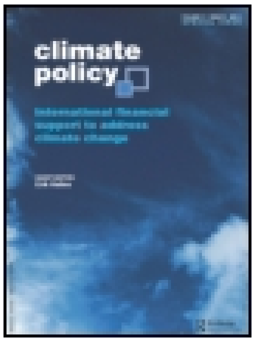

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climate policy

synthesis article

Constraining and enabling factors to using long-term climate information in decision-making

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We carry out a structured review of the peer-reviewed literature to assess the factors that constrain and enable the uptake of long-term climate information in a wide range of sectoral investment and planning decisions. Common applications of long-term climate information are shown to relate to urban planning and infrastructure, as well as flood and coastal management. Analysis of the identified literature highlights five categories of constraints: disconnection between users and producers of climate information, limitations of climate information, financial and technical constraints, political economy and institutional constraints and finally psycho-social constraints. Five categories of enablers to the uptake of long-term climate information in decision-making are also identified: collaboration and bridge work, increased accessibility of climate information, improvement in the underlying science, institutional reform and windows of opportunity for building trust.

Policy relevance
Our review suggests that stand-alone interventions aimed at promoting the uptake of climate information into decision-making are unlikely to succeed without genuine and sustained relationships between producers and users. We also highlight that not every decision requires consideration of long-term climate information 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 adaptation; climate information; climate services; decision-making; long-term planning

1. Introduction

Climate change poses considerable challenges to the management of socio-political, economic and ecological systems (Lemos et al., 2012). Decision makers are increasingly under pressure to ensure that long-term climate risks are factored into investment and planning decisions (Lemos and Rood, 2010). The push to include long-term climate information in decision-making is largely founded on the notion that anticipatory action and adaptation can be improved by better understanding changing risk profiles and their potential impact on investments (Barnett and O'Neill, 2010).

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Long-term climate information (predominantly associated with multidecadal and centennial timescales) is typically linked with investments and planning decisions that have long time horizons, such as large infrastructure and national development plans (Jones et al., 2015b). Failure to consider the implications of climate change and ensure adaptive management within such investments can increase the risk of maladaptation and lock-in of irreversible or costly development trajectories (Ranger and Garbett-Shiels, 2012). Although considerable progress has been made in incorporating weather and seasonal forecasts into decision-making (Pozzi et al., 2013; Tall et al., 2012; Thomson et al., 2006), the use of long-term climate information lags behind the pace of scientific developments (Kirchhoff et al., 2013b; Wilby et al., 2009). In this article we seek to better understand reasons for this shortfall.

The rationale for investigating the differences between timescales rests on the basis that the types of decisions and decision-makers that are associated with weather and seasonal forecasts and multidecadal climate information often differ considerably. For example, weather and seasonal forecasts are typically associated with localized and shorter-lived decisions that are relevant for guiding coping strategies for extreme weather or intra-annual and interannual variability (such as the El Niño–Southern Oscillation). Multidecadal climate information is commonly linked with the adaptation of longer-term investments and planning decisions to climate change, often taken by organizations or formal decision-making bodies (Jones et al. 2015b). Although there is likely to be considerable overlap in the constraining and enabling factors of weather, seasonal and multi-decadal climate information, we argue that many of the scientific, political and institutional contexts are markedly different and justify further structured exploration.

Through a structured review of the peer-reviewed literature, we assess constraining and enabling factors (Moser and Eckstrom 2010) for the uptake of climate information in decision-making. A number of reviews have assessed the constraints on the use of weather and short-term climate information in decision-making (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 climate information associated multidecadal timescales and beyond.

In critically assessing and synthesizing lessons from a wide range of peer-reviewed literature, this structured literature review answers the following research question: What are the main constraints and enablers to the uptake of long-term climate information in decision-making?

2. 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 structured literature review methodology to identify and analyse the uptake of long-term climate information in decision-making. Here we define long-term climate information as that ranging from multidecadal to centennial timescales (most commonly associated with multidecadal climate projections or palaeoclimate data). Scopus, the largest abstract and citation database of peer-reviewed literature, was selected for the review, focusing our efforts on the relative maturity of peer-reviewed literature on the topic. We do not include grey literature in the review.

The review targeted English-language peer-reviewed literature published between January 2006 and October 2014. The choice of 2006 relates to the cut-off date for inclusion within the Fourth Assessment

Report of the Intergovernmental Panel on Climate Change (IPCC). We also excluded studies on short-term climate information operating on monthly, seasonal or interannual timescales (Lemos et al., 2012; Siregar and Crane, 2011; Vogel and O'Brien, 2006; Ziervogel and Calder, 2003). Our search strategy deliberately targeted empirical case studies of long-term climate information being used by decision-making bodies or organizations. Consequently, this review excluded household-level decision-making (typically associated with weather and seasonal forecasting). See Supplemental Material Section S1 for further details of the review process.

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 uptak'e OR adapt*

AND

TABLE 1 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 second 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	79
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	47
Not focused on long-term climate information	7
Total number of included papers	31

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 2530 publications (Table 1). Articles subsequently underwent a two-stage screening process: (1) title and abstract screening, with 110 articles progressing; and (2) full text screening, with 31 articles advancing to full data extraction (see Supplemental Figures S1 and S2 in Supplemental Material). A full list of the literature identified under Stage 1 and 2, respectively, can be found in Sections S3 and S4 of the Supplemental Material.

In both screening stages, we used a decision tree to narrow down the number of relevant publications (see Supplemental Material Section S1). From the 31 articles that passed through both stages of the screening, we extracted information on the year of publication, author affiliations, geographic focus, spatial scale, sectoral focus of the climate information, type of evidence generated, data collection methods, timescale of the climate information and the type of decision-making process, as well as identifying the constraints and enablers to the uptake of climate information in decision-making and extracting associated quotes from the text. We did not critically evaluate or grade the quality of the studies, choosing instead to take all articles at face value and to focus on the emergent findings. The topics specified as constraints and enablers to the uptake of climate information were coded into five categories of constraints and five categories of enablers using a process of latent content analysis to identify recurring themes (Dey 2003). The categories were then iteratively refined to help reduce the overlaps between groupings, although some degree of duplication is inevitable given the related nature of many of the enablers and constraints.

3. Results

3.1. Descriptive analysis of the shortlisted literature

Analysis of the shortlisted articles reveals that the most frequently documented sectoral applications of climate information relate to urban planning and infrastructure and flood and coastal management planning. Within this grouping, climate information is primarily used to guide adaptation planning at various scales of governance. Other sectors include water resource management, environmental policy development, conservation planning and agriculture (see Figure 1). One of the most frequent uses of climate information is to support scenario planning, allowing the consideration of future risks and the implications of different development pathways.

Climate information is also used to identify 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' existing development plans and investments (Hegger et al., 2014). The use of 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, aiming 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 (Agrawala et al., 2012; Ranger and Garbett-Shiels, 2012).

The geographic focus of most of the papers is concentrated on North America and Europe, followed by papers spanning multiple regions (see Figure 2). Oceania and Africa receive notably fewer mentions.

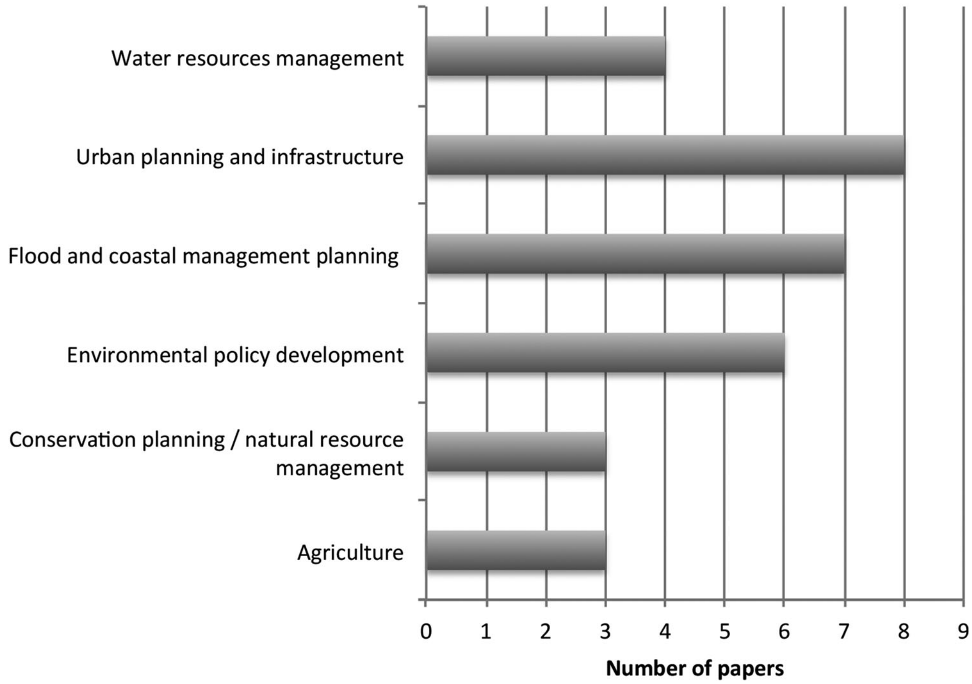

FIGURE 1 Primary sectoral focus of the short-listed literature.

In relation to the scale of focus for papers, multiscalar analyses are the largest grouping (Supplemental Figure S3 in the Supplementary Material). 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

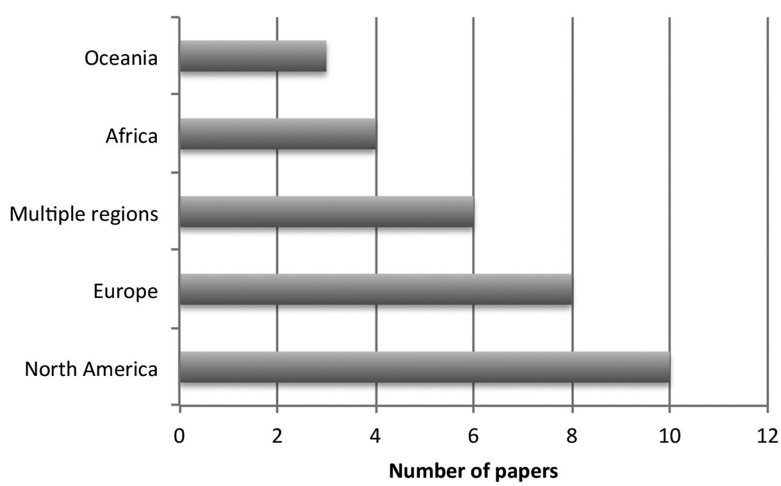

FIGURE 2 Primary geographic focus of the short-listed literature

levels of attention, with a single paper focused primarily at the municipal level. No papers focus on the supranational scale (see Supplemental Material Section S2 for definitions and further details).

Of the 31 articles that progressed to full data extraction, 30 were qualitative empirical studies, drawing on a variety of methods from across the social sciences. Only one quantitative assessment went to data extraction. 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 use information, as well as disciplines engaged in these topics.

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

All 31 papers cite at least one constraining or enabling factor that affects the use of climate information in decision-making, with many papers listing several. To synthesize the range of different factors, we cluster both constraints and enablers into five categories. These are used primarily for heuristic purposes.

3.2.1. Constraints

Ten individual constraints to the uptake of climate information in decision–making processes are identified in the literature (see Table 2). We grouped these into five overarching categories: disconnects between producers and users of climate information; limitations of climate science; financial and technical constraints; political economy and institutional constraints; and psycho-social constraints. The frequency of papers giving mention to each constraint and the categories assigned to them are detailed in Figure 3.

3.2.1.1. Disconnect between producers and users of climate information

The first category of constraint pertains to a disconnect between the producers and users of climate information. This is characterized by the inability of climate information to match the perceived informational needs of decision makers; communication challenges; and a lack of effective boundary organizations to broker, translate and facilitate engagements between relevant stakeholders (see Table 2).

(i) *Utility and relevance of climate information*

One of the primary constraints is a mismatch between perceived informational needs of decision makers and the ability of climate information to address them. 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 most investment 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 is likely to be low (Bryson et al., 2010). In the context of developing countries, this lack of relevance stems, in part, from the fact that those most vulnerable to the impacts of climate change are rarely involved in the production of climate information itself, thereby reducing ownership and limiting buy-in amongst key decision makers (Bremond, 2014). For example, the funding of climate information is often oriented towards addressing fundamental knowledge gaps in atmospheric dynamics rather than addressing the specific climate information needs identified by decision makers (Ziervogel and Zermoglio 2009).

TABLE 2 Constraints identified in the literature.

Category	Constraints	Summarized 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 between producers and users of climate information	Low accessibility of climate information. Formats and knowledge platforms are not always user-friendly Lack of collaboration and interaction between the 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 and 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	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 utilize available climate information in decision-making processes, particularly relating to associated uncertainties
1.4. Political economy and 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 multidecadal 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

Continued

TABLE 2 Continued

Category	Constraints	Summarized details
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

(ii) *Communication challenges between the producers and users of climate information*

Poor communication between producers and users of climate information hinders uptake at all stages of the decision making process (O'Toole and Coffey, 2013; Ryghaug, 2011; Ziervogel and Zermoglio, 2009). The literature identifies three distinct communication challenges: low accessibility to

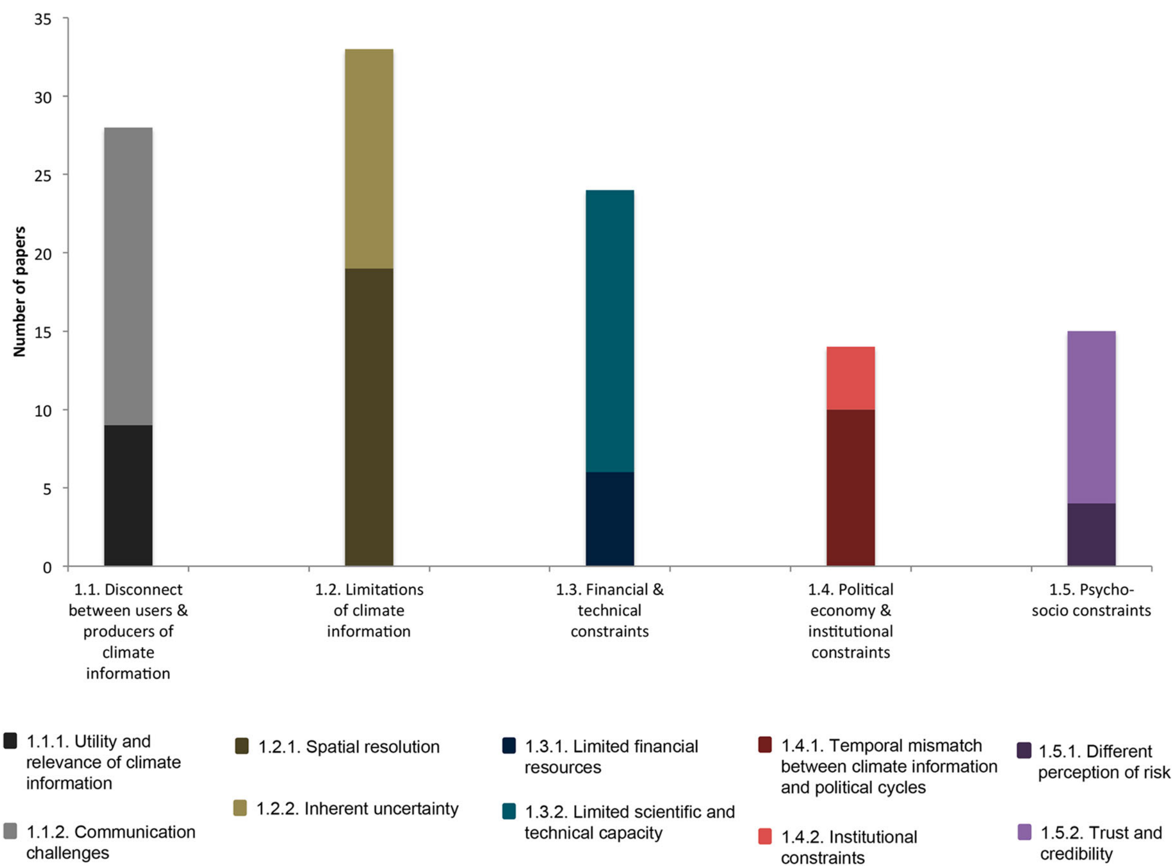

FIGURE 3 Number of papers per category of constraint. *Notes*: Categories are comprised of more than one constraint. It is therefore possible for a paper to feature more than once in any single category.

climate information; difficulties in translating climate information into actionable guidance for decision makers; and a lack of collaborative interaction between scientists and policy makers (Camp et al., 2013).

First, existing dissemination channels for 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 the available climate information (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 the capacity to communicate their results in formats that are accessible and comprehensible to decision makers, many of whom may not be accustomed to interpreting scientific output (Romsdahl, 2011). There is often a problem of poor translation of science outputs into practical measures, accompanied by the complexity and political economy of decision-making processes (Viviroli et al., 2011). The existence of a multitude of knowledge portals and data repositories for the dissemination and communication of climate information further underscores the lack of user-friendly applications and thus the difficulties decision makers have in knowing where to turn for reliable information (Agrawala et al., 2012; Barron et al., 2012).

Finally, the literature suggests that the lack of collaborative interaction between scientists and policy makers acts as a considerable constraint to effective communication of long-term climate information (Lemos and Rood 2010). The absence of effective boundary agents limits two-way communication and makes it difficult for producers and users of climate information to engage with one another (Ryghaug, 2011; Srinivasan et al., 2011a; Ziervogel and Zermoglio, 2009a).

3.2.1.2. Limitations of climate information

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

(i) *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. High computational demands and uncertainties in our understanding of the climate system limit our ability to simulate climate processes at higher resolutions. Although GCM outputs are useful in understanding the general characteristics of the overall climate, they are far removed from the scale and accuracy needed to inform local decision-making (Ziervogel and Zermoglio, 2009).

High-resolution downscaling techniques, both dynamical and statistical, are in high demand due to their perceived utility in informing locally-relevant decision-making. Given the high computational demands and technical requirements, statistical downscaling is currently more common – particularly in developing country contexts. However, large uncertainties persist in either approach (David et al., 2013; Yousefpour et al., 2013; Ziervogel and Zermoglio, 2009). Because dynamical and statistical downscaling both draw directly from global model outputs, regional climate models have many of the same biases with no greater accuracy (Agrawala et al., 2012; 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 derived outputs (Camp et al., 2013; David et al., 2013).

(ii) *Inherent uncertainty of climate information and inherent complexity of the climate system*

The majority of articles cited complexities associated with generating climate information – and communicating the uncertainties that go with it – as an impediment to uptake of climate information (Kirchhoff et al., 2013b; O'Toole and Coffey, 2013). After several scenario exercises in the UK Climate Impacts Programme (UKCIP), uncertainties linked to modelling outputs and scenarios were identified as 'a major barrier to the application of climate change information for decision-making' (Gawith et al. 2009, p.116). Much of this relates to the inability of climate information to inform many local investment trade-offs, because decision makers often call for high levels of certainty in weighing the implications of future options and conveying the nature of the uncertainties is often difficult for scientists. Decision makers' desire for certainty also encourages misrepresentation and misunderstanding of uncertainty in climate outputs, masking the true levels of uncertainty associated with future projections. The difficulty of communicating large uncertainties to investors and planners can even lead to the omission of climate information from decision-making processes altogether (Kirchhoff et al., 2013b).

3.2.1.3. Financial and technical constraints

(i) *Limited financial resources*

As previously mentioned, dynamical downscaling of climate data to regional and local scales is computationally expensive. Although statistical downscaling can be accomplished at a lower cost (Lawrence et al., 2013), the process often requires accurate and lengthy records of observational data. This is not always readily available, especially in developing countries. Methods for generating relevant information to guide adaptation planning are therefore constrained by financial resources and the available historical data. This limits access to high-resolution outputs for low-income regions, such as sub-Saharan Africa and South Asia, hindering decision makers' ability to use finer spatial resolutions (Agrawala and van Aalst, 2008). Similar challenges exist in securing the resources to maintain observational networks and to support integrated assessment modelling (IAM).

(ii) *Limited scientific and technical capacity*

The complexity of climate information requires strong scientific capacity to interpret and analyse the associated outputs. It also requires technical capacity to communicate the relevant information to decision makers in a manner that is both easily interpretable and does not sacrifice the integrity of the underlying science (Ziervogel and Zermoglio, 2009). Decision makers also need support in understanding the merits and limitations of utilizing climate information. Failure to acknowledge and address these challenges may lead to the misinterpretation of climate information or the under/overestimation of uncertainty and future risks (Romsdahl, 2011).

3.2.1.4. Political economy and institutional constraints

(i) *Temporal mismatch between climate information and political cycles*

Another impediment to the use of climate information is the fact that the time horizons associated with multidecadal 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' (Gawith et al., 2009, p. 120; see also Agrawala et al., 2012; Agrawala and van Aalst, 2008; Bryson et al. 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 interests (Agrawala and van Aalst, 2008; Ziervogel and Zermoglio, 2009). As a result, the implications of the long-term costs (or benefits) are often disregarded or left for consideration at a later stage in the policy cycle (Bryson et al., 2010).

(ii) *Institutional constraints*

Organizational cultures and institutional settings influence the way decisions are made and implemented. The use of climate information in decision-making may be hampered by competing institutional mandates, overlapping jurisdictions and budgets, overly complex bureaucracy and limited flexibility (Lemos and Rood 2010). Some institutions are reluctant to use new knowledge sources and prefer to rely on proven sources to guide their decisions. Others accept that climate risks are likely to change, but downplay the need to address them, placing higher priority on other financial and socio-economic concerns (Lemos and Rood 2010).

3.2.1.5. Psycho-social constraints

The fifth category is psycho-social constraints, namely: differences in the perceived level of future climate risk, and a perceived lack of trust in the credibility of climate information.

(i) *Different perceptions of risk*

Risk perception is a key driver of institutional and political change. Recognizing wider social and political pressures, decision makers must estimate the likelihood that future risks will affect investment and planning decisions based on the best available knowledge. Low levels of perceived risk can therefore contribute to inaction or the prioritization of other risks ahead of climate adaptation. Such differences, alongside institutional values, can prevent climate information from being acted on when considered alongside other competing economic and social concerns (Runhaar et al., 2012). Assessing adaptation policy in the Netherlands, Runhaar et al. (2012) describe how decisive action was prevented by disparities between decision makers and scientists regarding the urgency of addressing the risks associated with future flooding and heat stress.

(ii) *Trust and credibility*

Finally, a perceived lack of credibility of climate information can prevent decision makers from using and acting on available knowledge (Kirchhoff et al., 2013b). 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 trust in climate science amongst water resource managers in Brazil and the US (Kirchhoff et al., 2013b). A failure to address credibility constraints widens the knowledge gap and can trigger greater resistance between producers and users of climate information (Lemos and Rood, 2010; Romsdahl, 2011).

3.2.2. Enablers to the uptake of long-term climate information

The literature also identifies enabling factors that enhance the use of climate information. Many of the enablers inevitably correspond with constraints listed in Supplemental Section B1. However, in seeking to maintain objectivity within thematic clustering we categorize the enabling factors independently of the constraints identified earlier.

Twenty-four of the 31 short-listed papers present at least one enabler, and many papers present several. The enabling factors are classified into five overarching categories: collaboration and bridging work; enhanced technical capacity; improvements in underlying science; institutional reform; and windows of opportunity and trust. The largest category by far is 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 4). Table 3 presents a summary of the categories and the enabling factors that fall under each.

3.2.2.1. Collaboration and bridging work

A majority of the papers highlights the significant benefits in bringing different stakeholders together to promote the uptake of 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,

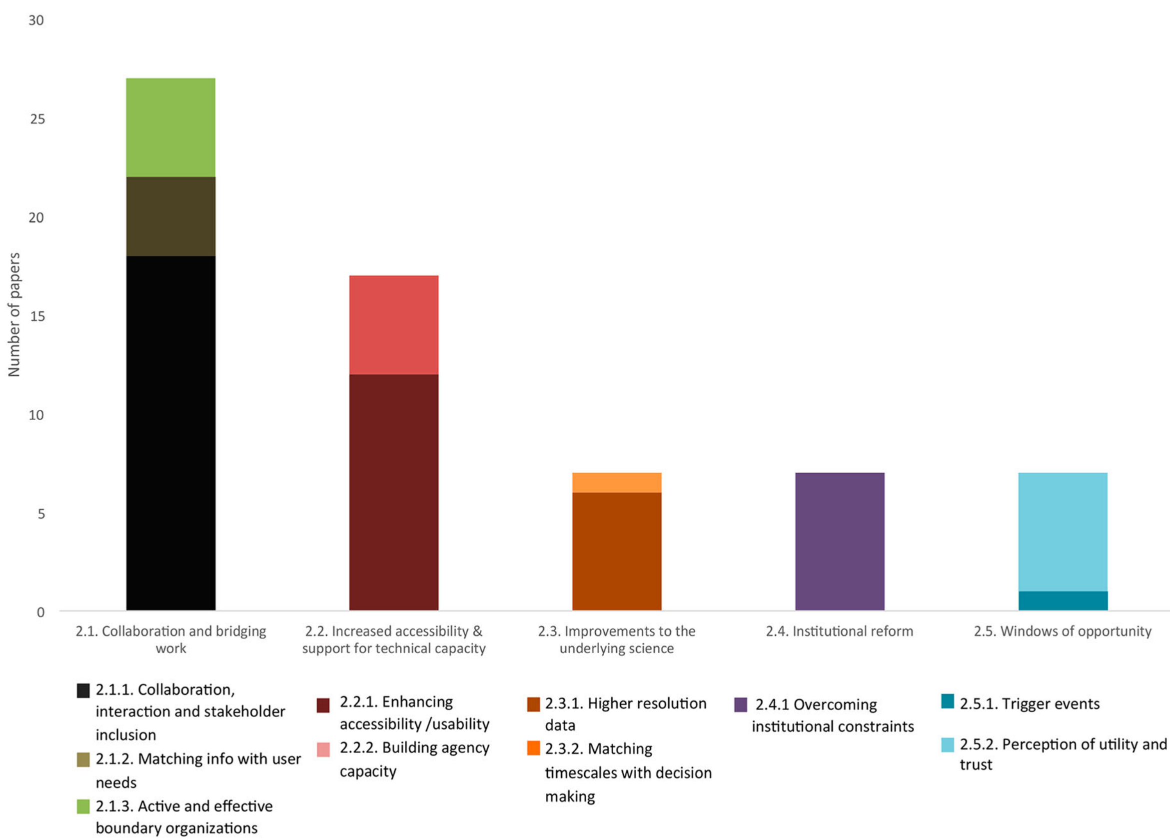

FIGURE 4 Number of papers per category of enabler.*Notes*: Categories are comprised of more than one enabler. It is therefore possible for a paper to feature more than once in any single category.

Table 3. Enabling factors identified in the literature.

Category	Enablers	Summarized 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. Active and effective boundary organizations	Effective boundary organizations or agents can bridge gaps and help translate information
2.2. Increased accessibility of climate information and support for the technical capacity to use it	2.2.1. Enhancing 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. Building agency capacity	Available in-house expertise and capacity to make use of climate information
2.3. Improvements to the underlying science	2.3.1. high-resolution data	Provision and use of high-resolution data tailored to the specific informational needs of decision makers
	2.3.2. Matching timescales with decision-making	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
2.5. 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 utility and trust	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

and promote co-production of knowledge. This category is made up of three individual enablers, consisting of: collaboration, interaction and stakeholder inclusion; matching information with user needs; and active and effective boundary organizations and agents.

(i) *Collaboration, interaction and stakeholder inclusion*

The successful uptake of climate information is often predicated on sustained interaction and engagement between information producers (climate scientists and other researchers) and decision makers who use information (whether governments, NGOs 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 long-term climate information (Berkhout et al., 2014; Corburn, 2009; Kirchhoff et al., 2013b). In particular, participatory engagement processes to bring stakeholders together encourage greater collaboration and lead to more 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; Ziervogel and Zermoglio, 2009).

> Valuable insights on success and challenges of transitioning climate information via collaboration or participatory efforts can be found throughout the science-policy literature and they echo what the interview participants in this study highlighted as important factors for decision support: increase capacity for understanding the science, increase awareness, ensure information is relevant, address location specific needs, communicate uncertainty levels, and develop translators or bridgers between science and decision-makers. Romsdahl (2011, p.526)

Trust was also a critical factor in the use of climate information for adaptation planning and decision-making (Barron et al., 2012; Burch et al., 2010). Although difficult to prove empirically, a common notion is that trust is built through effective and recurring engagement between users and producers. However, it is important to note that stakeholder participation cannot be viewed as a panacea (Kasperson 2006, in Romsdahl 2011).

(ii) *Matching information with user needs*

The uptake of climate information can be supported by matching it with specific user needs. This can only be done through interaction between producers and users to define the most relevant question for their needs (Berkhout et al., 2014; Jenni et al., 2014). For example, climate information producers can gain a better understanding of what information will best support decision makers, as well as appreciating the political and socio-economic context within which decisions are taken. In turn, decision makers can better articulate their information needs while recognizing the limitations of the available science (Berkhout et al., 2014). These processes require collaborative engagement between all of the relevant stakeholders (Déandreis et al., 2014).

(iii) *Active and effective boundary organizations*

Effective boundary organizations can help to facilitate mutual understanding between different stakeholders and improve the uptake of climate information. Such boundary organizations span research, policy and practice, helping to perform a number of important roles including: convening different stakeholders, producing and translating research outputs into forms that are more easily usable and mediating conflicts that arise between stakeholders (Kirchhoff et al., 2013b). Most importantly, boundary organizations can help to increase the uptake of climate information by customizing the information to the expressed needs of users through deeper understandings of decision-making contexts (Lemos and Rood 2010).

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

The second largest category of enablers relates to decision makers' access and use of climate information. Improved accessibility to climate information and support for the technical capacity to use it can be significant enabling factors for promoting uptake (see overlaps with constraints in Section 3.2.1).

(i) *Enhancing accessibility/usability*

There are various ways to enhance the accessibility and usability of climate information, including making it available in a range of different languages, encouraging it to be shared across different communication channels and ensuring that information and policy advice is interpretable by the appropriate audience (Lemos and Rood 2010; Romsdahl 2011). Above all, climate information producers, boundary agents and knowledge brokers should be aware of the needs, technical capacities and interests of end users. For example, the communication of climate information is often reliant on scientific terminology and technical figures. This can render information inaccessible to many decision makers who are unfamiliar with technical outputs or the assumptions that underlie their production (Girvetz et al., 2014).

(ii) *Building agency capacity*

The ability of organizations and institutions to apply climate information is a key factor in promoting its uptake within operational decision-making (Romsdahl 2011). Improving understanding of the underlying climate system and the probable social impacts of climate change is likely to be useful, but climate information will be effectively embedded within core decision-making processes only if investments are made in organizations' capacities to access, interpret and make use of it (Romsdahl 2011).

3.2.2.3. Improvements to the underlying science

This category relates to improvements in the underlying basis of climate science. Two enablers stand out: high-resolution data and matching timescales with decision-making.

(i) *High-resolution data*

The ability to produce information at appropriate resolutions for use in local and regional decision-making is an enabling factor for informed decision-making (Gawith et al., 2009; Runhaar et al., 2012; Ziervogel and Zermoglio, 2009). In studying the UKCIP program and its UKCIP02 scenarios, Gawith et al. (2009) provide evidence that high-resolution data (compared with the 1998 scenarios from the same program) increased the use of the information among professionals in the UK construction sector. Users were able to apply high-resolution information to their specific location and evaluate the implications of temperature changes on building design. Despite the advantages it offers, it must be recognized that high-resolution climate information still comes with many technical limitations that impede its utility to inform local decision-making processes and there may be thresholds beyond which an increase in resolution is no longer beneficial to decision makers – see section 3.2.1.2.(i).

ii) *Matching timescales with decision-making*

A temporal mismatch between decision makers' interests and the timescales associated with climate information was identified as a constraint to climate information uptake in multiple papers – see section 1.4.1. Only one article – Gawith et al., (2009) – documents successful efforts to align these timeframes. One of the tools developed within the UKCIP program is the Local Climate Impacts Profile (LCLIP), an approach that helps local authorities to 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 explores the projections of the likelihood of such events occurring during a future timeframe chosen by the decision makers. For example, an LCLIP developed by the Oxfordshire County Council focused on the projection of high-temperature days in the 2020s and the possible effects on summer road maintenance. The 2020s was chosen because it was most closely aligned with the county's planning timescale (Gawith et al., 2009). Ideally, climate information producers should work with the potential users to create products that match the decision makers' needs and better align with the policy-making cycle, although we recognize that this is not always an attainable goal.

3.2.2.4. Institutional reform

Institutional reform and overcoming institutional constraints are important factors for increasing the uptake of climate information. Identifying enablers to overcoming institutional constraints is difficult, primarily as many are context specific. However, organizations that improve human or technical capacity, or engage in flexible and iterative decision-making, are likely to be better able to make use of climate information (Kirchhoff et al., 2013b). From a research perspective, collaboration between scientists and researchers from a range of different disciplines can help to foster a greater understanding of user needs and enable climate information producers to generate more usable formats (Burch et al., 2010). Finding the appropriate entry point for policy engagement is also key. In reviewing how climate change adaptation can be integrated into sectoral development, 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.

3.2.2.5. Windows of opportunity, perceived utility and trust

This category focuses on the timing of change and the perceptions of information used to bring about the transition. It is the smallest of the five categories, and there are few examples within the 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 category.

(i) *Trigger event*

Kirchhoff et al. (2013b) found that the occurrence of an extreme event, such as drought, can trigger increased requests for climate information. However, this heightened use of climate information fades after the extreme event passes, suggesting a limited window of opportunity for effective dissemination. These findings suggest that '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, p.12). Climate information producers may therefore be able to capitalize on trigger events and take advantage of particular windows of opportunity when they arise.

(ii) *Perceptions of utility and trust*

This last enabler deals with how decision makers view climate information. There is a need to create greater trust between decision makers and climate information producers. Trusting climate scientists helps policy makers and planners view climate information as useful for their decision-making and increases their willingness to adopt it (Barron et al. 2012). 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 (Barron et al. 2012).

4. Discussion

Before drawing wider conclusions, we first highlight four observations regarding our findings. The first observation is that evidence of constraints is generally better documented than evidence of enablers. This emerges from several interrelated factors. The practical introduction of climate information into long-term planning processes is in its infancy. It is expected that there are more cases documenting struggles than successes. Thus, the efforts to integrate climate information into decision-making encounter challenges that are immediately observable and more easily documentable. However, there are fewer cases where the identified enabling factors are directly documented based on the successful application of climate information (Barron et al., 2012; Corburn 2009; Jenni et al., 2014; Romsdahl 2011). In many cases, the enabling factors identified are practical responses to the observed and experienced challenges (de Bremond et al. 2014; Camp et al., 2013; David et al., 2013; Runhaar et al., 2012; Srinivasan et al., 2011). In other words, they are simply proposed solutions to constraints. As such, when compared with constraints, enabling factors are not as robustly established by the empirical data, but remain at least partly hypothetical. Future studies of the integration of climate information into policy and planning processes would benefit from greater clarity and precision in distinguishing between observed and hypothesized constraints and enablers. This would help to strengthen the empirical foundations, and thus the credibility, of the field.

Second, although we limited our review to the use of long-term climate information and excluded research on short-term climate forecasts, the emergent constraints and enablers heavily overlap with those found in the literature on the uptake of weather information and seasonal forecasting (see Crane et al., 2010; Dilling and Lemos 2011; Kirchhoff et al., 2013a; Lemos and Rood, 2010; Pulwarty and Redmond, 1997; Vogel and O'Brien, 2006), along with more general efforts to get science outputs taken up by policy makers (see Cash, 2001; Cash et al., 2003; McNie, 2007). Although the two domains draw on different kinds of climate information and are typically oriented towards different kinds of decisions and decision makers, both appear to involve similar issues, however this could result from repetition of the same conventional wisdom as much as from empirical observation. The issues 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 seasonal and long-term climate information appears to be associated with co-production processes that involve iterative communication between scientists and decision makers, boundary actors, carefully tailored information and the willingness of both scientists and decision makers to move out of their institutional and informational comfort zones (Dilling & Lemos 2011; Lemos & Morehouse 2005). Accordingly, actors seeking to promote more effective use of long-term climate information may benefit substantially from the lessons learned in overcoming constraints to the uptake of information on shorter timescales. This is particularly relevant given the relative maturity of seasonal climate forecasting (in both research and practical application), as well as recent gains in improving communication, dissemination channels and the use of short-term climate information in decision-making (Goddard et al., 2010; Tall et al., 2012).

Third, 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 developed countries. The paucity of cases from developing countries may reflect a number of factors. Decision makers in developing countries are often less likely to use climate information to guide investments and plans, owing to the immediacy of basic development needs as well as a lack of technical capacity to integrate climate information into decision-making processes (Agrawala & van Aalst, 2008; Jones et al., 2015b). In addition, a weaker research capacity and fewer resources could be a barrier – resulting in a lower likelihood of research being carried out on the uptake of climate information in developing countries and subsequently being featured within peer-reviewed literature (Girvetz et al., 2014).

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

5. Conclusion

The literature showcases the diversity of challenges facing stakeholders who are engaged in the science–policy interface. Although the many constraints may appear overwhelming, the literature collectively suggests that they are not insurmountable. Clearly more needs to be done to advance our understanding of the climate system and the probable impacts of climate change on people and communities on long-term timescales. However, promoting the uptake of climate information is only marginally about improving basic climate science; many of the biggest constraints relate to how political economy and institutional factors affect decision-making. The results of this structured review highlight that uncertainty of institutional mandates, organizational structures and a lack of adequate incentives can act as concrete impediments to science uptake. They also limit the ability of knowledge brokers to effectively engage in decision-making processes.

Not every decision requires long-term climate information in order for successful outcomes to be achieved (Jones et al., 2015b). Rather, care should be taken to ensure that information is targeted towards investments and planning decisions that are relevant at longer-term timescales, either where infrastructure and impacts on livelihoods are felt long after the cycle of the intervention project 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 costs of retrofitting, such as long-lived infrastructural investments or urban planning.

Finally, 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 the 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. Investing time and resources in understanding the local political context and engaging with national and local partners can therefore help to promote both more effective communication and greater use of climate information. Above all, more needs to be done to ensure the co-production of knowledge between producers and users of long-term climate information.

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Supplemental material

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References

Agrawala, S., Matus Kramer, A., Prudent-Richard, G., Sainsbury, M., & Schreitter, V. (2012). Incorporating climate change impacts and adaptation in environmental impact assessments: Opportunities and challenges. *Climate and Development*, *4*, 26–39. doi:10.1080/17565529.2011.628791

Agrawala, S., & van Aalst, M. (2008). Adapting development cooperation to adapt to climate change. *Climate Policy*, *8*, 183–193. doi:10.3763/cpol.2007.0435

Barnett, J., & O'Neill, S. (2010). Maladaptation. *Global Environmental Change*, *20*, 211–213. doi:10.1016/j.gloenvcha.2009.11.004

Barron, S., Canete, G., Carmichael, J., Flanders, D., Pond, E., Sheppard, S., & Tatebe, K. (2012). A climate change adaptation planning process for low-lying, communities vulnerable to sea level rise. *Sustainability*, *4*, 2176–2208. doi:10.3390/su4092176

Berkhout, F., van den Hurk, B., Bessembinder, J., de Boer, J., Bregman, B., & van Drunen, M. (2014). Framing climate uncertainty: socio-economic and climate scenarios in vulnerability and adaptation assessments. *Regional Environmental Change*, *14*, 879–893. doi:10.1007/s10113-013-0519-2

Berrang-Ford, L., Ford, J. D., & Paterson, J. (2011). Are we adapting to climate change? *Global Environmental Change*, *21*, 25–33. doi:10.1016/j.gloenvcha.2010.09.012

Bremond, A. (2014). Improving the usability of integrated assessment for adaptation practice: Insights from the U.S. Southeast energy sector. *Environmental Science & Policy*, *42*, 45–55. doi:10.1016/j.envsci.2014.05.004

Bryson, J., Piper, J., & Rounsevell, M. (2010). Envisioning futures for climate change policy development: Scenarios use in European environmental policy institutions. *Environmental Policy and Governance*, *20*, 283–294. doi:10.1002/eet.542

Burch, S., Sheppard, S. r. j., Shaw, A., & Flanders, D. (2010). 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*, *3*, 126–139. doi:10.1111/j.1753-318X.2010.01062.x

Camp, J., Abkowitz, M., Hornberger, G., Benneyworth, L., & Banks, J. (2013). Climate change and freight-transportation infrastructure: current challenges for adaptation. *Journal of Infrastructure Systems*, *19*, 363–370. doi:10.1061/(ASCE)IS.1943-555X.0000151

Cash, D. W. (2001). "In order to aid in diffusing useful and practical information": Agricultural extension and boundary organizations. *Science, Technology and Human Values*, *26*, 431–453. doi:10.1177/016224390102600403

Cash, D. W., Clark, W. C., Alcock, F., Dickson, N. M., Eckley, N., Guston, D. H., … Mitchell, R. B. (2003). Knowledge systems for sustainable development. *Proceedings of the National Academy of Sciences of the United States of America*, *100*, 8086–8091. doi:10.1073/pnas.1231332100

Corburn, J. (2009). Cities, climate change and urban heat island mitigation: Localising. *Global Environmental Science Urban Studies*, *46*, 413–427. doi:10.1177/0042098008099361

Crane, T. A., Roncoli, C., Paz, J., Breuer, N., Broad, K., Ingram, K. T., & Hoogenboom, G. (2010). Forecast skill and farmers' skills: Seasonal climate forecasts and agricultural risk management in the southeastern United States. *Weather Climate and Society*, *2*, 44–59. doi:10.1175/2009WCAS1006.1

David, A., Braby, J., Zeidler, J., Kandjinga, L., & Ndokosho, J. (2013). Building adaptive capacity in rural Namibia. *International Journal of Climate Change Strategies and Management*, *5*, 215–229. doi:10.1108/17568691311327604

Déandreis, C., Pagé, C., Braconnot, P., Bärring, L., Bucchignani, E., Cerff, W.S.d., … Pieger, M. (2014). Towards a dedicated impact portal to bridge the gap between the impact and climate communities: Lessons from use cases. *Climatic Change*, *125*, 333–347. doi:10.1007/s10584-014-1139-7

Delaney, A., Chesterman, S., Crane, T. A., Tamas, P. A., & Ericksen, P. (2014). *A systematic review of local vulnerability to climate change: in search of transparency, coherence and comparability* (Working Paper No. 97). Copenhagen: CCAFS.

Dey, I. (2003). *Qualitative data analysis: A user friendly guide for social scientists*. London: Routledge.

Dilling, L., & Lemos, M. C. (2011). Creating usable science: Opportunities and constraints for climate knowledge use and their implications for science policy. *Global Environmental Change*, *21*, 680–689. doi:10.1016/j.gloenvcha.2010.11.006

Ford, J. D., & Pearce, T. (2010). What we know, do not know, and need to know about climate change vulnerability in the western Canadian Arctic: A systematic literature review. *Environmental Research Letters*, *5*, 014008. doi:10.1088/1748-9326/5/1/014008

Gawith, M., Street, R., Westaway, R., & Steynor, A. (2009). Application of the UKCIP02 climate change scenarios: Reflections and lessons learnt. *Global Environmental Change*, *19*, 113–121. doi:10.1016/j.gloenvcha.2008.09.005

Girvetz, E. H., Gray, E., Tear, T. H., & Brown, M. A. (2014). Bridging climate science to adaptation action in data sparse Tanzania. *Environmental Conservation*, *41*, 229–238. doi:10.1017/S0376892914000010

Goddard, L., Aitchellouche, Y., Baethgen, W., Dettinger, M., Graham, R., Hayman, P., … Meinke, H. (2010). Providing seasonal-to-interannual climate information for risk management and decision making. *Procedia Environmental Sciences 1*, 81–101. doi:10.1016/j.proenv.2010.09.007

Hallegate, S., Shah, A., Brown, C., Lempert, R., & Gill, S. (2012). *Investment decision making under deep uncertainty: Application to climate change* (Policy Research Working Paper No.). Washington, DC: The World Bank.

Hansen, J. W., Mason, S. J., Sun, L., & Tall, A. (2011). Review of seasonal climate forecasting for agriculture in sub-Saharan Africa. *Experimental Agriculture*, *47*, 205–240. doi:10.1017/S0014479710000876

Hegger, D., Zeijl-Rozema, A. V., & Dieperink, C. (2014). Toward design principles for joint knowledge production projects: Lessons from the deepest polder of The Netherlands. *Regional Environmental Change*, *14*, 1049–1062. doi:10.1007/s10113-012-0382-6

Jenni, K., Graves, D., Hardiman, J., Hatten, J., Mastin, M., Mesa, M., ... Maule, A. (2014). Identifying stakeholder-relevant climate change impacts: A case study in the Yakima River Basin, Washington, USA. *Climatic Change*, *124*, 371–384. doi:10.1007/s10584-013-0806-4

Jones, L., Carabine, E., Roux, J., & Tanner, T. (2015a). *Promoting the use of climate information to achieve long-term development objectives in sub-Saharan Africa: Results from the future climate for Africa scoping phase*. London: Climate and Development Knowledge Network.

Jones, L., Dougill, A., Jones, R. G., Steynor, A., Watkiss, P., Kane, C., ... Roux, J. P. (2015b). Ensuring climate information guides long-term development. *Nature Climate Change*, *5*, 812–814.

Kasperson, R. E. (2006). Editorial: rerouting the stakeholder express. *Global Environtal Change*, *16*, 320–322.

Kirchhoff, C. J., Carmen Lemos, M., & Dessai, S. (2013a). Actionable knowledge for environmental decision making: broadening the usability of climate science. *Annual Review of Environment and Resources*, *38*, 393–414. doi:10.1146/annurev-environ-022112-112828

Kirchhoff, C. J., Lemos, M. C., & Engle, N. L. (2013b). What influences climate information use in water management? The role of boundary organizations and governance regimes in Brazil and the U.S. *Environmental Science & Policy*, *26*, 6–18. doi:10.1016/j.envsci.2012.07.001

Lawrence, J., Reisinger, A., Mullan, B., & Jackson, B. (2013). Exploring climate change uncertainties to support adaptive management of changing flood-risk. *Environmental Science & Policy*, *33*, 133–142. doi:10.1016/j.envsci.2013.05.008

Lemos, M. C., Kirchhoff, C. J., Ramprasad, V. (2012). Narrowing the climate information usability gap. *Nature Climatic Change*, *2*, 789–794. doi:10.1038/nclimate1614

Lemos, M. C., & Morehouse, B. J. (2005). The co-production of science and policy in integrated climate assessments. *Global Environmental Change*, *15*, 57–68. doi:10.1016/j.gloenvcha.2004.09.004

Lemos, M. C., & Rood, R. B. (2010). Climate projections and their impact on policy and practice. *WIREs Climate Change*, *1*, 670–682. doi:10.1002/wcc.71

Marshall, N. A., Gordon, I. J., & Ash, A. J. (2011). The reluctance of resource-users to adopt seasonal climate forecasts to enhance resilience to climate variability on the rangelands. *Climatic Change*, *107*, 511–529. doi:10.1007/s10584-010-9962-y

Mase, A. S., & Prokopy, L. S. (2013). Unrealized potential: A review of perceptions and use of weather and climate information in agricultural decision making. *Weather Climate and Society*, *6*, 47–61. doi:10.1175/WCAS-D-12-00062.1

McNie, E. (2007). Reconciling the supply of scientific information with user demands: An analysis of the problem and review of the literature. *Environmental Science & Policy*, *10*, 17–38. doi.org/10.1016/j.envsci.2006.10.004

Moser, S. C., & Ekstrom, J. A. (2010). A framework to diagnose barriers to climate change adaptation. *Proceedings of the National Academy of Sciences of the United States of America*, *107*, 22026–22031. doi:10.1073/pnas.1007887107

O'Toole, K., & Coffey, B. (2013). Exploring the knowledge dynamics associated with coastal adaptation planning. *Coastal Management*, *41*, 561–575. doi:10.1080/08920753.2013.848747

Picketts, I. M., Curry, J., Déry, S. J., & Cohen, S. J. (2013). Learning with practitioners: Climate change adaptation priorities in a Canadian community. *Climatic Change*, *118*, 321–337. doi:10.1007/s10584-012-0653-8

Pozzi, W., Sheffield, J., Stefanski, R., Cripe, D., Pulwarty, R., Vogt, J. V., . . . Lawford, R. (2013). Toward global drought early warning capability: Expanding international cooperation for the development of a framework for monitoring and forecasting. *Bulletin of the American Meteorological Society*, *94*, 776–785. doi:10.1175/BAMS-D-11-00176.1

Pulwarty, R. S., & Redmond, K. T. (1997). Climate and salmon restoration in the Columbia River Basin: The role and usability of seasonal forecasts. *Bulletin of the American Meteorological Society*, *78*, 381–397.

Ranger, N. (2013). *Topic guide. Adaptation: Decision making under uncertainty*. London: Evidence on Demand.

Ranger, N., & Garbett-Shiels, S.-L. (2012). Accounting for a changing and uncertain climate in planning and policymaking today: Lessons for developing countries. *Climate and Development*, *4*, 288–300. doi:10.1080/17565529.2012.732919

Romsdahl, R. J. (2011). Decision support for climate change adaptation planning in the US: Why it needs a coordinated internet-based practitioners' network. *Climatic Change*, *106*, 507–536. doi:10.1007/s10584-010-9947-x

Runhaar, H., Mees, H., Wardekker, A., Sluijs, J. van der, & Driessen, P. P. J. (2012). Adaptation to climate change-related risks in Dutch urban areas: Stimuli and barriers. *Regional Environmental Change*, *12*, 777–790. doi:10.1007/s10113-012-0292-7

Ryghaug, M. (2011). Obstacles to sustainable development: The destabilization of climate change knowledge. *Sustainable Development*, *19*, 157–166. doi:10.1002/sd.431

Siregar, P. R., & Crane, T. A. (2011). Climate information and agricultural practice in adaptation to climate variability: The case of climate field schools in Indramayu, Indonesia. *CAFÉ*, *33*, 55–69. doi:10.1111/j.2153-9561.2011.01050.x

Srinivasan, G., Rafisura, K. M., & Subbiah, A. R. (2011). Climate information requirements for community-level risk management and adaptation. *Climate Research*, *47*, 5–12.

Tall, A., Mason, S. J., van Aalst, M., Suarez, P., Ait-Chellouche, Y., Diallo, A. A., & Braman, L. (2012). Using seasonal climate forecasts to guide disaster management: The red cross experience during the 2008 West Africa floods. *International Journal of Geophysics*, *2012,* e986016. doi:10.1155/2012/986016

Thomson, M. C., Doblas-Reyes, F. J., Mason, S. J., Hagedorn, R., Connor, S. J., Phindela, T., . . . Palmer, T. N. (2006). Malaria early warnings based on seasonal climate forecasts from multi-model ensembles. *Nature*, *439*, 576–579. doi:10.1038/nature04503

Viviroli, D., Archer, D. R., Buytaert, W., Fowler, H. J., Greenwood, G. B., Hamlet, A. F., . . . Woods, R. (2011). Climate change and mountain water resources: Overview and recommendations for research, management and policy. *Hydrology and Earth System Science*, *15*, 471–504. doi:10.5194/hess-15-471-2011

Vogel, C., & O'Brien, K. (2006). Who can eat information? Examining the effectiveness of seasonal climate forecasts and regional climate-risk management strategies. *Climate Research*, *33*, 111–122. doi:10.3354/cr033111

Wilby, R. L., Troni, J., Biot, Y., Tedd, L., Hewitson, B. C., Smith, D. M., & Sutton, R. T. (2009). A review of climate risk information for adaptation and development planning. *International Journal of Climatology*, *29*, 1193–1215. doi:10.1002/joc.1839

WRI. (2011). *World resources 2010–2011: Decision making in a changing climate—Adaptation challenges and choices*. Washington, DC: World Resources Institute.

Yousefpour, R., Temperli, C., Bugmann, H., Elkin, C., Hanewinkel, M., Meilby, H., . . . Thorsen, B. J. (2013). Updating beliefs and combining evidence in adaptive forest management under climate change: A case study of Norway spruce (*Picea abies* L. Karst) in the Black Forest, Germany. *Journal of Environmental Management*, *122*, 56–64. doi:10.1016/j.jenvman.2013.03.004

Ziervogel, G., & Calder, R. (2003). Climate variability and rural livelihoods: Assessing the impact of seasonal climate forecasts in Lesotho. *Area*, *35*, 403–417. doi:10.1111/j.0004-0894.2003.00190.x

Ziervogel, G., & Zermoglio, F. (2009). Climate change scenarios and the development of adaptation strategies in Africa: Challenges and opportunities. *Climate Research*, *40*, 133–146.