

# Explaining and overcoming barriers to climate change adaptation

Klaus Eisenack<sup>1\*</sup>, Susanne C. Moser<sup>2</sup>, Esther Hoffmann<sup>3</sup>, Richard J. T. Klein<sup>4,5</sup>, Christoph Oberlack<sup>6</sup>, Anna Pechan<sup>1</sup>, Maja Rotter<sup>7</sup> and Catrien J. A. M. Termeer<sup>8</sup>

**The concept of barriers is increasingly used to describe the obstacles that hinder the planning and implementation of climate change adaptation. The growing literature on barriers to adaptation reveals not only commonly reported barriers, but also conflicting evidence, and few explanations of why barriers exist and change. There is thus a need for research that focuses on the interdependencies between barriers and considers the dynamic ways in which barriers develop and persist. Such research, which would be actor-centred and comparative, would help to explain barriers to adaptation and provide insights into how to overcome them.**

Adaptation to the unavoidable consequences of climate change has become a necessity globally. However, practitioners, policymakers and scientists encounter and report on many barriers that impede adaptation planning and implementation<sup>1,2</sup>. Implementation of adaptation is not keeping pace with the ever-increasing need: the ‘adaptation deficit’<sup>3</sup> is getting wider. It is therefore critically important to identify and analyse barriers to adaptation to identify possible opportunities to overcome them. This Perspective takes stock of current knowledge and outlines the contours of a research agenda to identify, explain and overcome barriers to adaptation.

Generally defined, barriers to adaptation are challenges, obstacles, constraints or hurdles that impede adaptation<sup>4</sup>. For example, investment to increase the robustness of infrastructure to more frequent extreme weather events might be delayed due to a lack of financial resources. Our Perspective focuses on barriers that are conceptualized as being related to human actions or decisions, and, as opposed to limits, surmountable in principle (for example, through concerted effort). We propose a more precise definition of barriers to adaptation below.

There is an increasing body of case study literature on the barriers to adaptation. This literature carefully describes and categorizes barriers in different ways<sup>5-7</sup>. Research is, however, still far from conclusive on causal explanations for the occurrence of barriers and on how they can be overcome. This Perspective is based on an intensive reflection during an international workshop on the barriers to adaptation to climate change held in Berlin in 2012. This workshop synthesized participants’ expertise and knowledge of the literature with a qualitative approach (see [http://www.climate-chameleon.de/htm\\_engl/workshop\\_engl](http://www.climate-chameleon.de/htm_engl/workshop_engl) for detailed documentation). The workshop results are further substantiated in this article by drawing on a large sample of peer-reviewed papers, some published interim.

The following three sections report on the state of research on barriers to adaptation and identify limitations of current research. To address these research gaps, we propose components for a research agenda in the fourth section. We argue that more systematic causal explanations are crucial for overcoming barriers. Case studies need

to be compared and synthesized into higher-order findings that enable generalization and/or explication of how contextual factors modify the general insights. We conclude with crucial proposals to generate more broadly applicable and transferable knowledge on how decision-makers could avoid, reduce or overcome those barriers perceived as problematic.

## Conceptualizing barriers to adaptation

The IPCC’s fifth assessment report characterizes adaptation barriers (synonymous with adaptation constraints) as “factors that make it harder to plan and implement adaptation actions or that restrict options”<sup>4</sup>. Only a few studies on barriers to adaptation provide a clear-cut definition beyond the IPCC characterization<sup>7</sup>. To complicate matters, researchers use the term differently. Some scholars use the terms ‘limits’ and ‘barriers’ interchangeably<sup>8,9</sup>, but more often they have different meanings. Whereas barriers are considered surmountable or mutable, limits are seen to be absolute or unsurpassable<sup>10-12</sup>. The concept of barriers has also been defined in relation to adaptive capacity. Barriers are understood as either a reason for adaptive capacity not being translated into action<sup>8,13,14</sup>, or as one reason for low adaptive capacity<sup>15,16</sup>.

Moser and Ekstrom<sup>11</sup> define barriers as obstacles that make adaptation less efficient, less effective or may require changes that lead to missed opportunities or higher costs. They can be overcome, avoided or reduced by individual or collective action with concerted effort, creative management, changed ways of thinking, political will, and reprioritization of resources, land uses and institutions. Barriers can arise from three sources: the actor(s) making adaptation-related decisions, the context (for example, social, economic or biophysical) in which the adaptation takes place or the system that is at risk of being affected by climate change (called ‘system of concern’). This conceptualization follows a positive (that is, descriptive or explanatory) approach instead of a normative one in which barriers are judged as inherently problematic.

Eisenack and Stecker<sup>15</sup> also take a positive approach, and argue for a precise specification of (1) the adaptations to which a barrier

<sup>1</sup>Department of Economics, Carl von Ossietzky University Oldenburg, Ammerländer Heerstraße 114-118, 26129 Oldenburg, Germany, <sup>2</sup>Susanne Moser Research and Consulting, Santa Cruz, California 95060, USA, <sup>3</sup>Institute for Ecological Economy Research, Potsdamer Str. 105, 10785 Berlin, Germany, <sup>4</sup>Stockholm Environment Institute, Linnégatan 87D, Box 24218, 104 51 Stockholm, Sweden, <sup>5</sup>Centre for Climate Science and Policy Research and Department of Thematic Studies, Linköping University, 58183 Linköping, Sweden, <sup>6</sup>Department of Economics, University of Freiburg, Platz der Alten Synagoge, 79085 Freiburg, Germany, <sup>7</sup>Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), Friedrich-Ebert-Allee 40, 53113 Bonn, Germany, <sup>8</sup>Public Administration and Policy Group, Wageningen University, Hollandseweg 1, 6700 EW Wageningen, The Netherlands. \*e-mail: klaus.eisenack@uni-oldenburg.de

refers, and (2) the means necessary to implement these adaptations. The conditions that give reason to why these means are not employed for the specified adaptations are called barriers. This conceptualization emphasizes that barriers are relative to the specified adaptive actions that are considered, to the actors that may exercise them and to the specific situation in which they may be taken. In line with other work<sup>17</sup>, Eisenack and Stecker<sup>15</sup> and Moser and Ekstrom<sup>11</sup> recognize the role of norms and values in understanding barriers. Research on barriers, however, does not need to make such value judgements. There might be barriers that are judged as being problematic by one actor and viewed as beneficial by others. The actor would prefer to remove these barriers, while others would probably work with them strategically.

Taking account of these considerations, we propose the following refined definition here: a 'barrier to adaptation' is (1) an impediment (2) to specified adaptations (3) for specified actors in their given context that (4) arise from a condition or set of conditions. A barrier can be (5) valued differently by different actors, and (6) can, in principle, be reduced or overcome. In this definition, conditions are the attributes of adaptations, actors, and their context.

### Commonly reported barriers

The growing number of case studies and theoretical work has produced a large collection of commonly reported barriers<sup>5,7,17–21</sup>. Several attempts have been made to categorize these barriers<sup>5,11,15</sup>. Ekstrom and Moser<sup>6</sup>, for example, identify four categories of barriers most commonly encountered in the local urban context: institutional, attitudinal, financial and political. Biesbroek *et al.*<sup>5</sup> identify seven barrier categories: (1) conflicting timescales, (2) substantive, strategic and institutional uncertainty, (3) institutional crowdedness and institutional void, (4) institutional fragmentation, (5) lack of awareness and communication, (6) motives and willingness to act, and (7) lack of resources.

At this abstract level, most of these barrier categories are not specific to the governance of climate adaptation. Other change, policy and management processes encounter similar barriers. Governance of adaptation faces many of the same difficulties involved in dealing with other complex problems. Some scholars, however, argue that there is a set of barriers that are particular for adaptation<sup>22,23</sup>. For example, conflicting timescales can be very pronounced, as short-term interventions based on a long-term vision demand an enduring commitment by taxpayers, politicians and the private sector; persistent uncertainties about the nature and scale of risks and the effectiveness of adaptations feature strongly, particularly in the context of large-scale adaptation investments<sup>22,24</sup>; and institutional fragmentation is a persistent problem, as many adaptation strategies depend on the interaction of various sectors, for example, in water management, spatial planning and infrastructure design, and from various policy levels, from local to global<sup>6,25</sup>.

These general and descriptive barrier categories subsume a wide variety of specific barriers that are highly context and actor specific. As an example, in the Chilean capital Santiago, institutional fragmentation hinders urban adaptation as the regional decision-making authority is dispersed among 52 mayors<sup>26</sup>. In other cities, the most crucial barrier can stem from institutional fragmentation among administrative departments<sup>27</sup>. With regard to political barriers, in some cases, elected officials delay adaptation due to high costs<sup>28</sup>; in others, delays are due to the complexity of the system to be adapted or the perceived trade-offs among different constituencies<sup>27,29</sup>.

Why do these commonly reported barriers appear? What makes them often so persistent? Few systematic explanations are offered in the literature. Many studies are primarily descriptive and do not trace the origins of barriers, whereas others identify different, and sometimes diverging, reasons for the same type of barrier. For instance, while a low priority for adaptation in urban policy agendas has been traced to low awareness about climate impacts among citizens

and administrative staff<sup>30</sup>, the same barrier has been attributed to unclear roles and responsibilities in the Australian multi-level governance system<sup>31</sup>. A financial constraint impeding the assessment of adaptation options might result from an actor having failed to secure an appropriate budget (even though the municipality is in a healthy financial situation), or from a widespread financial crisis (in this case the cause is contextual)<sup>6,32</sup>. Low problem awareness at the local level is sometimes traced back to a low priority for adaptation at higher institutional levels<sup>30</sup>; in other instances, it results from unclear responsibilities for adaptation at the local level<sup>31</sup>. Missing leadership, and also dominant leadership by certain actors, can lead to an absence of appropriate decision-making routines<sup>27,33–36</sup>. And, finally, a lack of local leadership is frequently explained by missing top-down support<sup>27,37</sup>, but too much involvement from higher levels can also discourage local leadership<sup>38,39</sup>. Importantly, these diverging findings do not indicate disagreement in the scientific literature, but stem from differences in the cases studied.

Moreover, some studies indicate that different barriers cannot be understood in isolation. Long-term financial shortages give rise to and magnify other barriers, such as those stemming from lack of information, inadequate interagency coordination and specific personal beliefs<sup>30,40</sup>. Other studies conclude that the absence of appropriate decision-making routines can be the underlying reason for inappropriate budgets<sup>27</sup>. Uncertainty and lack of awareness can impede adaptation and interact bidirectionally: uncertainty can undermine the motivation of actors to become more aware, while lack of awareness can inhibit efforts directed towards reducing uncertainty<sup>41</sup>.

To complicate matters, barriers are not static but change over time. For example, budget constraints can become more pressing over time, for example, due to a broad financial crisis or local budgetary priorities given to other policy issues<sup>6,32</sup>. Adaptation investment in long-lived infrastructure is strongly shaped by competition regulation and expectations about the future<sup>35,42</sup>. At the same time, the current needs, options and costs of adaptation depend on investment decisions made in the past<sup>38,43,44</sup>. Both past decisions and current barriers to adaptation may lead to path dependencies that constrain future action<sup>6,27</sup>.

Taken together, current barrier research offers a broad and diverse empirical and conceptual base. Few studies, however, explain the occurrence of barriers. If explanations are offered, they mostly apply to the unique case under investigation, with little grounds yet for generalization. Although single studies illustrate the importance of understanding how barriers are related to each other or how they change over time, there is a need to address these questions explicitly and systematically for a broader set of cases. Existing meta-studies (including the IPCC's fifth assessment report<sup>4</sup>) categorize barriers into variably generic or fine-grained lists. Barrier categories are, however, primarily descriptive and do not yet offer systematic explanations.

### Overcoming barriers

So far, there are only a few studies that explicitly investigate how barriers perceived as problematic might be overcome. Yet some studies of instances where adaptation is already occurring provide insights on enabling factors that either prevent barriers from emerging or that help actors to deal with them<sup>6,45–48</sup>.

Of those actions that have already been implemented, only a few have been large or costly<sup>27,49</sup>, and many are essentially extensions of previous policies. A related and important enabling condition is the integration of adaptation into other policies (frequently called 'mainstreaming', for example, by including climate change projections in water management, urban planning or health<sup>50–52</sup>). Also, experience of extreme events or significant climate variability can initiate adaptation planning<sup>45</sup>. Keskkitalo *et al.*<sup>53</sup> found that extreme events opened policy windows for adaptation in the United Kingdom, Sweden and Finland, but not in Italy — a contrast attributed to the

different interpretation of the events and the available policy options in Italy. Generally, much observable adaptation to date involves building internal capacity (for example, creating a knowledge base among staff, assessing risks, improving internal communication and establishing collaborative partnerships)<sup>6</sup>. Other ways of overcoming barriers are informal partnerships, formal interagency working groups and other deliberative venues<sup>54,55</sup>.

National and international policies can also enable, incentivize or prescribe adaptation measures<sup>56</sup>. Clear assignment of responsibilities and accompanying monitoring mechanisms can overcome barriers<sup>31,57</sup>. However, top-level involvement can also discourage local adaptation<sup>38,39</sup>. National policies need to take into account local circumstances<sup>31,58</sup>. On the other hand, action on the national level may be substituted by local efforts, for example, through regional and local actor networks<sup>59,60</sup> or individual leaders.

As research on barriers to date indicates, many barriers have deep historical roots<sup>6,17,27,29,31,33</sup>. Furthermore, it takes time to overcome them. For example, first steps are frequently driven and led by a few committed individuals (for example, a staff member or elected official) who create the necessary action space for other actors<sup>6,27,33,61,62</sup>. This can require enduring local leadership<sup>6</sup> or stable support from higher governance levels<sup>41</sup>. Leadership (regardless of position or authority) can be crucial in the early stages of adaptation. Inspired leadership can establish novel governance mechanisms and create a significantly changed context for decision-making<sup>27,61</sup>. The set of involved actors may change if clear responsibilities are assigned. On the other hand, reliance on individual leaders can also make jurisdictions susceptible to abuse of power, stalled social learning and dominance by single influential actors<sup>34</sup>. Individual leadership has been found to undermine mutual ownership among administrative departments, thus challenging the coordination of adaptation activities<sup>63</sup>.

To summarize the current knowledge, only a few studies yield systematic insights into how barriers can be overcome. Reported observations of 'early adopters' indicate that there are no one-size-fits-all solutions, probably reflecting the multiple and context-specific origins of barriers. Moreover, overcoming barriers can be pictured as a process in time (for example, involving leadership), adding to the difficulties of making a systematic analysis. In short, the limitations of our current knowledge on overcoming barriers are related to the limited state of the art in systematically explaining barriers. A clear understanding of the underlying causes giving rise to barriers would offer entry points for reducing or overcoming them, or — in those cases where barriers are judged as beneficial — for strategically upholding them. Given the widening adaptation deficit, we see such research not only as beneficial in its own right, but also as highly policy and practice relevant.

### Proposals for a research agenda

The above examples and categories of barriers suggest a rich and vibrant foundation for research on adaptation. Yet, the transferability of knowledge on why barriers emerge and how they might be addressed is still quite limited. An important next step now is to go beyond describing and enumerating barriers towards explaining them, to provide clear and valid analyses leading to identification of entry points and strategies for intervention. Although studies occasionally indicate the importance of a dynamic perspective and consideration of causal interdependencies among barriers, these issues are yet rarely researched in an explicit way. The huge diversity of actors and contexts between single cases is clearly a major challenge in this regard. This section elaborates these research themes further and makes methodological suggestions.

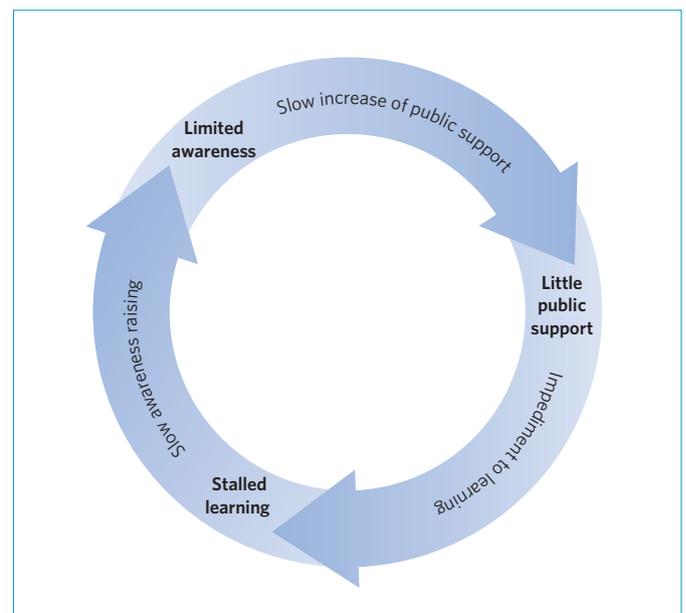
First, consider interdependency. Some case studies mention a co-occurrence (or 'clustering') of multiple barriers<sup>19,30,57</sup>. This reflects that the barrier categories discussed above are sometimes independent of each other. But in many cases they are not mutually

exclusive; in fact, they are often interdependent. Some barriers from different categories co-occur or reinforce each other; some 'remote' and less obvious barriers can cause proximate barriers to adaptation. Few studies have attempted to trace back the apparent or proximate set of conditions impeding adaptation to the underlying causes of why or how these conditions have arisen and why they endure<sup>6,11</sup>.

For example, unresolved conflicts between the involved actors' goals can be a proximate impediment to adaptation<sup>27,28</sup>. But what is the root cause of such conflicts? A conflict may arise from multiple actors being affected by the same climate change impacts and adaptations in different ways. Alternatively, the impacts can cause resource scarcity as a root of conflict, if accompanied by a lack of institutionalized mechanisms for conflict resolution. When two barriers are interdependent, it is not always obvious which of them underlies the other.

We argue that understanding the interdependencies of barriers is central for explaining their occurrence, persistence and resolution. It is also crucial from a practical viewpoint. Policies or approaches to reduce or overcome barriers might prove to be ineffective if they disregard causal interdependencies, while a well-designed intervention can simultaneously address multiple related barriers. It might also be necessary to address multiple interdependent barriers in parallel.

Second, consider dynamics. Several components in the proposed definition of barriers to adaptation (see above) can be dynamic: the actors involved and the actions under consideration; the institutional, socioeconomic and — of course — climatic context of the involved actors; and the value judgements of actors. Dynamics may be the result of historical events, contingent factors or specific interventions, or they may be the consequence of specific interdependencies among barriers. Overlapping with the interdependency theme detailed above, the degree of mutual interaction can also change over time. Some barriers might reinforce or balance other barriers over time. For example, interlinked barriers may lead to vicious or virtuous cycles<sup>64</sup>, either mutually enforcing or mitigating



**Figure 1 | Example of dynamically interlinked barriers.** Limited problem awareness can lead to a slow pace in garnering public acceptance and support for adaptation<sup>28,30,41</sup>. In turn, lack of public support can be an impediment to actors learning about climate change impacts and possible adaptation actions<sup>6,27,38</sup>. Learning itself is, in turn, a dynamic process that can build problem awareness over time<sup>38,41,65</sup>.

a particular cluster of barriers. Figure 1 offers an example of a vicious cycle, where the existence of some barriers enforces the pace in which other barriers develop over time. Effective interventions in such a vicious cycle require that actors understand these dynamics.

When actors get entangled in dynamic webs of barriers, which interventions can help break through vicious cycles, and when is the best time to intervene? How can virtuous cycles be initiated? Planning and implementation of adaptation typically takes time. Adaptation can be initiated and implemented too late, but as many adaptation choices are costly, adaptation can also be implemented too early<sup>66,67</sup>. Owing to the long-term nature of the challenge, it is unavoidable that actors and their contexts will change over time. Previous barriers are overcome or reduced, and new ones arise.

Finally, consider the methods to advance explanatory adaptation research with specific focus on the interdependency and dynamics of barriers. While both research foci are not well established yet, it can be expected that researching them does not require novel scientific methods. We instead propose that established comparative, actor-centred and time-sensitive frameworks and methods are best suited to advance our understanding of adaptation barriers and to generate transferable findings that can inform efforts to overcome barriers.

Comparative research designs (comparative case studies, small-*N* or large-*N* studies, meta-analyses and qualitative comparative analysis) can contribute to our causal understanding of the multiple conditions that create barriers, to resolve possibly diverging evidence and explain interdependencies of barriers. Comparative research can examine the conditions that are common to different barriers and the case-specific differences of similar barriers (that emerge from the actors, the specific contexts in which they act or from the systems of concern that they attempt to manage). Existing meta-studies of adaptation at the municipal level, for example, suggest that some barrier categories are interdependent in similar ways across cases, but interdependencies differ in detail<sup>30,56</sup>. Future research may provide a conceptual synthesis of how barriers combine into common patterns that relate proximate barriers with underlying causes, resulting effects and mediating mechanisms<sup>34,68</sup>. We do not claim that such research can come up with grand generalized explanations of all barriers and their interdependencies. We believe, however, that it is worthwhile to attempt to identify communalities of intermediate generality that can at least be transferred across specified subsets of cases<sup>69</sup>. Such research may identify distinct, repeated diagnostic patterns that attribute impediments in adaptation processes to specific governance problems. Strategies to overcome barriers may be derived from previous efforts in cases with a similar diagnosis.

Actor-centred approaches to adaptation research are increasingly undertaken<sup>6,11,12,15,23</sup> and should be advanced, because, after all, many barriers to adaptation are related to the actors themselves, and barriers can only be addressed and overcome by actors and actions. Actor-centred adaptation research takes individuals and collectives, their actions and how decisions are made as starting points for analysis. This does not imply an exclusive focus on single actors or disregard of the institutional systems in which they are embedded, but simply puts actors at the centre of the analysis. Actor-centred research can focus on individuals or organizations, citizens, firms or policymakers. Once the relevant actors are identified, analysis can proceed to explain why and under which (actor specific or contextual) conditions actions are undertaken or not (a positive question), or why they should be undertaken and by whom (a normative question).

Actor-centred approaches can be fruitful for resolving *prima facie* diverging evidence. Take extreme events as motivation to begin adaptation as a case in point. Many studies find that disasters motivate adaptation planning<sup>40,53,70</sup>, but this need not be the case. Hoffmann and Rotter<sup>71</sup> found that managers of selected German utilities had a low level of awareness for adaptation, due to their perception that the companies had coped well with extreme weather events in the past and that future events would not differ greatly from past experience.

Presumably, actor attributes such as risk perception, understanding of climate change and coping capacity, together with their guiding norms and goals, may explain why extreme events motivate action in some cases, while adaptation is impeded by barriers in other cases. To put it more generally, actor-centred approaches can help to develop meaningful frameworks for comparative research to explain barriers and ways to overcome them. Although we do not suggest a single and specific framework here, adaptation decision-making can be researched by mapping the actors' norms and goals, perceptions, incentives, authorities, rules and resources with sufficient specificity. These, in turn, are dependent on the institutional, socioeconomic and biophysical context, as well as the intrapersonal and community attributes of the actors<sup>30,57,60,72</sup>. Frameworks with such components would unpack the heterogeneity of actors and the contexts for their actions.

Time-sensitive methods from different scientific disciplines can contribute to explaining dynamically interlinked barriers to adaptation as well as to assessing strategies to overcome barriers over time. Starting points may be heuristic temporal models of adaptation processes and decision-making<sup>11,73</sup>. Research on institutional change<sup>74</sup>, organizational learning<sup>75,76</sup> or path dependency<sup>27,77</sup> may be fruitful in this context. Applied methods that explicitly deal with changes over time would be helpful. Longitudinal studies, scenario analysis and backcasting, for example, are established (interdisciplinary) methods for analysing change<sup>78,79</sup>. Understanding the roots of barriers in historical case studies may help in designing adaptive solutions now. Systems thinking and tools such as causal loop diagrams can help analyse dynamic interdependencies<sup>80–82</sup>. Such diagrams can visualize dynamic patterns<sup>80</sup>, thus contributing to the identification of opportunities for effective interventions.

In summary, using comparative approaches together with an actor-centred perspective and time-sensitive methods that enable the analysis of variables influencing adaptation decisions and processes would be a significant step forward from the diverse landscape of individual case studies or generic conceptualizations available to date. Identifying common causal patterns, interdependency and the dynamics of adaptation will significantly advance our ability to explain the occurrence of barriers and find promising ways to overcome them.

## Conclusions

This Perspective reflected on the growing body of empirical and conceptual research on barriers to adaptation. A rich and diverse set of case studies forms a solid foundation to improve our understanding of the reasons why adaptation is proceeding more slowly than the growing urgency of climate change would lead us to expect. This body of research, however, is mostly descriptive and/or case specific. We believe that the time is ripe for more explanatory research on barriers: on what causes them, how they interact and change over time. Comparative, actor-centred and time-sensitive approaches promise an improved understanding that would help transfer knowledge on adaptation among places and sectors. Such an in-depth understanding, we believe, would certainly assist decision-makers in planning and implementing adaptation actions and policies.

Received 20 March 2014; accepted 24 July 2014; published online 25 September 2014

## References

- Gagnon-Lebrun, F. & Agrawala, S. Implementing adaptation in developed countries: an analysis of progress and trends. *Clim. Policy* 7, 392–408 (2007).
- Tompkins, E. L. *et al.* Observed adaptation to climate change: UK evidence of transition to a well-adapting society. *Glob. Environ. Change* 20, 627–635 (2010).
- Burton, I. in *Earthscan Reader on Adaptation to Climate Change* (eds Schipper, E. L. F. & Burton, I.) 89–95 (Earthscan, 2009).

4. Klein, R. J. T. *et al.* in *IPCC Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects* (eds Field, C. B. *et al.*) Ch. 16 (Cambridge Univ. Press, 2014).
5. Biesbroek, G. R., Klostermann, J. E. M., Termeer, C. J. A. M. & Kabat, P. Barriers to climate change adaptation in the Netherlands. *Clim. Law* **2**, 181–199 (2011).
6. Ekstrom, J. A. & Moser, S. C. Identifying and overcoming barriers in urban adaptation efforts to climate change: case study findings from the San Francisco Bay Area, California, USA. *Urban Clim.* <http://dx.doi.org/10.1016/j.uclim.2014.06.002> (in the press).
7. Biesbroek, G. R., Klostermann, J. E. M., Termeer, C. J. A. M. & Kabat, P. On the nature of barriers to climate change adaptation. *Reg. Environ. Change* **13**, 1119–1129 (2013).
8. Adger, W. N. Commentary. *Environ. Plan. A* **41**, 2800–2805 (2009).
9. Laube, W., Schraven, B. & Awo, M. Smallholder adaptation to climate change: dynamics and limits in Northern Ghana. *Climatic Change* **111**, 753–774 (2012).
10. Hulme, M. *et al.* *Limits and Barriers To Adaptation: Four Propositions* Tyndall Briefing Note 20 (Tyndall Centre for Climate Change Research, 2007).
11. Moser, S. C. & Ekstrom, J. A. A framework to diagnose barriers to climate change adaptation. *Proc. Natl Acad. Sci. USA* **107**, 22026–22031 (2010).
12. Dow, K. *et al.* Limits to adaptation. *Nature Clim. Change* **3**, 305–307 (2013).
13. Naess, L. O., Bang, G., Eriksen, S. & Veatne, J. Institutional adaptation to climate change: flood responses at the municipal level in Norway. *Glob. Environ. Change* **15**, 125–138 (2005).
14. O'Brien, K., Eriksen, S., Sygna, L. & Naess, L. O. Questioning complacency: climate change impacts, vulnerability, and adaptation in Norway. *AMBIO* **35**, 50–56 (2006).
15. Eisenack, K. & Stecker, R. A framework for analyzing climate change adaptations as actions. *Mitig. Adapt. Strat. Glob. Change* **17**, 243–260 (2012).
16. Hinkel, J. Indicators of vulnerability and adaptive capacity: towards a clarification of the science–policy interface. *Glob. Environ. Change* **21**, 198–208 (2011).
17. Adger, W. N. *et al.* Are there social limits to adaptation to climate change? *Climatic Change* **93**, 335–354 (2009).
18. Lorenzoni, I., Nicholson-Cole, S. & Whitmarsh, L. Barriers perceived to engaging with climate change among the UK public and their policy implications. *Glob. Environ. Change* **17**, 445–459 (2007).
19. Burch, S. In pursuit of resilient, low-carbon communities: an examination of barriers to action in three Canadian cities. *Energ. Policy* **38**, 7575–7585 (2010).
20. Eakin, H., Lerner, A. M. & Murtinho, F. Adaptive capacity in evolving peri-urban spaces: responses to flood risk in the Upper Lerma River Valley, Mexico. *Glob. Environ. Change* **20**, 14–22 (2010).
21. Jones, L. & Boyd, E. Exploring social barriers to adaptation: insights from Western Nepal. *Glob. Environ. Change* **21**, 1262–1274 (2011).
22. Termeer, C. J. A. M., Dewulf, A. & Breeman, G. in *Climate Change Governance* (eds Knieling, J. & Filho, W. L.) 27–41 (Springer, 2012).
23. Klein, R. J. T. & Juhola, S. A framework for Nordic actor-oriented climate adaptation research. *Environ. Sci. Policy* **40**, 101–115 (2014).
24. Arvai, J. *et al.* Adaptive management of the global climate problem: bridging the gap between climate research and climate policy. *Climatic Change* **78**, 217–225 (2006).
25. Huitema, D., Aerts, J. C. J. H. & van Asselt, H. D. in *Global Warming and Climate Change* (ed. Grover, V. L.) 527–561 (Science Publishers, 2008).
26. Krellenberg, K. in *Resilient Cities 2: Cities and Adaptation to Climate Change — Proceedings of the Global Forum 2011* (ed. Otto-Zimmermann, K.) 233–240 (Springer, 2012).
27. Burch, S. Transforming barriers into enablers of action on climate change: insights from three municipal case studies in British Columbia, Canada. *Glob. Environ. Change* **20**, 287–297 (2010).
28. Vine, E. Adaptation of California's electricity sector to climate change. *Climatic Change* **111**, 75–99 (2012).
29. Inderberg, T. H. Institutional constraints to adaptive capacity: adaptability to climate change in the Norwegian electricity sector. *Local Environ.* **16**, 303–317 (2011).
30. Lehmann, P. *et al.* Barriers and opportunities for urban adaptation planning: analytical framework and evidence from cities in Latin America and Germany. *Mitig. Adapt. Strat. Glob. Change* <http://dx.doi.org/10.1007/s11027-013-9480-0> (2013).
31. Mukheibir, P., Kuruppu, N., Gero, A. & Herriman, J. Overcoming cross-scale challenges to climate change adaptation for local government: a focus on Australia. *Climatic Change* **121**, 271–283 (2013).
32. Reyer, C. *et al.* Climate change adaptation and sustainable regional development: a case study for the Federal State of Brandenburg, Germany. *Reg. Environ. Change* **12**, 523–542 (2012).
33. Garrelts, H. & Lange, H. Path dependencies and path change in complex fields of action: climate adaptation policies in Germany in the realm of flood risk management. *AMBIO* **40**, 200–209 (2011).
34. Oberlack, C. *Institutional Diagnostics of Climate Adaptation* Constitutional Economics Network Paper No. 2014–01 (Univ. Freiburg, 2014).
35. Pechan, A. *Does Regulation Give Incentives to Adapt Network Infrastructure to Climate Change? A German Case Study* Oldenburg Discussion Papers in Economics V-365-14 (Carl von Ossietzky Univ., 2014).
36. Galaz, V. Social-ecological resilience and social conflict: institutions and strategic adaptation in Swedish water management. *AMBIO* **34**, 567–572 (2005).
37. Gleick, P. H. Roadmap for sustainable water resources in southwestern North America. *Proc. Natl Acad. Sci. USA* **107**, 21300–21305 (2010).
38. Crabbé, P. & Robin, M. Institutional adaptation of water resource infrastructures to climate change in Eastern Ontario. *Climatic Change* **78**, 103–133 (2006).
39. Harries, T. & Penning-Rowsell, E. Institutional inertia and policy innovation for climate change adaptation: the case of flood risk management. *Glob. Environ. Change* **21**, 188–197 (2011).
40. Ebert, S., Hulea, O. & Strobel, D. Floodplain restoration along the lower Danube: a climate change adaptation case study. *Clim. Dev.* **1**, 212–219 (2009).
41. Rudberg, P. M., Wallgren, O. & Swartling, Å. G. Beyond generic adaptive capacity: exploring the adaptation space of the water supply and wastewater sector of the Stockholm region, Sweden. *Climatic Change* **114**, 707–721 (2012).
42. Inderberg, T. H. Governance for climate-change adaptive capacity in the Swedish electricity sector. *Public Manag. Rev.* **14**, 967–985 (2012).
43. Arnell, N. W. & Delaney, E. K. Adapting to climate change: public water supply in England and Wales. *Climatic Change* **78**, 227–255 (2006).
44. Hallegatte, S. Strategies to adapt to an uncertain climate change. *Glob. Environ. Change* **19**, 240–247 (2009).
45. Berrang-Ford, L., Ford, J. D. & Paterson, J. Are we adapting to climate change? *Glob. Environ. Change* **21**, 25–33 (2011).
46. Ford, J. D., Berrang-Ford, L. & Paterson, J. A systematic review of observed climate change adaptation in developed nations. *Climatic Change* **106**, 327–336 (2011).
47. Hamin, E., Gurran, N. & Emlinger, A. M. Barriers to municipal climate adaptation: Examples from Coastal Massachusetts' smaller cities and towns. *J. Am. Planning Assoc.* (in the press).
48. Fidelman, P. I. J., Leitch, A. M. & Nelson, D. R. Unpacking multilevel adaptation to climate change in the Great Barrier Reef, Australia. *Glob. Environ. Change* **23**, 800–812 (2013).
49. Kates, R. W., Travis, W. R. & Wilbanks, T. J. Transformational adaptation when incremental adaptations to climate change are insufficient. *Proc. Natl Acad. Sci. USA* **109**, 7156–7161 (2011).
50. Mickwitz, P. *et al.* *Climate Policy Integration, Coherence and Governance — PEER Report No 2* (Partnership for European Environmental Research, 2009).
51. Stecker, R., Mohns, T. & Eisenack, K. *Anpassung an den Klimawandel — Agenda Setting und Politikintegration in Deutschland* Zeitschrift für Umweltpolitik und Umweltrecht 2012/2 179–208 (Deutscher Fachverlag, 2012).
52. Persson, Å. & Klein, R. J. T. in *Climate Change and Foreign Policy: Case Studies from East to West* (ed. Harris, P.) 162–177 (Routledge, 2009).
53. Keskitalo, E. C. H., Westerhoff, L. & Johula, S. Agenda-setting on the environment: the development of climate change adaptation as an issue in European states. *Environ. Policy Govern.* **22**, 381–394 (2012).
54. Pelling, M., High, C., Dearing, J. & Smith, D. Shadow spaces for social learning: a relational understanding of adaptive capacity to climate change within organisations. *Environ. Plan. A* **40**, 867–884 (2008).
55. Rouillard, J. J., Heal, K. V., Reeves, A. D. & Ball, T. Impact of institutions on flood policy learning. *Water Policy* **14**, 232–249 (2012).
56. Oberlack, C. & Eisenack, K. Alleviating barriers to urban climate change adaptation through international cooperation. *Glob. Environ. Change* **24**, 349–362 (2014).
57. Runhaar, H., Mees, H., Wardekker, A., van der Sluijs, J. & Driessen, P. P. J. Adaptation to climate change-related risks in Dutch urban areas: stimuli and barriers. *Reg. Environ. Change* **12**, 777–790 (2012).
58. Ruijgh-van der Ploegh, T. Manifestations of adaptive capacity: an institutional analysis of adaptation of a local stormwater system. *Clim. Law* **2**, 201–217 (2011).
59. Heinrichs, D. *et al.* in *Cities and Climate Change: Responding to an Urgent Agenda* (eds Hoornweg, D., Freire, M., Lee, M. J., Bhada-Tata, P. & Yuen, B.) 193–224 (The World Bank, 2011).
60. Westerhoff, L., Keskitalo, E. C. H. & Johula, S. Capacities across scales: local to national adaptation policy in four European countries. *Clim. Policy* **11**, 1071–1085 (2011).
61. Roberts, D. Thinking globally, acting locally — institutionalizing climate change at the local government level in Durban, South Africa. *Environ. Urban.* **20**, 521–537 (2008).

62. Rotter, M. *et al.* *Limiting Factors for a Robust Railway System* (International Research Workshop on the Barriers to Adaptation to Climate Change, 2012).
63. Storbjörk, S. & Hedrén J. Institutional capacity-building for targeting sea-level rise in the climate adaptation of Swedish coastal zone management: lessons from Coastby. *Ocean Coast. Manag.* **54**, 265–273 (2011).
64. Vermaak, H. *Nobody Has All the Answers, but Collectively We Can Find Them: Using Causal Loop Diagrams to Deal with Ambiguity* (Fifth International Conference on Management Consulting, 2011); available via <http://hansvermaak.com/en/files/2012/04/hans-vermaak-causal-loop-diagrams-ambiguity.pdf>
65. Huntjens, P. *et al.* Institutional design propositions for the governance of adaptation to climate change in the water sector. *Glob. Environ. Change* **22**, 67–81 (2012).
66. Mendelsohn, R. The role of markets and governments in helping society adapt to a changing climate. *Climatic Change* **78**, 203–215 (2006).
67. Agrawala, S. & Fankhauser, S. in *Economic Aspects of Adaptation to Climate Change: Costs, Benefits and Policy Instruments* (eds Agrawala, S. & Fankhauser, S.) 19–28 (OECD, 2008).
68. Biesbroek, G. R., Termeer, C. J. A. M., Klostermann, J. E. M. & Kabat, P. Rethinking barriers to adaptation: mechanism-based explanation of impasses in the governance of an innovative adaptation measure. *Glob. Environ. Change* **26**, 108–118 (2014).
69. Eisenack, K. in *Human/Nature Interactions in the Anthropocene: Potentials of Social-Ecological Systems Analysis* (eds Glaser, M., Krause, G., Ratter, B. & Welp, M.) 107–122 (Routledge, 2012).
70. Haigh, N. & Griffiths, A. Surprise as a catalyst for including climatic change in the strategic environment. *Bus. Soc.* **1**, 1431–1450 (2012).
71. Hoffmann, E. & Rotter, M. *Making Sense of Climate Risks — Organizational Response to Climate Change Impacts* (28th EGOS Colloquium, 2012).
72. Measham, T. G. *et al.* Adapting to climate change through local municipal planning: barriers and challenges. *Mitig. Adapt. Strat. Glob. Change* **16**, 889–909 (2011).
73. Berkhout, F. Adaptation to climate change by organizations. *WIREs Clim. Change* **3**, 91–106 (2012).
74. Kingston, C. & Caballero, G. Comparing theories of institutional change. *J. Inst. Econ.* **5**, 151–180 (2009).
75. Argyris, C. & Schön, D. A. *Organizational Learning: A Theory of Action Perspective* (Addison-Wesley, 1978).
76. The Social Learning Group *Learning to Manage Global Environmental Risks: A Comparative History of Social Responses to Climate Change, Ozone Depletion and Acid Rain* (MIT Press, 2001).
77. Libecap, G. D. Institutional path dependence in climate adaptation: Coman's "Some Unsettled Problems of Irrigation". *Am. Econ. Rev.* **101**, 64–80 (2011).
78. Dortmans, P. J. & Eiffe, E. An examination of future scenarios using historical analogy. *Futures* **36**, 1049–1062 (2004).
79. Dreborg, K. H. Essence of backcasting. *Futures* **28**, 813–828 (1996).
80. Senge, P. M. *The Fifth Discipline — The Art and Practice of the Learning Organization* (Doubleday, 1990).
81. Meijerink, S. V., Nooteboom, S. G. & Termeer, C. J. A. M. *Real Barriers to Climate Adaptation: A Systems Approach to Learn About New Modes of Governance* (European Group of Public Administration Conference, 2008).
82. Eisenack, K., Lüdecke, M., Petschel-Held, G., Scheffran, J. & Kropp, J. in *Advanced Methods for Decision Making and Risk Management in Sustainability Science* (eds Kropp, J. & Scheffran, J.) 83–127 (Nova Science Publishers, 2007).

## Acknowledgements

Parts of this paper are work of the Chameleon Research Group ([www.climate-chameleon.de](http://www.climate-chameleon.de)), funded by the German Ministry for Education and Research under grant 01UU0910. Further parts have been supported by the Norden Top-level Research Initiative sub-programme 'Effect Studies and Adaptation to Climate Change' through the Nordic Centre of Excellence for Strategic Adaptation Research (NORD-STAR). We thank M. Steinhäuser for his support in coding of case studies, and all participants of the International Research Workshop on the Barriers to Adaptation to Climate Change.

## Author contributions

All authors contributed to the intellectual content. K.E., S.M. and C.O. conducted systematic literature reviews. A.P., K.E., E.H. and M.R. planned the project. All authors contributed references to the review. K.E. led the drafting of the text, with main contributions from S.M. All authors reviewed and edited the text.

## Additional information

Reprints and permissions information is available online at [www.nature.com/reprints](http://www.nature.com/reprints). Correspondence and requests for materials should be addressed to K.E.

## Competing financial interests

The authors declare no competing financial interests.