found in Appendices 4 and 5.

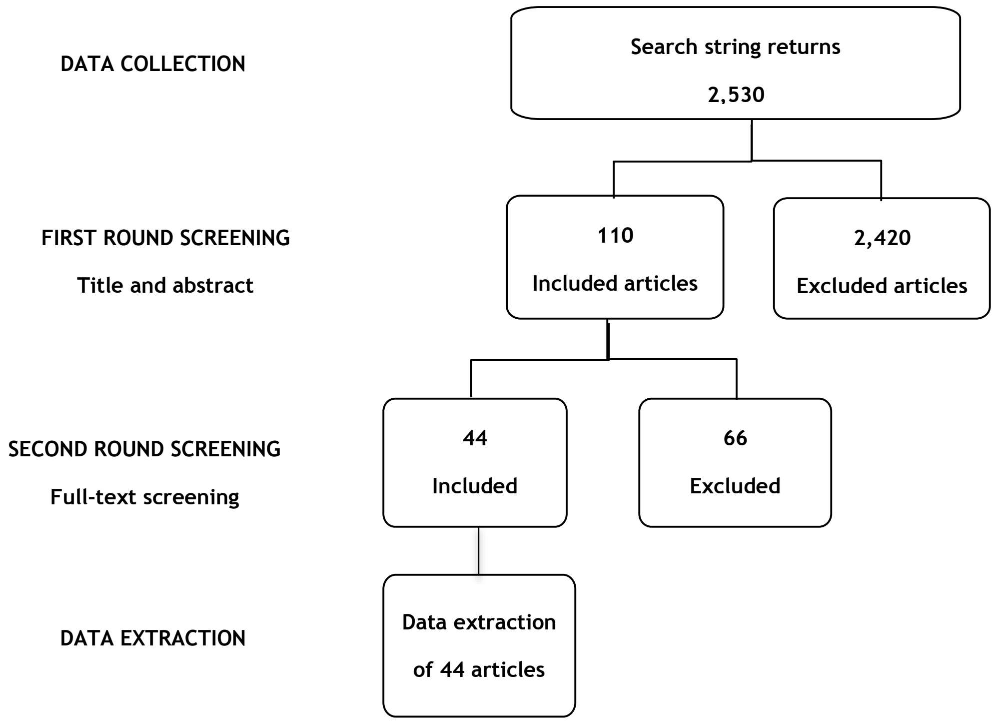


Figure 1: *Key steps in the review methodology*

Results

We present results of the data analysis of shortlisted articles, separated into the two research questions.

How is medium- to long-term climate information currently being used in decision-making and investment planning?

Analysis of the short-listed articles reveals that the most frequently documented sectoral application of medium- to long-term climate information relates to environmental policy and planning. Within this grouping, climate information is primarily used to guide adaptation planning at various scales of governance. Other areas of sectoral assessment relate to urban planning and infrastructure, flooding and coastal management, and agriculture (see **Figure 2**). One of the most frequent uses of long-term climate information is to support scenario planning, allowing consideration of future risks as well as implications of different development pathways.

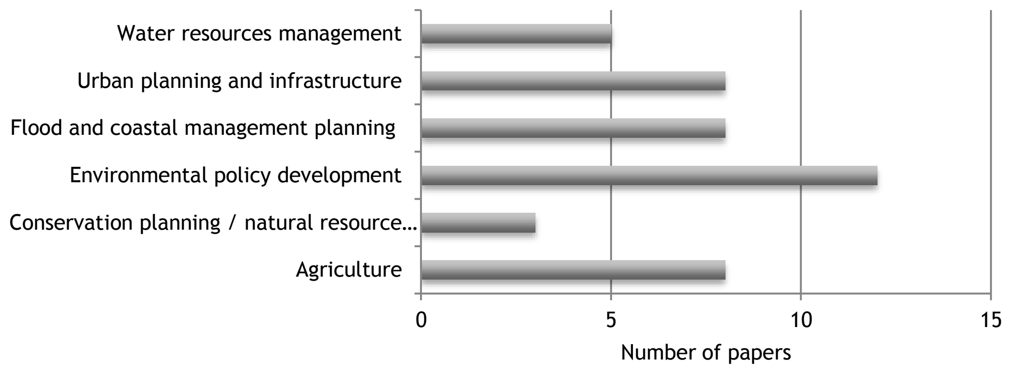


Figure 2: *Primary sectoral focus of short-listed literature*

Climate information is also considered a useful tool for identifying hotspots or areas with high potential for future vulnerability to climate risk. This often translates into guidance for adaptation planning at multiple scales, as well as support for 'climate proofing' of existing development plans and investments (Hegger et al., 2014). Use of medium- to long-term climate information is particularly associated with long-lived large-scale infrastructure investments (Agrawala et al., 2012; Camp et al., 2013). Here, information about the range of future risk is used to guide the design and implementation of critical infrastructure – the primary aims being to: prevent climate change from resulting in negative economic returns in capital investment; to reduce the likelihood of infrastructural damage and redundancy; and to limit the risk of maladaptation (Ranger and Garbett-Shiels, 2012). For example, Agrawala et al. (2012) describe how projections of future precipitation were used to adjust the design of a series of dams and dykes built to provide water for covering containment cells of radioactive waste at two decommissioned uranium mines in Canada. In another example, climate information was used by planners in the Pacific island nation of Kiribati to help make investment decisions for measures to guard against sea level rise, such as constructions of sea walls and planting of mangroves. Government officials have also used projected sea level rise to formulate another contingency plan: an initiative dubbed "Migration with Dignity" which is aimed at identifying other countries in which Kiribati citizens can fulfill labor needs and then formulate seasonal overseas work programs to help begin the transition (Donner and Webber 2014).

The geographic focus of most papers spans multiple regions, shortly followed by those concentrating primarily on North America and Europe (see Figure 3). Oceania and Africa receive notably fewer mentions, with Asia only addressed by a single short-listed paper. In relation to the scale of focus for papers, multi-scalar analyses are by far the largest grouping (Figure 4). This is perhaps unsurprising, given the cross-scalar nature of long-lived large-scale investment and planning. National, regional and local scales each receive high levels of attention, with a single paper focused primarily at the municipal level. No papers focus on the supra-national scale (see Appendix 3 for definitions and further details).

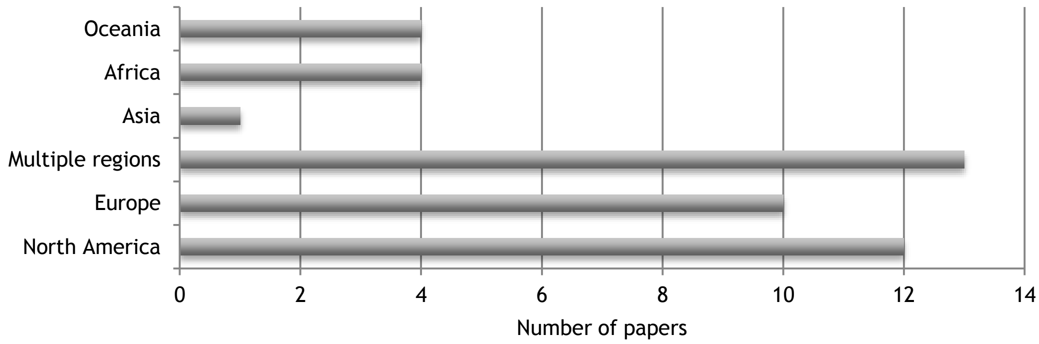


Figure 3: *Primary geographic focus of short-listed literature*

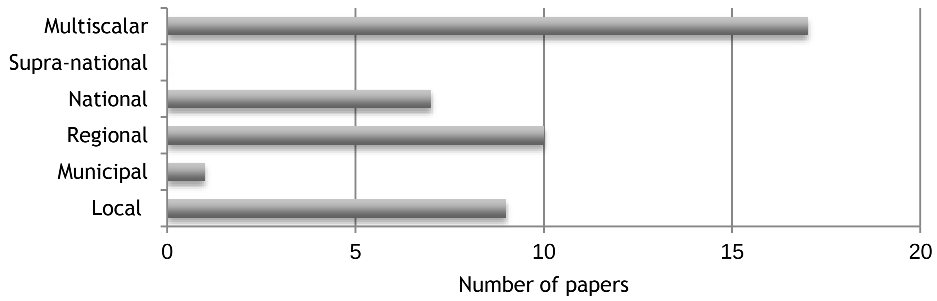


Figure 4: *Primary scale of focus of short-listed literature*

Of the 44 articles that progressed through to full data extraction, 35 were qualitative empirical studies, drawing on a variety of methods from across the social sciences (**Figure 5**). Only one quantitative assessment went past the final round of text-screening. The prevalence of qualitative research likely reflects the relative complexity of capturing the various social, political and economic drivers that shape how decision making processes draw on information, as well as the disciplines that engage in these topics. Additionally, seven conceptual studies and one commentary were included.

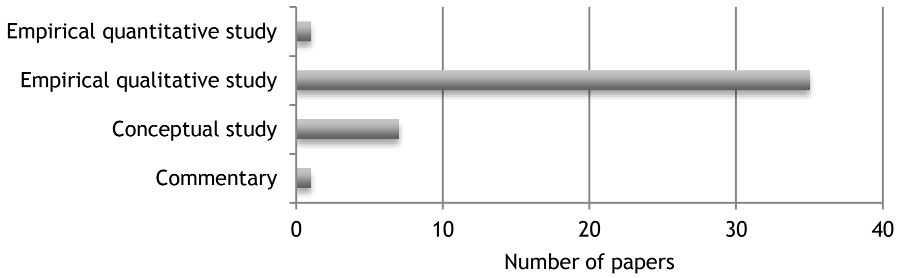


Figure 5: *Type of evidence generated in short-listed literature*

What are the main constraints and enablers to the uptake of medium- to long-term climate information in decision making and investment planning?

All 44 papers cite at least one constraining or enabling factor to the use of climate information in decision making, with many listing several. To synthesise the range of different factors we further cluster constraints and enablers into distinct categories.

Constraints to the uptake of medium- to long-term climate information

Ten individual constraints to the uptake of climate information in decision making processes are identified in the literature (see Table 2). These are then grouped into five overarching categories, namely: a disconnect between producers and users of climate information; limitations of climate science and information; financial and technical constraints; political economy and institutional constraints; and psycho-socio constraints. The frequency of papers giving mention to each constraint and the categories assigned to them are detailed in **Figure 6**.

Figure 6: *Number of papers per category of constraints*

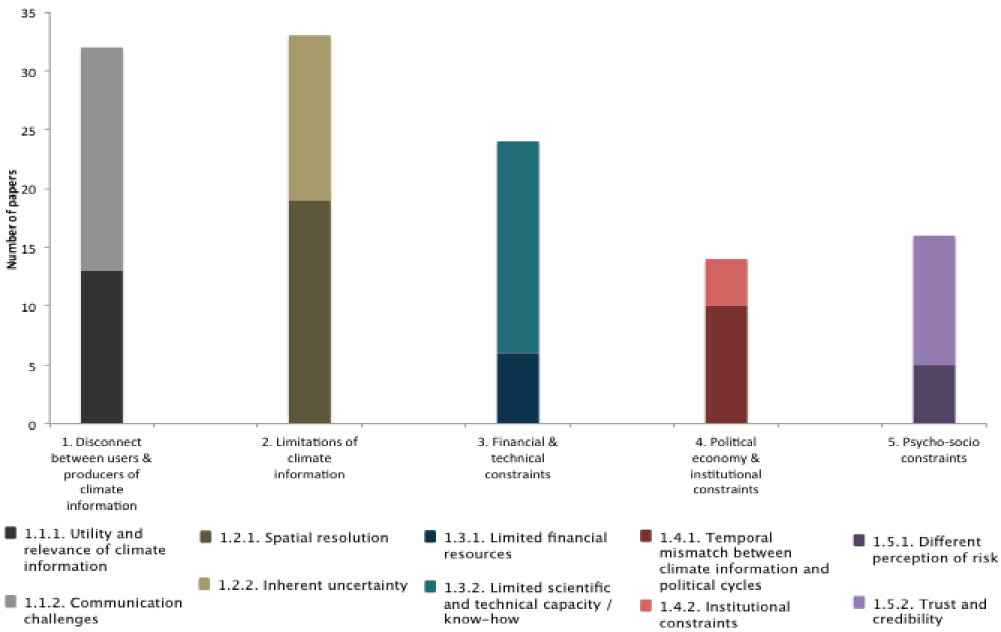


Table 2: *Identified constraints in the literature*

Category	Constraints	Summarised details
1.1. Disconnect between users and producers of climate information	1.1.1. Utility and relevance of climate information	- Inability of available medium- to long-term climate information to address the perceived informational needs of decision makers
	1.1.2. Communication challenges	- Low accessibility of climate information. Formats and knowledge platforms are not always user-friendly - Lack of collaboration and interaction between producers and users of climate information - Few effective boundary organizations
1.2. Limitations of climate information	1.2.1. Spatial resolution	- Poor spatial resolution hinders the ability of climate information to inform local decisions
	1.2.2. Inherent uncertainty	- Inherent uncertainty of climate models and the intrinsic complexity of the climate system
1.3. Financial & technical constraints	1.3.1. Limited financial resources	- Lack of financial resources at national and local levels to access relevant climate information and tools to implement adaptation activates
	1.3.2. Limited scientific and technical capacity / know-how	- Limited scientific capacity to interpret and analyse climate information - Limited technical capacity to communicate climate information to decision makers in a manner that does not sacrifice the integrity of the underlying science - Limited capacity of decision makers to understand and utilise available climate information in decision making processes, particularly relating to associated uncertainties
1.4. Political economy & institutional constraints	1.4.1. Temporal mismatch between climate information and political cycles	- Political cycles (typically 4-5 years in duration) are poorly matched with the timescales associated with medium-to long-term climate information (typically multi-decadal in duration)
	1.4.2 Institutional constraints	- Reluctance of institutions to act on available knowledge – many relying on past information to guide decision making - Higher priority allocated to addressing other development challenges and/or competing agendas - Limited flexibility in decision making over institutional structure, direction and budgeting
1.5. Psycho-socio constraints	1.5.1. Different perceptions of risk	- Differing levels of risk perception amongst producers and users of climate information
	1.5.2. Trust and credibility	- Perceived lack of accuracy, reliability, and credibility in climate information amongst many potential users and decision makers

Disconnect between producers and users of climate information

The first category of constraining factors pertains to a disconnect between producers and users of climate information. It is largely characterized by: the inability of medium to long-term climate information to match the perceived informational needs of decision makers; communication challenges; and a lack of effective boundary organizations able to broker, translate and facilitate engagements between relevant stakeholders (see **Table**). Below we briefly summarise some of the key issues associated with each individual constraint.

Utility and relevance of climate information

One of the primary constraints identified by the review is a mismatch between perceived informational needs of decision makers and the inability of climate information to address them. Medium- to long-term climate information is largely considered to be inaccessible (in terms of both language and availability) to many decision makers, and of little practical use in the context of most investments and planning decisions (Bryson et al., 2010; Romsdahl, 2011).

If decision makers fail to see the relevance and practical utility of available climate information, willingness to apply it in decision making is likely to be reduced (Bryson et al., 2010). Indeed, many decision makers place greater emphasis on personal experience and judgment than on climate information in formulating actions and decisions, further emphasizing the disconnect (Rosentrater, 2010). In the context of developing countries, this lack of relevance stems, in part, from the fact that those most vulnerable to impacts of climate change are rarely involved in the production of climate information itself, thereby detracting ownership and limiting buy-in amongst key decision makers (Bremond, 2014). Ziervogel and Zermoglio (2009: 136) describe how the funding and delivery of climate information centres primarily on addressing fundamental knowledge gaps and “gaining greater understanding of atmospheric dynamics”, rather than approaching the challenge from the bottom up: addressing specific needs identified by decision makers.

Communication challenges

Poor communication between producers and users of medium- to long-term climate information hinders uptake at all stages of the decision making process (Lu, 2011; O’Toole and Coffey, 2013; Ryghaug, 2011; Srinivasan et al., 2011; van Drunen et al., 2011; Ziervogel and Zermoglio, 2009). We identify three distinct communication challenges from within the shortlisted literature: low accessibility to climate information; difficulties in translating climate information into actionable guidance for decision makers; and a lack of collaboration and interaction between scientists and policy makers (Camp et al., 2013; Lu, 2011).

Firstly, existing dissemination channels for medium- to long-term climate information often do not reach decision makers and communities equally. This is particularly evident in the context of developing countries, where many rural or disadvantaged areas do not have access to adequate technology or technical resources to make use of available climate information, such as in the case of rural communities in Namibia without access to newspapers, television or Internet (David et al., 2013).

The second communication challenge pertains to difficulties in translating science into practical options and guidance. Producers of climate information often lack sufficient expertise in effectively communicating their results in formats that are easily accessible and comprehensible to decision makers – many of whom may not be accustomed to interpreting scientific outputs (Meinke et al., 2006; Romsdahl, 2011). The "naive assumption that knowledge can be transferred as an unambiguous signal" directly points to a lack of translation of science into practical measures, but also to the complexity and political economy of decision making processes (Meinke et al., 2006: 102; Viviroli et al., 2011). The existence of a vast multitude of different knowledge portals and data repositories associated with the dissemination and communication of medium- to long-term climate information further underscores the difficulties decision makers have in knowing where to turn for reliable information and the lack of user-friendly applications (Agrawala et al., 2012; Barron et al., 2012).

Finally, a lack of interaction and collaboration between scientists and policy makers acts as a considerable constraint to effective communication of medium- to long-term climate information (Dilling and Lemos, 2011). A large reason for this challenge relates to the absence of effective boundary agents and organizations, limiting two-way communication and making it difficult for producers and users of climate information to engage with one another (Clarke et al. 2013; Ryghaug, 2011; Srinivasan et al., 2011a; Ziervogel and Zermoglio, 2009a).

Limitations of climate information

The second category of constraints concerns limitations in the production and utility of medium- to long-term climate information.

Spatial resolution

The mainstay of climate modelling is coarse-resolution coupled Ocean-Atmosphere General Circulation Models (OA/GCMs). These models break the Earth down into individual grid-cells with horizontal resolutions of roughly 150-300 km^2. Physical processes at smaller scales are parameterised. High computational demands and uncertainties in our understanding of the climate system limit our ability to simulate climate processes at higher resolutions. While GCM outputs are of notable use in understanding the general characteristics of the overall climate, they are far removed from the scale and accuracy needed to inform local decision making and trade-offs on the ground (Lemos and Rood, 2010).

As a result high-resolution downscaling techniques are in high demand due to their perceived utility in informing locally-relevant decision making. However, large uncertainties persist (David et al., 2013; Yousefpour et al., 2013; Ziervogel and Zermoglio, 2009). Given that dynamical downscaling feeds directly from global model outputs, regional climate models have many of the same biases with no greater accuracy (Agrawala et al., 2012; Miles et al., 2006; Runhaar et al., 2012). In other words, the ability to downscale to finer temporal or spatial dimensions does not necessarily imply that confidence is any higher in the outputs that are derived (Camp et al., 2013; David et al., 2013). In addition, the high resource and computational costs associated with downscaling make it difficult for decision makers in developing countries to carry out, and have access to, high resolution climate information (Lawrence et al., 2013). This is particularly the case in Africa, where few regional modelling centres have the capacity to generate downscaled outputs, particularly outside of South Africa (Ziervogel and Zermoglio 2009).

Inherent uncertainty of climate information and inherent complexity of the climate system

The majority of articles identify the complexities associated with generating medium- to long-term climate information, and the uncertainties that go with it, as a key impediment to its uptake into decision making (Kirchhoff et al., 2013b; Lemos and Rood, 2010; Lu, 2011; O'Toole and Coffey, 2013; Rosentrater, 2010). After examining several cases and lessons learnt from the UK Climate Impacts Programme (UKCIP) scenario exercises in the UK, Gawith et al. (2009: 116) find that uncertainties linked to modelling outputs and scenarios were "a major barrier to the application of climate change information for decision making". Much of this relates to the inability of climate information to inform many local investment trade-offs as decisions makers often call for high levels of certainty in weighing the implications of future options. This desire also encourages misrepresentation and misunderstanding of climate outputs, masking true levels of uncertainty associated with future projections. Large uncertainties can even lead to investors and planners omitting climate information from decision making processes altogether (Kirchhoff et al., 2013b).

Financial and technical constraints

The third category of constraints relates to financial and technical constraints.

Limited financial resources

As referred to in the preceding section, dynamical downscaling of climate data at regional and local scales is computationally expensive (Lawrence et al., 2013). Ensuring that relevant information is able to feed into and guide adaptation planning is therefore limited by the availability of financial resources. Inevitably, this means that many low-income regions, such as sub-Saharan Africa and South Asia, have access to fewer high resolution outputs able to guide decision makers at a finer spatial resolutions (Agrawala and van Aalst, 2008; Srinivasan et al., 2011). Similar challenges exist in securing resources to maintain observational networks, as well as the financial and technical resources needed to support Integrated Assessment Modelling (IAM).

Limited scientific and technical capacity

The complexity of medium- to long-term climate information requires high levels of scientific capacity to interpret and analyse associated outputs. It also requires technical capacity to communicate relevant information to decision makers in a manner that is both easily interpretable to decision makers and does not sacrifice the integrity of the underlying science (Ziervogel and Zermoglio, 2009). Alongside this, decision makers need to be supported in understanding the merits and limitations of utilising available climate information in decision making processes. Failure to acknowledge and address these challenges may lead to the misinterpretation of climate information or under/overestimation of uncertainty and future risks (Bolson et al., 2013; Romsdahl, 2011; Rosentrater, 2010; Srinivasan et al., 2011).

Political economy and institutional constraints

The fourth category of constraining factors relates to political, socio-economic and institutional factors.

Temporal mismatch between climate information and political cycles

One of the largest impediments to the use of medium- to long-term climate information is the fact that time horizons associated with multi-decadal climate projections are often ill-matched with the needs of decision makers, who are usually "more concerned with the next 10 years than they are with the next 100 years" (Agrawala et al., 2012; Agrawala and van Aalst, 2008; Bryson et al. 2010; Clarke et al., 2013; Gawith et al., 2009: 120; Rosentrater, 2010). This is particularly prevalent in the context of developing countries, where tackling pressing social and economic development issues often forces policy makers' attention towards short-term timescales (Agrawala and van Aalst, 2008; Ziervogel and Zermoglio, 2009). As a result, the implications of long-term costs (or benefits) are often disregarded or left for consideration at a later stage in the policy cycle (Bryson et al., 2010; Clarke et al., 2013).

Institutional constraints

Organizational cultures and institutional settings are important factors that influence the way decisions are made and carried out. Issues such as: competing institutional mandates; overlapping jurisdictions and budgets; overly complex levels of bureaucracy; and limited flexibility are each elements that may hamper the use of climate information in decision making (Dilling and Lemos, 2011, Miles et al., 2006). Some institutions are reluctant to use new sources of knowledge and prefer to rely on proven sources to guide their decisions (Lemos and Rood, 2010); others accept that climate risks are likely to change, but downplay the need to address them, placing higher priority on addressing other financial and socio-economic concerns (Dilling and Lemos, 2011).

Psycho-socio constraints

The fifth and final category of constraint pertains to psycho-socio constraints for which we identify two constraints to the uptake of climate information in policy making, namely: a gap in the perception of risk between scientists and decision makers; and a perceived lack of trust in and credibility of climate information.

Different perceptions of risk

Risk perception is a key driver of institutional and political change (Rosentrater, 2010). Recognising wider social and political pressures, decision makers have to weigh up the likelihood of future risks affecting investment and planning decisions based on best available knowledge. Low levels of perceived risk can therefore contribute to inaction or the prioritization of addressing other risks ahead of climate adaptation. Such differences, alongside wider values, can serve to prevent climate information from being acted upon when considered alongside other competing economic and social concerns (Runhaar et al., 2012). Indeed, in their assessment of adaptation policy in the Netherlands, Runhaar et al (2012) describe how disparities between risk perception and the need for urgency in tackling the risks associated with future flooding and heat stress between decision makers and scientists act to prevent decisive action.

Trust and credibility

Finally, a perceived lack of credibility with regards to medium- to long-term climate information can prevent decision makers from using and acting upon available knowledge (Kirchhoff et al., 2013b; Meinke et al. 2006). This is particularly relevant in the context of widespread scepticism of the validity of climate information amongst many decision makers, notably the ability of climate models to replicate and predict the complexities of the climate system. For example, a perceived lack of accuracy, reliability and credibility were each found to drive low levels of trust in climate science amongst water resources managers in Brazil and U.S.A. (Kirchhoff et al., 2013b). A failure to recognize and address cognitive constraints only serves to widen the knowledge gap and can trigger greater levels resistance between producers and users of climate information (Lemos and Rood, 2010; Romsdahl, 2011).

Enablers to the uptake of medium- to long-term climate information

In analysing data extracted from the short-listed papers, we also identify enabling factors for enhancing the use of medium- to long-term climate information. Inevitably, many of the enablers relate directly to individual constraints listed in Section B1. However, in seeking to maintain objectivity within thematic clustering we categorise enabling factors independently of the constraints identified earlier.
A total of 33 out of the 44 short-listed papers present at least one enabler, many papers present multiple. Enabling factors are classified into five overarching categories consisting of: collaboration and bridging work; enhancing technical capacity; improvements to our understanding of underlying science; institutional reform; and windows of opportunity and trust. By far the largest category is that of collaboration and bridging work. The second largest category is accessibility and support for technical capacity. The remaining three categories receive notably fewer mentions, despite their relevance (see **Figure 7**). **Table 3** presents a summary of the categories and the enabling factors which fall under each. Below we briefly summarise some of the key issues associated with each individual enabler.

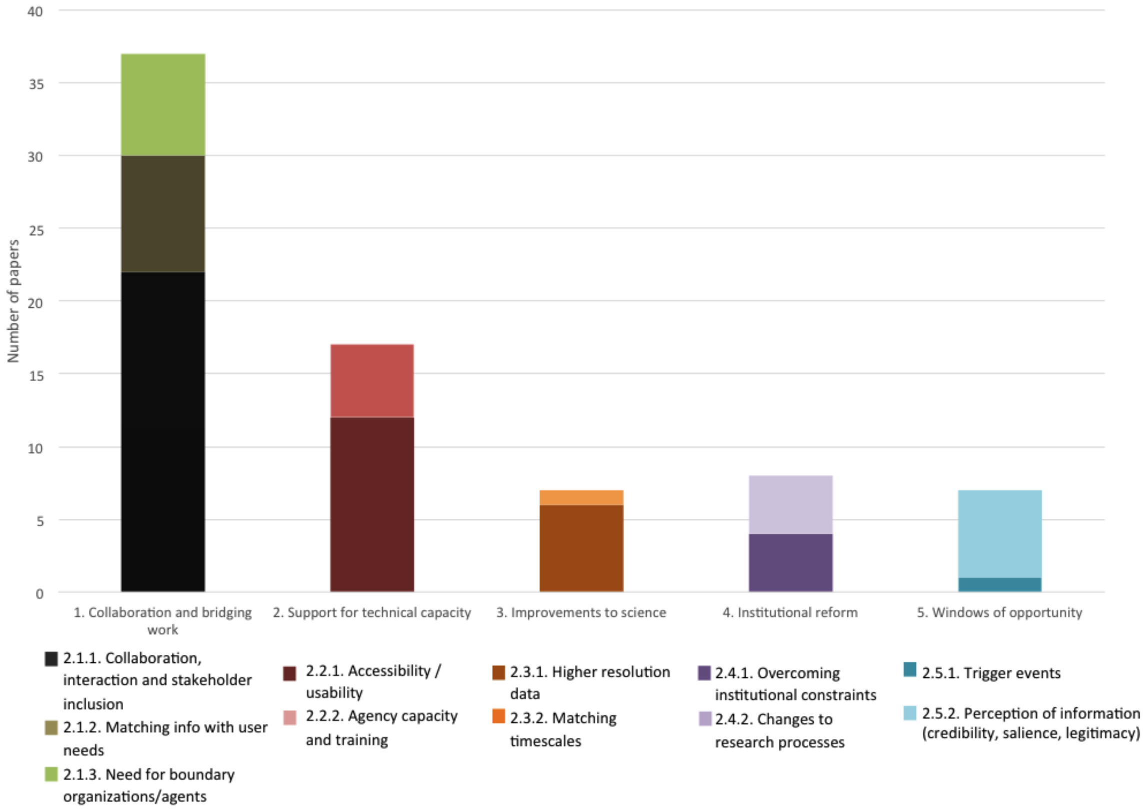


Figure 7: *Number of papers per category of enablers*

Table 3: *Identified enablers in the literature*

Category	Enablers	Summarised details
2.1. Collaboration and bridging work	2.1.1 Collaboration, interaction and stakeholder inclusion	- Involvement of decision makers in co-creating climate information - Positive interaction between producers and users of medium- to long-term climate information - Long-term commitment from funders and researchers, leading to trust-building with decision makers - Effective and recurring engagement between users and producers
	2.1.2 Matching info with user needs	- Information tailored to user needs, and users assisted to formulate their information requests
	2.1.3 Need for boundary organisations/agents	- Effective boundary organizations or agents can bridge gaps and help translate information
2.2. Support for technical capacity	2.2.1 Accessibility/ usability	- Decision makers can more readily use climate information that is accessible (e.g., in the appropriate language, via an appropriate communication channel, in a comprehensible format to the intended audience)
	2.2.2 Agency capacity and training	- Available in-house expertise and capacity to make use of climate information
2.3. Improvements to understanding of underlying science	2.3.1 Higher resolution data	- Provision and use of higher resolution data tailored to the specific informational needs of decision makers
	2.3.2 Matching timescales	- Matching timescales of climate scenarios with timescales of decision making
2.4. Institutional reform	2.4.1 Overcoming institutional constraints	- Promoting flexible decision making within institutions - Organizations with greater human or technical capacity to use climate information
	2.4.2 Changes to research processes	- Increased multi-disciplinarity in research, including greater involvement of social science. Ensuring the research funding and delivery flexibly responds to stakeholder needs - Extending peer review process to incorporate feedback from a wider range of stakeholders
2.5. Windows of opportunity and trust	2.5.1 Trigger event	- Occurrence of a climate event heightens use of climate information; decision makers are more receptive to including climate information following such an event
	2.5.2 Perception of info (credibility, salience, legitimacy)	- Users of climate information that perceiving it to be credible, salient and useful have higher rates of uptake than decision makers who do not perceive the information to be useful

Collaboration and Bridging Work

A majority of the papers highlight significant benefits in bringing different stakeholders together to promote the uptake of medium- to long-term climate information in decision making. Increasing levels of collaboration and two-way communication between producers and users of climate information can help to build trust, encourage better understanding and respect of stakeholders' expertise, and promote co-production of knowledge. This category is made up of three individual enablers, consisting of: a) Collaboration, interaction and stakeholder inclusion; b) Matching information with user needs; c) Active and effective boundary organizations and agents.

Collaboration, interaction and stakeholder inclusion
The successful uptake of medium- to long-term climate information is often predicated on sustained interaction and engagement between those producing information (typically climate scientists and researchers from related fields) and those that use it to inform decision making (whether government, NGO or private sector). Many articles cite successful uptake of climate information and scenarios as heavily dependent on decision makers being explicitly involved and contributing to the formulation of medium- to long-term climate information (Berkhout et al., 2014; Corburn, 2009; Dilling and Lemos, 2011; Kirchhoff et al., 2013b; Miles et al., 2006). In particular, the merits of using participatory processes of engagement to bring stakeholders together are shown to encourage sharing of different perspectives and support greater collaboration in promoting utility and effective use of climate information (Barron et al., 2012; Berkhout et al., 2014; Bryson et al., 2010; Gawith et al., 2009; Picketts et al., 2013; Rosentrater, 2010; van Drunen et al., 2011; Ziervogel and Zermoglio, 2009): "*In order to raise awareness and develop climate adaptation planning, there is a growing recognition of the need for sustained relationships between producers of decision support resources and the decision-makers who might use them*". Romsdahl (2011: 524).

Successful use of seasonal climate forecasts has been achieved through iterative interaction between producers of information and users (Dilling and Lemos 2011; Bolson et al. 2013). Such engagement helps the producers' of information understand the decision making context of users thereby increasing the ability to customize the information to meet user needs. Such interaction is also a driver for use of long-term climate information. Corburn (2009) documented a case in New York City of the co-production of climate change scenarios and models in which city planners and climate scientists worked together to refine the models that were used to predict urban heat island effects. Local planners were hesitant to adopt the models as first presented, but once they were given the opportunity to contribute and make adjustments, the project moved forward and the planners (the climate information users) had more buy-in to the process and more trust of the scientists and their supporting science.

Trust was also found to be a critical factor in the use of climate information for adaptation planning and decision making (Barron et al., 2012; Burch et al., 2010). The community-level adaptation planning process in the low-lying municipality of Delta, British Columbia, Canada at the mouth of the Fraser River (mentioned above), lasted several years and provided ample opportunity for the researchers to interact with and form trusting bonds with the community stakeholders (Barron et al. 2012; Burch et al. 2010). Both the local community staff and members of the public were receptive to the project, and therefore willing to make use of the climate information in the form of visualized scenarios, because of the longer-term commitment that was shown on the part of researchers and the trust that was built between stakeholders. Trust is also mentioned as an opportunity for increasing climate information use (Kirchhoff, Lemos, and Engle 2013) and is noted as a key component required in establishing a National Climate Service (Miles et al. 2006).

Although difficult to prove empirically, a common notion is that trust is largely built through effective and recurring engagement between users and producers. Lu (2011: 88) echoes this point, stating that "partnerships and collaboration among relevant stakeholder groups is critical to the efficient and effective provision, delivery and application of climate change information." However, it is important to note that stakeholder participation cannot be viewed as a panacea (Kasperson 2006 in Romsdahl 2011).

Matching information with user needs

Uptake of medium- to long-term climate information can be supported by matching it with specific user needs. This can only be done through interaction with producers and users to define the question that is most relevant to their needs (Berkhout et al., 2014; Jenni et al., 2014). In the Dutch Climate Changes Spatial Planning programme, for example, scenarios created by the Royal Netherlands Meteorological Institute (KNMI) were a starting point for creating tailored scenarios according to the needs of specific users. Climate modellers and stakeholders worked together to gradually align their frames of references. In one specific instance, there was a need identified for a 'standard hydrological year' in a project that was working with provincial governments to create adaptation strategies. The 'standard year approach' was the approach preferred by decision makers, even though it had some limitations—year-to-year variability and changes in extremes are not fully explored in such an approach. The decision makers preferred the simpler approach instead of using full-scale 30-year model simulations (Berkhout et al. 2014). We can deduce that having the climate modellers tailor the information to what the decision makers were asking drove the uptake of the climate information.

Connecting users with information that is relevant to them is a key enabler in establishing its utility and uptake: "*An effective climate service goes beyond the production of information. It has to be embedded into an end-to-end system that serves the members of target community with information that would enable them to initiate actions to reduce or avoid risks*" (Srinivasan et al., 2011: 10). For example, producers of climate information can be encouraged to gain a better understanding of what information will best support decision makers as well as the political and socio-economic context within which decisions are taken. In turn, decision makers can be encouraged to better articulate their information needs in a manner that recognises the limitations of available science. Doing so requires a collaborative processes between all relevant stakeholders (Miles et al., 2006).

Active and effective boundary organizations

Effective boundary organizations can also help in bringing about mutual understanding between different stakeholders and facilitate the uptake of medium- to long-term climate information. With this in mind, Selvaraju et al. (2011: 106), call for the establishment of "multi-disciplinary institutional mechanisms at national and sub-national levels with specific roles and responsibilities pertaining to generation, translation, communication and use of climate information for decision making." Such boundary organizations span research, policy and practice helping to perform a number of roles including: the convening of different stakeholders, production and translation of research outputs; and support in communicating the costs and benefits of different policy options (Clarke et al., 2013).

Increased accessibility of climate information and support for the technical capacity to use it

The second largest category of enablers relates to access and use of medium- to long-term climate information by decision makers. Improved accessibility of climate information and support for technical capacity to use it can be significant enabling factors in promoting uptake (see overlaps with Section B1.3.2).

Enhancing accessibility/usability

There are various components to enhancing the accessibility and usability of medium- to long-term climate information, including: making it available in a range of different languages; encouraging it to be shared across a range of different communication channels; and carefully ensuring that information and policy advice is interpretable by non-experts and tailored to the appropriate audience (Dilling and Lemos, 2011; Romsdahl 2011). One way of making climate information accessible is through a knowledge portal that makes scientific knowledge available to decision makers and stakeholders in easily understandable formats. CSIRO maintains a coastal research web portal that provides access to data from coastal research projects to local councils and other stakeholders (Clarke et al. 2013), although empirical evidence documenting how successful it has been in spurring the uptake of climate information was not documented. One project that has been successful in terms of making information accessible to end-users has been the UKCIP02 program. Stakeholders involved in an evaluation of the UKCIP02 program responded that documents were written in simple language and were clear and concise, making them easily understandable by people without scientific backgrounds (Gawith et al. 2009).

Above all, producers of climate information, boundary agents and knowledge brokers should each be aware of the various needs, technical capacities and interests of respective end users (Lu, 2011). For example, the communication of medium- to long-term climate information is often heavily reliant of the use of scientific terminology and technical figures and charts. This can render information inaccessible to many decision makers if they are unfamiliar with technical outputs or the assumptions that underlie their production (Girvetz et al., 2014).

Building agency capacity

The ability of decision makers to understand and apply climate information was found to be a driving factor of uptake in both Bolson et al. (2009) and Romsdahl (2011), relating to the barrier regarding lack of capacity. Bolson et al. (2009) further cited agency size as a driver of uptake of climate information. In larger water resource systems that were part of their study, the bigger organizations had more expertise and in-house capacity to make use of climate information. They surveyed water resource managers and concluded that "the underlying message appears to be the need for major improvements in (1) marketing and (2) training about the forecasts and information" (p. 150). Marketing is tied to the above driver of making climate information accessible, while training on how to use the information would build capacity among decision makers to make use of the products created by climate scientists.

A case study of the Southeast Climate Consortium (SECC), which is a Regional Integrated Sciences and Assessments program (RISA) under the Climate Program Office of the National Oceanic and Atmospheric Administration (NOAA), revealed that an enhanced ability to understand the climate science presented is an important factor in adoption of decision support mechanisms among decision makers (Romsdahl 2011). The SECC is a collaboration between state universities in Florida, Georgia, and Alabama, and involves a strong partnership with the respective State Cooperative Extension Services. A strategic plan of the SECC Extension Program emphasized the development of educational materials and training programs to assist decision makers in comprehending and subsequently using climate information (Romsdahl 2011).

Also acknowledging the role of capacity building, a conceptual review of the Nairobi Work Program (an activity under the UNFCCC) noted that two of the highest priority areas that have been defined by the Parties and partner organizations are providing technical guidance on the use of climate data and scenarios products and building the technical capacity of in-country experts to enhance the use of climate information and services (Lu 2011). This opportunity as described in the conceptual review aligns with the empirical evidence provided in the case study.

Improvements to the underlying science

This category relates to improvements in the underlying basis of climate science. Two enablers stand out in particular: a) higher resolution data; and b) matching timescales with decision making.

Higher resolution data

The ability to produce information at appropriate resolution for use in local and regional decision making is a considerable enabling factor to informed decision making (Gawith et al., 2009; Runhaar et al., 2012; Ziervogel and Zermoglio, 2009). In studying the UKCIP program, Gawith et al. (2009) provide evidence that higher resolution data increased the use of the information among professionals in the UK building sector. Users were able to apply high scale resolution information to their specific location and evaluate the implications of future temperature change on building design. Despite the advantages it offers, it must be recognised that high resolution climate information still comes with many technical limitations that impede its utility to inform local decision making processes.

Matching timescales with decision making

A temporal mismatch between decision makers' interests and the timescales associated with medium- to long-term climate information was identified as a constraint to climate information uptake in multiple papers. Examples of successful efforts to align these time frames is only documented in one article (Gawith et al., 2009). One of the tools developed underneath the UKCIP program is the Local Climate Impacts Profile (LCLIP), an approach that helps local authorities assess their vulnerability to climate change. Information is gathered on the impacts of previous weather events in a location, and then climate information from the UKCIP scenarios is used to explore the projections of the likelihood of such events at a timeframe in the future chosen by the local authorities. For example, an LCLIP developed by the Oxfordshire County Council (OCC) focused on the projection of high temperature days in the 2020s and the possible effects on summer road maintenance. The 2020s was chosen because that timescale was most closely aligned with the county council's planning timescale (Gawith et al., 2009). Given the related constraint identified in Section 1.4.1, there is an opportunity for the producers of medium- to long-term climate information to work with potential users to create products that match the decision makers' needs in terms of timescales. Creating climate information that is better aligned with the policy making cycle can be an enabling factor in uptake.

Overcoming institutional constraints is considered an important factor for increasing uptake of medium- to long-term climate information

Overcoming institutional constraints

Identifying enablers to overcoming institutional constraints is difficult, primarily as many are context specific. However, organizations that have sufficient human or technical capacity, or engage in processes of flexible and iterative decision making, are likely to be better able to make use of climate information (Bolson et al., 2009; Kirchhoff et al., 2013b). For example, Meinke et al. (2006) call for institutional reform among Australian climate research agencies and agricultural policy makers to better align scientific outputs with policy needs and recommend that risk management systems become more holistic and incorporate climate risk management into the broader strategies for rural communities. Finding the appropriate entry point for policy engagement is also key. In reviewing ways in which development practitioners can build climate change adaptation into their sector, Agrawala and van Aalst (2008) identify investment plans, land-use planning, and disaster management strategies as appropriate entry points for the uptake of climate information in national decision making processes.

Changes to research

This category of enablers contains a variety of factors. In a commentary addressing whether the scientific research agenda and processes for commissioning and carrying out research in practice are adapting successfully to address the complex problems being created by climate change, Averyt (2010) makes a case for the benefits of integrated and user-driven research. She calls for incentives that encourage climate scientists to engage with researchers from other disciplines as well as end-users of climate information throughout their careers, not just after they have achieved tenure. Greater multi- and interdisciplinary research is needed, in part, because the issues behind climate change and adaptation are very complex and span numerous sectors (Viviroli et al., 2011). Collaboration between scientists and researchers from a range of different disciplines can help foster greater understanding of user needs and support producers of climate information to provide information in more usable formats (Burch et al., 2010). In discussing how to improve incentives for creating usable climate information, Dilling and Lemos (2011) also cite a need for flexibility in how research is commissioned and procured, recognising needs and problems often shift and change through time.

Windows of opportunity and trust

This category focuses on the timing of change and perceptions of information used to bring about transition. It is the smallest of the five categories, and there are few examples within the short-listed literature of how these enablers have been successfully used. Yet, the topics are sufficiently important and distinct from the previous categories to justify a stand-alone.

Trigger event

In both their literature review and participant interviews, Kirchhoff et al. (2013b) found that the occurrence of a climate event, such as an extreme drought, can trigger increased requests for climate information. However, this heightened use of climate information fades after the climate event passes, suggesting a limited window of opportunity for effective dissemination. The authors argue that these findings suggest "increased receptivity during drought events might serve as opportunities to overcome skepticism and train managers to use climate information, since associated impacts are fresh in their psyche" (Kirchhoff et al 2013b:12). Producers of climate information may therefore be able to make greater use of trigger events in order to take advantage of particular windows of opportunity when they arise.

Perception of information

This last enabler deals with ways in which decision makers view climate information. There is a need to encourage greater levels of trust between decision makers in relation to producers of climate information, especially in the utility of their scientific outputs in supporting decision making. Policy makers and planners often need to view medium- to long-term climate information as useful for their decision making before being willing to adopt it (Dilling and Lemos, 2011). Beyond seeing the relevance of the information, users also need to believe that it is credible and trust those who are producing it. Trust is often built up through collaboration and interaction (Corburn, 2009). As identified previously, collaborating with decision makers to co-produce climate information can increase levels of trust and thereby increase rates of uptake. Dilling and Lemos (2011) highlight how credibility, legitimacy and salience strongly determined use of climate information in decision making processes.

Discussion

Before drawing wider conclusions, we first highlight four observations with regards to the outputs of the systematic review. First, in reflecting on the typology of the studies found within the review, it is clear that there is a strong skew within the peer-reviewed literature towards documenting the uptake of climate information in developed countries and regions. A lack of developing countries focus may reflect a number of factors. Decision makers in developing country are often less likely to use climate information to guide investments and plans, owing to the immediacy of basic development needs as well as lack of technical capacity to integrate climate information into decision making processes (Agrawala and van Aalst, 2008; Selvaraju et al., 2011). Another factor may be due to lower research capacity and resources, and hence less likelihood for research to be carried out on the uptake of climate information in developing countries and subsequently featured within peer-reviewed literature (Girvetz et al., 2014). It is possible that we would have found more cases in developing countries had we included grey literature instead of limiting our research to peer reviewed literature.

Our second observation is that in examining the number of papers that cited evidence within each category of constraint and enabler, constraints appear to be relatively evenly distributed amongst the different categories. Enablers, on the other hand, are clustered heavily within the category of “collaboration and bridging work”. Reasons behind this are unclear. It may be that this category relates to a large number of different activities. It may also reflect the genuine gains that may be had in promoting successful uptake within decision making, or the comparative ease with which it may be overcome compared to many of the other opportunities (particularly in relation to difficulties in driving forward with political and institutional change as well as overcoming current scientific limitations).
Third, although we limit our review to use of medium- and long-term climate information and excluded research on short-term climate forecasts, the constraints and enablers that emerge from our study closely align with those found in the literature on the uptake of weather and seasonal forecasting (see Crane et al., 2010; Kirchhoff et al., 2013a; Lemos and Rood, 2010; Vogel and O’Brien, 2006). While the two domains draw on different kinds of climate information and are typically oriented toward different kinds of decisions and decision makers, both appear to involve similar sets of fundamental issues. These include mismatching spatial and temporal specificity, poor connections between processes of information production and application, communication challenges, and lack of institutional incentives for scientists and decision makers. Furthermore, successful uptake in both domains appears to be associated with co-production processes that involve iterative communication between scientists and decision makers, boundary actors, carefully tailored information, and willingness of both scientists and decision makers to move out of their institutional and informational comfort zones. Most importantly, this suggests that actors seeking to promote more effective use of medium- to long-term climate information may gain substantially from drawing on the lessons learned in overcoming constraints to the uptake of seasonal climate information. This is particularly relevant given the latter category’s greater maturity (in both academia and practice) as well as recent gains in improving ways of communication,

dissemination channels and use of short-term climate information in decision making (Goddard et al., 2010; Tall et al., 2012).

Lastly, it is important to note that there are limitations with our study and its design. Principally, our results are restricted to peer-reviewed literature, in English, and therefore may capture only a subset of available knowledge and literature. Indeed, there is a body of grey literature that offers insights into the subject at hand (Hallegate et al., 2012; Jones et al., 2015; Ranger, 2013; Wilby et al., 2009; WRI, 2011). Casting the net more widely to include non-peer reviewed papers, as well as comparison of the main findings of different types of publications, would be an interesting area for additional research.

Conclusion

Evidence from the literature showcases the diversity of challenges facing stakeholders engaged at every stage of the science-policy interface. While many of the constraints may appear overwhelming, evidence suggests that they are not insurmountable. Clearly more needs to be done to advance our understanding of the climate system and the likely impacts of climate change on people and communities on medium- to long-term timescales. However, promoting the uptake of climate information is not just about improving climate science; many of the biggest constraints relate to issues of political economy and institutional factors. As the evidence in this systematic review highlights, the uncertainty of institutional mandates, organisational structures and a lack of adequate incentives can each act as concrete impediments to science uptake. They also limit the ability of knowledge brokers to have meaningful impact with targeted decision making processes.

Isolated external interventions targeted at promoting the uptake of climate information into decision making are unlikely to succeed without the establishment of meaningful and sustained relationships between relevant scientists and policy making stakeholders. Effectiveness is also largely dependent on bottom-up demand for and – where possible – national ownership of available climate services. Spending time and investing resources to understand the local political context and engage with national and local partners can therefore help tailor more effective communication and use of climate information. Above all, more needs to be done to ensure co-production of knowledge between producers and users of medium- to long-term climate information.

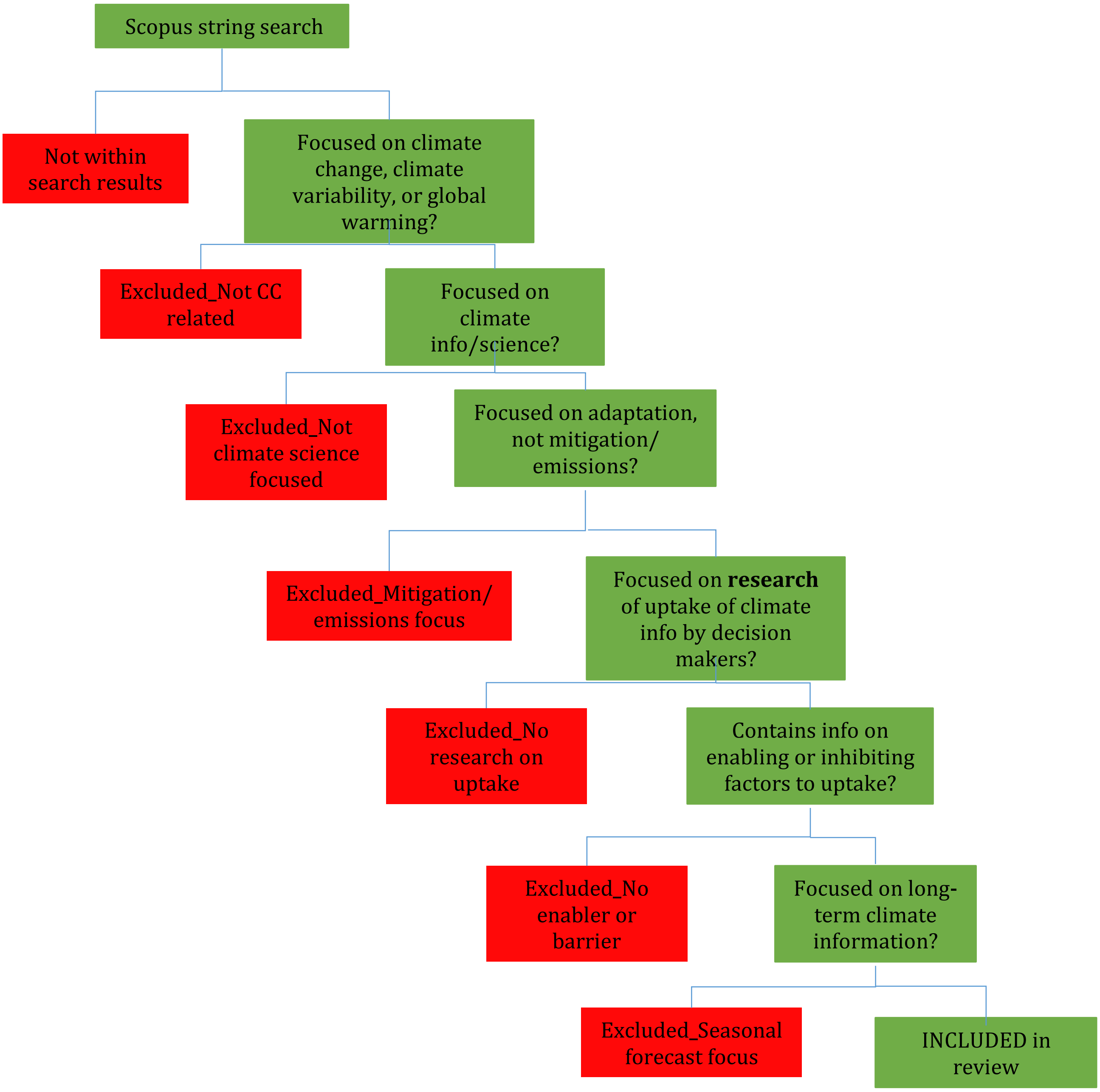
Not every decision requires long-term climate information to be taken into account in order for successful outcomes to be achieved. This is particularly the case in the context of developing countries, where the immediacy of development challenges means that decision-makers often prioritise short-term interventions. Rather, care should be taken to ensure that information is targeted towards investments and planning decisions that are relevant to longer-term timescales, either where infrastructure and impacts on livelihoods are felt long after the intervention project-cycle or where their influence is expected over multiple decades. Such targeting should also be conscious of investments and planning decisions that pose higher risks of maladaptation or 'lock-in' due to technical difficulties or high cost of retrofitting, such as long-lived infrastructural investments or urban spatial planning.

Appendix 1: Steps conducted under the systematic review

a) Using a decision tree to screen articles

We conducted the Scopus search on October 1st, 2014, receiving 2,530 hits from the original string (see the Data and Methods section in the paper for the search terms). In order to narrow down on publications relevant to the research questions, we used the decision tree outlined in Figure 1 (numbers of papers excluded at each point in the decision tree can be seen in A2).

Figure 1: Systematic review decision tree



Our first selection criterion was whether the paper focused on climate change, climate variability or global warming. Next, we reviewed whether the paper dealt with climate information or climate science. We then verified if the paper was primarily focused on climate change adaptation, omitting papers focused on mitigation and greenhouse gas emissions. The next test was whether the paper specifically dealt with research on the uptake of climate information - this step in the decision tree was where most of the papers were excluded. We then assessed whether the article contained information on factors enabling or inhibiting uptake. Following this, we evaluated whether the focus of the paper was on long-term climate information.

The decision tree was applied twice: during the initial title and abstract screening and then again during the full text screening.

b) Title and abstract screening

Titles and abstracts of the returned articles were screened by two independent reviewers. Both reviewers screened the first 600 titles and abstracts at which point results were compared and discussed with discrepancies reviewed through an adjudicating review team (comprised of three additional individuals). The Kappa inter-annotator agreement test (McGinn et al., 2004) performed for this round of screening scored 0.508 between the two independent reviewers. Due to a modest Kappa score, the team revisited the inclusion/exclusion criteria and clarified the protocol and its implementation. The remaining articles were independently screened. If, during the title and abstract screening, it was not clear whether or not the article fully satisfied the criteria for inclusion in or exclusion from the study, it was marked as "unclear" and passed to the full text screening. 110 articles showed initial relevance to our inclusion criteria (with 52 clearly relevant to our inclusion criteria and 58 marked as "unclear").

c) Full text screening

The next stage involved the full text screening of the 110 papers that made it through the title and abstract screen. An initial pilot screening of 10 papers was carried out to test the full text screening strategy. This was followed by discussion on any discrepancies and the remaining 100 articles were independently screened by two independent teams each made up of two reviewers. In the cases where screened full texts remained "unclear", each pair of reviewers first discussed discrepancies internally before consulting with the other team in order to reach agreement. However, when consensus was not reached, an external reviewer was consulted for a final decision on inclusion or exclusion of the articles in question. The full text screening yielded a Kappa test scored 0.916, deemed highly consistent (McGinn et al., 2004). Only literature that fully satisfied inclusion criteria were included in the final database for data extraction. Of the 110 peer-reviewed articles available from the first round of screening, 44 were retained for data extraction.

d) Data extraction

Data from the 44 papers was extracted into an Excel spreadsheet and analysed according to the two primary research questions. The extraction process assessed information on year of publication, author affiliation, geographic focus, spatial scale, sectoral focus of climate information, type of evidence generated, data collection method, timescale of climate information, type of decision-making process, as well as identified constraints and enablers to the uptake of climate information in decision-making and associated quotes from the text.

A pilot extraction on 5 papers was carried out to iron out any discrepancies and amend information categories for the extraction process.

Topics specified as constraints and enablers to the uptake of medium- to long-term climate information in decision making in the papers were coded respectively into ten categories according to their recurring and overarching themes: five categories of constraints and five categories of enablers (see Results section).

Appendix 2: Numbers of papers excluded at each stage of screening

First round of screening: Title and abstract	
Total number of papers screened	**2530**
Total number of excluded papers	**2420**
Not focused on climate change, climate variability or global warming	111
Not focused on climate information	81
Not focused on adaptation (e.g. mitigation/emissions)	812
Not focused on research of decision making	1386
Does not contain enablers or inhibitors	13
Not focused on long-term climate information	17
Straight to second round (Included)	**52**
Unclear (Included)	**58**
Total number of papers through to 2nd round of screening	**110**

Second round of screening: Full text screening	
Total number of papers screened for full text	**110**
Total number of excluded papers	**66**
No access to full text	4
Not in English	2
Not focused on climate change, climate variability or global warming	1
Not focused on climate information	18
Not focused on research of decision making processes	37
Not focused on long-term climate information	4
Total number of included papers	**44**

Appendix 3: Terms and definitions

In relation to the geographic scales outlined in Figure 3, categories refer to the primary geographic focus of shortlisted articles. Here, ‘Multiple regions’ relates to articles that describe case studies in more than one country across more than one continent; ‘Municipal’ refers to the town or city levels; and ‘Local’ refers to the household, community or village levels. Additional scales are referred to in Figure 4. Here, ‘Multiscalar’ studies relate to studies that transcend scales from, from local to supranational; ‘Supranational’ scale refers to case studies that span more than one country; National scale refers to a country scale of analysis; and ‘Regional’ refers to a regional administrative unit within a country.

Appendix 4: Articles included in the analysis (n=44)

1. Agrawala, S.; Matus Kramer, A.; Prudent-Richard, G.; Sainsbury, M.; Schreitter, V. Incorporating climate change impacts and adaptation in environmental impact assessments: Opportunities and challenges. *Climate and Development* 2012, *4*, 26-39.
2. Agrawala, S.; Van Aalst, M. Adapting development cooperation to adapt to climate change. *Climate Policy* 2008, *8*, 183-193.
3. Averyt, K. Are we successfully adapting science to climate change? *Bulletin of the American Meteorological Society* 2010, *91*, 723-726.
4. Barron, S.; Canete, G.; Carmichael, J.; Flanders, D.; Pond, E.; Sheppard, S.; Tatebe, K. A climate change adaptation planning process for low-lying, communities vulnerable to sea level rise. *Sustainability* 2012, *4*, 2176-2208.
5. Berkhout, F.; Hurk, B.v.d.; Bessembinder, J.; Boer, J.d.; Bregman, B.; Drunen, M.v. Framing climate uncertainty: Socio-economic and climate scenarios in vulnerability and adaptation assessments. *Regional Environmental Change* 2014, *14*, 879-893.
6. Bolson, J.; Martinez, C.; Breuer, N.; Srivastava, P.; Knox, P. Climate information use among southeast us water managers: Beyond barriers and toward opportunities. *Regional Environmental Change* 2013, *13*, 141-151.
7. Bremond, A. Improving the usability of integrated assessment for adaptation practice: Insights from the u.S. Southeast energy sector. *Environmental Science & Policy* 2014, *42*, 45-55.
8. Bryson, J.; Piper, J.; Rounsevell, M. Envisioning futures for climate change policy development: Scenarios use in european environmental policy institutions. *Env. Pol. Gov.* 2010, *20*, 283-294.
9. Burch, S.; Sheppard, S.r.j.; Shaw, A.; Flanders, D. Planning for climate change in a flood-prone community: Municipal barriers to policy action and the use of visualizations as decision-support tools. *Journal of Flood Risk Management* 2010, *3*, 126-139.
10. Camp, J.; Abkowitz, M.; Hornberger, G.; Benneyworth, L.; Banks, J. Climate change and freight-transportation infrastructure: Current challenges for adaptation. *Journal of Infrastructure Systems* 2013, *19*, 363-370.
11. Clarke, B.; Stocker, L.; Coffey, B.; Leith, P.; Harvey, N.; Baldwin, C.; Baxter, T.; Bruekers, G.; Galano, C.D.; Good, M., *et al.* Enhancing the knowledge–governance interface: Coasts, climate and collaboration. *Ocean & Coastal Management* 2013, *86*, 88-99.
12. Corburn, J. Cities, climate change and urban heat island mitigation: Localising global environmental science. *Urban Stud.* 2009, *46*, 413-427.
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Appendix 5: Articles excluded after full text screening (n=66)*

	AUTHORS	TITLE	DATE	JOURNAL TITLE
1	[No author name available]	Examination of environmental consequences of climate adaptation measures - approaches for consideration in sea, eia and impact regulation [Umweltfolgenprüfung von Klimaanpassungsmaßnahmen]	2010	Naturschutz und Landschaftsplanung
2	Aldum N., Duggie J., Robson B.J.	Climate change adaptation support tools in Australia	2014	Regional Environmental Change
3	Ali F.M.M., Jones K.	Negotiating community resilience in the city in a time of political change and deficit reduction	2013	International Journal of Disaster Resilience in the Built Environment
4	Andersson L., Olsson J.A., Arheimer B., Jonsson A.	Use of participatory scenario modelling as platforms in stakeholder dialogues	2008	Water SA
5	Appeaning Addo K., Walkden M., Mills J.P.	Detection, measurement and prediction of shoreline recession in Accra, Ghana	2008	ISPRS Journal of Photogrammetry and Remote Sensing
6	Archer E., Mukhala E., Walker S., Dilley M., Masamvu K.	Sustaining agricultural production and food security in Southern Africa: An improved role for climate prediction?	2007	Climatic Change
7	Baard P., Vredin Johansson M., Carlsen H., Edvardsson Bjornberg K.	Scenarios and sustainability: Tools for alleviating the gap between municipal means and responsibilities in adaptation planning	2012	Local Environment
8	Bartels W.-L., Furman C.A., Diehl D.C., Royce F.S., Dourte D.R., Ortiz B.V., Zierden D.F., Irani T.A., Fraisse C.W., Jones J.W.	Warming up to climate change: A participatory approach to engaging with agricultural stakeholders in the Southeast US	2013	Regional Environmental Change
9	Bert F.E., Podesta G.P., Satorre E.H., Messina C.D.	Use of climate information in soybean farming on the Argentinean pampas	2007	Climate Research
10	Bobojonov I., Aw-Hassan A., Sommer R.	Index-based insurance for climate risk management and rural development in Syria	2014	Climate and Development
11	Boezeman D., Vink M., Leroy P.	The Dutch Delta Committee as a boundary organisation	2013	Environmental Science and Policy
12	Bohunovsky L., Jager J., Omann I.	Participatory scenario development for integrated sustainability assessment	2011	Regional Environmental Change
13	Bosetti V., Buchner B.	Data Envelopment Analysis of different climate policy scenarios	2009	Ecological Economics
14	Brown C., Ghile Y., Laverty M., Li K.	Decision scaling: Linking bottom-up vulnerability analysis with climate projections in the water sector	2012	Water Resources Research
15	Brown I., Castellazzi M.	Scenario analysis for regional decision-making on sustainable multifunctional land uses	2014	Regional Environmental Change

16	Chandramowli S., Felder F.F.	Climate change and power systems planning-opportunities and challenges	2014	Electricity Journal
17	Chaudhury M., Vervoort J., Kristjanson P., Ericksen P., Ainslie A.	Participatory scenarios as a tool to link science and policy on food security under climate change in East Africa	2013	Regional Environmental Change
18	Coffee J.E., Parzen J., Wagstaff M., Lewis R.S.	Preparing for a changing climate: The Chicago climate action plan's adaptation strategy	2010	Journal of Great Lakes Research
19	Crabbe P., Robin M.	Institutional adaptation of water resource infrastructures to climate change in Eastern Ontario	2006	Climatic Change
20	Crane R., Landis J.	Introduction to the special issue: Planning for climate change: Assessing progress and challenges	2010	Journal of the American Planning Association
21	de Bruin K., Goosen H., van Ierland E.C., Groeneveld R.A.	Costs and benefits of adapting spatial planning to climate change: Lessons learned from a large-scale urban development project in the Netherlands	2014	Regional Environmental Change
22	Dulal H.B.	Governing climate change adaptation in the ganges basin: Ass cessing needs and capacities	2014	International Journal of Sustainable Development and World Ecology
23	Fraisse C.W., Breuer N.E., Zierden D., Bellow J.G., Paz J., Cabrera V.E., Garcia y Garcia A., Ingram K.T., Hatch U., Hoogenboom G., Jones J.W., O'Brien J.J.	AgClimate: A climate forecast information system for agricultural risk management in the southeastern USA	2006	Computers and Electronics in Agriculture
24	Goldstein J.H., Caldarone G., Duarte T.K., Ennaanay D., Hannahs N., Mendoza G., Polasky S., Wolny S., Daily G.C.	Integrating ecosystem-service tradeoffs into land-use decisions	2012	Proceedings of the National Academy of Sciences of the United States of America
25	Graham N.E., Georgakakos K.P.	Toward understanding the value of climate information for multiobjective reservoir management under present and future climate and demand scenarios	2010	Journal of Applied Meteorology and Climatology
26	Grantz K., Rajagopalan B., Zagona E., Clark M.	Water management applications of climate-based hydrologic forecasts: Case study of the Truckee-Carson River Basin	2007	Journal of Water Resources Planning and Management
27	Hallegatte S.	Strategies to adapt to an uncertain climate change	2009	Global Environmental Change
28	Harrison P.A., Holman I.P., Cojocaru G., Kok K., Kontogianni A., Metzger M.J., Gramberger M.	Combining qualitative and quantitative understanding for exploring cross-sectoral climate change impacts, adaptation and vulnerability in Europe	2013	Regional Environmental Change
29	Harvey B., Carlile L., Ensor J., Garside B., Patterson Z.	Understanding context in learning-centred approaches to climate change communication	2012	IDS Bulletin
30	Kamau J.W., Mwaura F.	Climate change adaptation and EIA studies in Kenya	2013	International Journal of Climate Change Strategies and Management
31	Knopman D.S.	Success matters: Recasting the relationship among geophysical, biological, and behavioral scientists to support decision making on major environmental challenges	2006	Water Resources Research
32	Kriegler E., Edmonds J.,	A new scenario framework for climate	2014	Climatic Change

	Hallegatte S., Ebi K.L., Kram T., Riahi K., Winkler H., van Vuuren D.P.	change research: The concept of shared climate policy assumptions		
33	Lopez A., Fung F., New M., Watts G., Weston A., Wilby R.L.	From climate model ensembles to climate change impacts and adaptation: A case study of water resource management in the southwest of England	2009	Water Resources Research
34	O'Neill B., Pulver S., Vandeveer S., Garb Y.	Where next with global environmental scenarios?	2008	Environmental Research Letters
35	Parson E.A.	Useful global-change scenarios: Current issues and challenges	2008	Environmental Research Letters
36	Peake S.	Policymaking as design in complex systems-the international climate change regime	2010	E:CO Emergence: Complexity and Organization
37	Pesonen H.-L., Horn S.	Evaluating the climate SWOT as a tool for defining climate strategies for business	2014	Journal of Cleaner Production
38	Rosqvist T., Molarius R., Virta H., Perrels A.	Event tree analysis for flood protection - An exploratory study in Finland	2013	Reliability Engineering and System Safety
39	Salinger M.J., Bell J.D., Evans K., Hobday A.J., Allain V., Brander K., Dexter P., Harrison D.E., Hollowed A.B., Lee B., Stefanski R.	Climate and oceanic fisheries: Recent observations and projections and future needs	2013	Climatic Change
40	Semazzi F.H.M.	Framework for climate services in developing countries	2011	Climate Research
41	Stainforth D.A., Downing T.E., Washington R., Lopez A., New M.	Issues in the interpretation of climate model ensembles to inform decisions	2007	Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences
42	Stein A., Moser C.	Asset planning for climate change adaptation: Lessons from Cartagena, Colombia	2014	Environment and Urbanization
43	Tanner T.	Climate risk screening of development portfolios and programmes	2008	IDS Bulletin
44	Tryhorn L.	Improving policy for stormwater management: Implications for climate change adaptation	2010	Weather, Climate, and Society
45	Tschakert P., Dietrich K., Tamminga K., Prins E., Shaffer J., Liwenga E., Asiedu A.	Learning and envisioning under climatic uncertainty: An African experience	2014	Environment and Planning A
46	Tschakert P., Dietrich K.A.	Anticipatory learning for climate change adaptation and resilience	2010	Ecology and Society
47	Twomlow S., Mugabe F.T., Mwale M., Delve R., Nanja D., Carberry P., Howden M.	Building adaptive capacity to cope with increasing vulnerability due to climatic change in Africa - A new approach	2008	Physics and Chemistry of the Earth
48	Wei Y., Langford J., Willett I.R., Barlow S., Lyle C.	Is irrigated agriculture in the Murray Darling Basin well prepared to deal with reductions in water availability?	2011	Global Environmental Change
49	Wibeck V.	Enhancing learning, communication and public engagement about climate change - some lessons from recent literature	2014	Environmental Education Research
50	Winkler J.A., Guentchev	Climate Scenario Development and	2011	Geography Compass

	G.S., Liszewska M., Perdinan S., Tan P.-N.	Applications for Local/Regional Climate Change Impact Assessments: An Overview for the Non-Climate Scientist: Part II: Considerations When Using Climate Change Scenarios Climate scenario development and applications II		
51	Wratt D.S., Tait A., Griffiths G., Espie P., Jessen M., Keys J., Ladd M., Lew D., Lowther W., Mitchell N., Morton J., Reid J., Reid S., Richardson A., Sansom J., Shankar U.	Climate for crops: Integrating climate data with information about soils and crop requirements to reduce risks in agricultural decision-making	2006	Meteorological Applications
52	Chandler R.E., Thorne P., Lawrimore J., Willett K.	Building trust in climate science: Data products for the 21st century	2012	Environmetrics
53	Finucane M.L., Miller R., Corlew L.K., Keener V.W., Burkett M., Grecni Z.	Understanding the climate-sensitive decisions and information needs of freshwater resource managers in Hawaii	2013	Weather, Climate, and Society
54	Hennessey R.	Scenario planning as a tool to ensure robust adaptation	2010	Plan Canada
55	Kiem A.S., Verdon-Kidd D.C., Austin E.K.	Bridging the gap between end user needs and science capability: Decision making under uncertainty	2014	Climate Research
56	Mase A.S., Prokopy L.S.	Unrealized potential: A review of perceptions and use of weather and climate information in agricultural decision making	2014	Weather, Climate, and Society
57	McNie E.C.	Delivering climate services: Organizational strategies and approaches for producing useful climate-science information	2013	Weather, Climate, and Society
58	O'Toole K., Coffey B.	Exploring the Knowledge Dynamics Associated with Coastal Adaptation Planning	2013	Coastal Management
59	Pringle P., Conway D.	Voices from the frontline: The role of community-generated information in delivering climate adaptation and development objectives at project level	2012	Climate and Development
60	Prokopy L.S., Haigh T., Mase A.S., Angel J., Hart C., Knutson C., Lemos M.C., Lo Y.-J., McGuire J., Morton L.W., Perron J., Todey D., Widhalm M.	Agricultural advisors: A receptive audience for weather and climate information?	2013	Weather, Climate, and Society
61	Romana S., Marta M., Valentina K.	Adaptation strategy to hydrological impact of climate change strategie [Adaptace na hydrologické dopady změny klimatu]	2010	Journal of Hydrology and Hydromechanics
62	Russell S.L., Greenaway A., Carswell F., Weaver S.	Moving beyond "mitigation and adaptation": examining climate change responses in New Zealand	2014	Local Environment
63	Sosa-Rodriguez F.S.	From federal to city mitigation and adaptation: Climate change policy in Mexico City	2013	Mitigation and Adaptation Strategies for Global Change
64	Szlafsztein C.F.	Development projects for small rural communities in the Brazilian Amazon region as potential strategies and practices of climate change adaptation	2014	Mitigation and Adaptation Strategies for Global Change

65	Valdivia C., Seth A., Gilles J.L., Garcia M., Jimenez E., Cusicanqui J., Navia F., Yucra E.	Adapting to climate change in Andean ecosystems: Landscapes, capitals, and perceptions shaping rural livelihood strategies and linking knowledge systems	2010	Annals of the Association of American Geographers
66	Whiteman M.I., Maginness C.H., Farrell R.P., Gijsbers P.J.A., Ververs M.	The National Groundwater Modelling System: Providing wider access to groundwater models	2012	Geological Society Special Publication

**A full list of references returned from the first stage (2530) is available upon request to the corresponding author.*

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