Climatic Change
https://doi.org/10.1007/s10584-020-02659-9

Surveying perceptions and practices of high-end climate change

Richard Taylor[1] · Ruth Butterfield[1] · Tiago Capela Lourenço[2] · Adis Dzebo[3,4] · Henrik Carlsen[3] · Richard J. T. Klein[5,6]

Received: 17 May 2019 / Accepted: 15 January 2020/Published online: 03 April 2020

Abstract

We surveyed members of the adaptation community about their views on high-end climate change—here defined as global average temperature increase exceeding 2 °C at the end of the century—at consecutive conferences in 2016 and 2018. Most strikingly our surveys show that a majority of the community disagrees that the Paris Agreement has reduced the possibility of the world reaching dangerous levels of climate change. Consistent with this, around two thirds of people consulted are considering high-end climate change or using high-end scenarios in their work all the time, or starting to. However, this is still not done by all. Preparedness for the specific threats posed by high-end impacts is not keeping pace, and more work needs to be done to strengthen the research basis and understand adaptation needs under high-end climate change. Moreover, views on finding information on impacts and tools for decision-making have not changed between 2016 and 2018, showing that there is no improvement. This situation underlines that the adaptation community needs to do better in supporting exchange of information and data between all actors—in addition to finding and filling knowledge gaps. Despite this, there is widespread support for avoiding delaying large-scale adaptation until we have more certainty.

The online version of this article(https://doi.org/10.1007/s10584-020-02659-9) contains supplementarymaterial, which is available to authorized users.

✉ Richard Taylor
richard.taylor@sei.org

[1] Stockholm Environment Institute (SEI), 29 Grove Street, Oxford OX2 7JT, UK

[2] Centre for Ecology, Evolution and Environmental Changes, Faculty of Sciences, University of Lisbon, 1749-016 Lisbon, Portugal

[3] Stockholm Environment Institute (SEI), P.O. Box 24218, SE-104 51 Stockholm, Sweden

[4] Copernicus Institute of Sustainable Development, Utrecht University, Princetonlaan 8a, 3584 CB Utrecht, The Netherlands

[5] Stockholm Environment Institute (SEI), P.O. Box 200818, 53138 Bonn, Germany

[6] Centre for Climate Science and Policy Research, Linköping University, 581 83 Linköping, Sweden

Keywords High-end climate change · Survey · Paris Agreement · Adaptation decision-making · High-end scenarios

1 Introduction

The Paris Agreement and current emissions trajectories are at odds with each other. Whilst the Paris Agreement (UNFCCC 2015) sets out a target to limit the increase in global mean temperature to well below 2 °C above pre-industrial levels along with the pursuit of efforts to limit the increase to 1.5 °C, current emissions trajectories, as for example implied by the Nationally Determined Contributions, point to increased temperatures between 2.6 and 3.1 °C (Rogelj et al. 2016) by 2100, with warming continuing afterwards (UNEP 2018). Already today average global temperatures have risen ~1 °C compared to pre-industrial times and warming is projected to reach 1.5 °C within two to three decades (IPCC 2018 p. 6).

Although global CO_2 emissions flattened out between 2014 and 2016, they increased by 1.6% in 2017 and 1.7% in 2018 (IEA 2019). This development is mainly driven by higher economic growth and slower declines in energy, and especially carbon, intensity compared with 2014–2016 (UNEP 2018: pp. 5–6). However, there is considerable uncertainty as to whether the 2014–2016 slowdown was driven primarily by short-term economic factors (Ibid.). Short of a global economic downturn, global CO_2 emissions are likely to continue rising in 2019 (Jackson et al. 2018). It is clear that the world has a long way to go before greenhouse gas concentrations are stabilised at levels that would prevent potentially dangerous climate change. High-end climate change (HECC), defined as global average temperature increase beyond 2 °C with possible increases of 4 °C or more in the long-term, is becoming increasingly plausible.

Relative to lower levels of climate change, HECC may imply increasing climate variability and extremes, crossing thresholds and therefore profound changes to the environment that are very difficult to project. The IPCC Special Report on global warming of 1.5 °C (IPCC 2018) shows considerable differences in impacts between 1.5 and 2 °C global temperature increase, which suggests that it is important to focus on further comparisons among scenarios, including those at the higher end. Existing literature, reviewed in the next section of this paper, points to much more severe consequences beyond 2 °C, and it is therefore important to raise questions regarding how well-informed members of the 'adaptation community' feel about potential challenges of HECC.

This paper presents results from two identical surveys sent out to participants at two consecutive international conferences on climate change adaptation, Adaptation Futures 2016[1] (259 responses) and 2018[2] (198 responses) (see Appendix Table 1). There is a vast literature on surveying climate change opinions, both public and expert (Hamilton 2018; Tàbara et al. 2012). Marquart-Pyatt et al. (2015) describe techniques for integrating climate data into sociological analysis, using spatial (cross-sectoral) and/or temporal (time series) variation. Tàbara et al. (2012) show that social science research on public perceptions of global warming has embraced an increasing number of topics and questions and identified a widening range of influencing factors. They also review annual surveys of the general public (1000 people in each of 24 countries), showing that concern for climate change is growing worldwide. Our sample is small compared to such large-scale public surveys, but is substantial for a relatively specialised field. To our knowledge, these are the largest surveys of their kind

[1] http://www.adaptationfutures2016.org/results/introduction
[2] https://adaptationfutures2018.capetown

assessing the climate change adaptation community's preparedness for climate change beyond the Paris Agreement.

Section 2 reviews the literature on impacts beyond 2 °C, perceptions on HECC and societal and political responses to the risks. Section 3 presents the methods and materials employed. Section 4 presents the results. Section 5 discusses the significance of the results and Section 6 concludes.

2 Background on high-end climate change

2.1 Considering the impacts of HECC

Although recent research on impacts beyond 2 °C is relatively sparse, the existing literature points to much more severe consequences compared to the historical period,[3] such as those described for flood risk (Alfieri et al. 2015), sea-level rise (Golledge et al. 2015; Cooper and Lemckert 2012), water scarcity (Schewe et al. 2014) and heat stress (Sherwood and Huber 2010) and on sectors including agriculture (crops—Ostberg et al. 2018, Parkes et al. 2018, agricultural welfare—Stevanović et al. 2016), freshwater (Koutroulis et al. 2018) and groundwater (Portmann et al. 2013). The IPCC AR5 (Oppenheimer et al. 2014) includes a section on risks from > 4 °C above pre-industrial levels, claiming that the evidence base has only recently become sufficient to allow for assessment. Relevant climate scenarios include those based on RCP 8.5,[4] which in 2081–2100 is projected to result in a temperature rise of 4.3 °C ± 0.7 °C with temperature above 4 °C *as likely as not*[5] (Collins et al. 2013, p. 1056).

HECC scenarios, impacts, responses and solutions were the focus of three complementary European Union (EU) projects assessing impacts and adaptation across a range of land, water and coastal ecosystems: HELIX (High-End cLimate Impacts and eXtreme); IMPRESSIONS (IMPacts and REsponses from high-end Scenarios: Strategies for Innovative SolutiONS) and RISES-AM (Responses to coastal climate change: Innovative Strategies for high-End Scenarios–Adaptation and Mitigation). Berry et al. (2017) bring together key findings from these three projects. Regional integrated assessment modelling was used to compare impacts of low-end (< 2 °C) and high-end (> 4 °C) climate change scenarios for Europe (Harrison et al. 2019b). The authors found that many indicators showed impacts are much greater under HECC in the 2050s and 2080s.

Furthermore, HECC might lead to non-linear and irreversible effects (Steffen et al. 2018) and more severe systemic effects due to cross-sectoral interactions (Harrison et al. 2016) and transnational impacts (Hedlund et al. 2018). Finally, HECC might push ecosystems and societies beyond their limits of adaptation (Dow et al. 2013; Klein et al. 2015) resulting in loss and damage (James et al. 2014).

[3] Projections are often compared with a historical reference period. However, there is a degree of discrepancy, for instance the IPCC AR5 uses 1976–2005 and 1850–1900 as historical baselines.

[4] RCPs, or representative concentration pathways, specify a level of radiative forcing—net energy radiation in W/m^2. RCPs contain information on future levels of greenhouse gases, aerosols and land cover. RCP 8.5 exceeds 8.5 W/m^2 by 2100.

[5] Indicating that this outcome has an assessed likelihood of 33–66%

2.2 Perceptions around HECC

The body of research on perceptions and work practices related to HECC is limited. The IPCC AR5 discussed perceptions of climate change risks and its influence on adaptive capacities and thus vulnerability (Oppenheimer et al. 2014: pp.1050) but not relating specifically to HECC.

Capela Lourenço et al. (2019) found that decision-makers perceived HECC scenarios as neither more likely nor urgent nor useful than lower end scenarios, but that they considered them useful for anticipating the implementation of adaptation action. Similarly, in an interview study in the land resources context in Scotland, Dunn et al. (2017) found that decision-makers generally perceive HECC as having low probability of occurrence. Capela Lourenço et al.'s study (2019), which included three countries and the European level, showed that whilst the uptake of information on HECC did occur, its influence on decisions was very variable and case study contingent.

Finally, terminology might be a barrier to a better understanding of HECC. Within the research community, there is still no universally agreed definition of 'high-end climate change'. The three EU funded studies mentioned above (Berry et al. 2017) consider high-end scenarios in which global average warming exceeds 2 °C in 2100 with respect to pre-industrial levels. However, Capela Lourenço et al. (2014) suggest that high-end scenarios are more usually defined in the range exceeding 4 °C, and this is also the case with some of the EU research (e.g. Harrison et al. 2019a). The Fifth Assessment report of the IPCC (Collins et al. 2013, p. 1055) shows that higher-end RCPs generate global average temperatures that vary quite widely (multimodel mean ± 1 standard deviation range of 3.7 ± 0.7 for RCP 8.5 and 2.2 ± 0.5 for RCP 6). Thus, the mapping between the starting point of modelling and the projected impacts is complex. Within climate change impacts research, a precise definition of HECC is likely to remain elusive. This could also be significant for how the issue is perceived in policy and practice.

2.3 Response to HECC risk

The potentially more severe consequences associated with HECC will require new risk management approaches, as conventional strategies and solutions may not be enough. Extreme sea-level rise (SLR) is the area that has probably been considered the most. Cooper and Lemckert (2012) explored SLR of + 1, + 2 and + 5 m by 2100 and adaptation options for resort cities on the Gold Coast, Australia. They conclude that pre-planned adaptation would probably enable the city to survive SLR of 1 m, whilst an unplanned response would have marginal chances of success. For a 2 m SLR, they contend that even with an adaptation plan in place, the scale of measures required would severely stretch the city's resources. Under a 5 m SLR, they believe that no amount of planning would enable the city to survive as a coastal resort. Reeder and Ranger (2011) addressed SLR and flooding in the Thames Estuary in the UK, finding that it would become difficult to protect London at 5 m.

Environmental or forced migration is a further area that has been studied in some depth as an adaptation response to severe climate change risk (Piguet 2010; Hamza et al. 2010). For example, the HELIX project included case studies of migration to abrupt drying (Longueville et al. 2015) or to accelerated SLR and related changes (Zickgraf 2015) in the focal region of

West Africa. Both studies found that migration dynamics have shifted towards migration for longer periods or over greater distances, although affecting different groups of people differently. It is also thought that further changes could exacerbate the vulnerability beyond the limits of adaptation and lead to 'distress migration' as a strategy of last resort.

Potential responses in the agriculture sector have also been investigated. Parkes et al. (2018) consider how maize yields and crop failure rates are influenced by surface warming levels of 2 °C and 4 °C, using RCP 8.5 scenarios. They examined the efficacy of adaptation methods to mitigate the effects, finding that crops grown with runoff capture water show a smaller change in yields than crops adapted to high temperature stress. Beyond these specific HECC risks, there are more studies considering systemic risks and solutions. Within the complementary EU projects, results underline that HECC together with socio-economic changes most likely will require transformative solutions. That is, solutions are needed that change economic and social systems and tackle the underlying causes of vulnerability and unsustainability.

Transformative (sometimes termed transformational) adaptation (Kates et al. 2012; Lonsdale et al. 2015; Tàbara et al. 2019) has emerged as counterpoint to incremental adaptation, sometimes seen as insufficient to tackle climate change. Transformative adaptation focuses on more radical or disruptive change and long-term adaptation often requiring a change in the objectives and/or functioning of the system to be adapted. It involves addressing root causes and connections among a range of interconnected forces through reinvention and innovation across more than one system (Lonsdale et al. 2015). Criteria include that actions are adopted at a much larger scale, are new to a particular region or resource system, or involve the shifting of such systems to other locations (Kates et al. 2012). A transformative agenda or *paradigm* (Hermwille 2016) might be a suitable response to risks associated with HECC. One aim of proposed 'Transformative Climate Science' (Tàbara et al. 2019) is to understand and support agents' transformative capacities. Hölscher et al. (2019) provide a conceptual framework of capacities for transformative climate governance which enables climate mitigation and adaptation whilst purposefully steering societies towards low-carbon, resilient and sustainable objectives. Frantzeskaki et al. (2019) present a methodology that combines transition management and high-end climate and socio-economic change scenarios to identify sustainability pathways for Europe.

A very different school of thought is the 'wait and see' approach to climate action. This is the argument that we should wait with taking decisions until more information is available, and uncertainty about climate impacts (and the benefits of adaptation) is reduced. 'Wait and see' as a climate policy approach has long been associated with the United States (US) administration. It is also recognised in climate change adaptation research[6]; for example Berkhout et al. (2006) identified it as a relevant organisational strategy, and Jones and Preston (2011) as a form of adaptation risk management. Several authors express concerns about inaction, however. Recently Magnan et al. (2016) designated the 'wait and see' approach as maladaptation, since it actively failed to address known vulnerability.

[6] The economic rationale is that 'wait and see' can avoid the potential waste of resources and lock-in to irreversible investments.

3 Method and material

3.1 Survey development and distribution

Our research centred on perceptions and work practices relating to HECC. Research conferences present a good opportunity for collecting views on a topic such as this, serving as forums to help generate and evaluate certain hypotheses; yet as such they seem underused. If sufficient responses can be obtained, these may arguably represent the views of a specific professional community as a whole. Our focus is on the international community of decision-makers, practitioners and researchers working on climate change adaptation. Given the broad appeal of the conference and the choice of method—i.e. we think surveys are more representative than other approaches such as expert interviews, panel discussions or case studies—we hope to capture general views of the community as a whole, although we also discuss some of the limitations below.

The conference surveys collected participant personal attributes as well as perceptions and practices around HECC and usage of climate change platforms[7] (see Appendix Table 1).[8] The surveys were administered at two consecutive international conferences from the Adaptation Futures series, co-hosted by the World Adaptation Science Programme. Since 2010, the conference has been held every 2 years, and was held in Rotterdam, Netherlands, in 2016 and in Cape Town, South Africa, in 2018, when the surveys were carried out. The conference has become the biggest and most important venue for the international community of adaptation researchers, and its two most recent meetings registered a total of 3000 attendees.[9]

The seven statements used in the HECC surveys were:

1. 'The likelihood of high-end climate change now becoming reality has decreased after the Paris agreement'
2. 'It is easy to find information about potential impacts of high-end climate change'
3. 'It is easy to find information about decision making with respect to impacts, adaptation and vulnerability in the context of high-end climate change'
4. 'We, as a society, have tools in place to deal with impacts from high-end climate change'
5. 'In my work I am considering climate changes of more than 2 degrees C'
6. 'I am using high end climate change scenarios for decision-making processes in the context of adaptation/mitigation'
7. 'We should wait with large-scale adaptation activities until we have more certainty about the impacts of high-end climate change'

The same set of statements were used in both years, so that we could identify significant shifts in opinion. Using respondent attribute information, we were also able to consider occupational and regional differences. Data were collected shortly after the conference—however with the event being held shortly before the summer holiday period (May or June), we sent reminder emails in September in order to maximise the number of responses. We used SurveyMonkey to administer and collect the data and R statistical software (R Core Team 2019) to carry out

[7] Platforms included those available online only, plus online platforms that included other forms of knowledge brokering.

[8] The survey reported here was part of a larger survey also including questions about the conference in general. All delegates who registered received the link to the survey by email from the organisers.

[9] Approximately 1700 in Rotterdam and 1300 in Cape Town.

analyses. The HECC part of the survey collected only 'categorical' data; some questions used a standard 5-point Likert scale and some of them non-Likert ordinal data. A dataset with results from both years is available (Taylor et al. 2020).

3.2 Survey response analysis

There were 259 and 198 responses to the 2016 and 2018 surveys, respectively. A majority of 2016 delegates were based in Europe whereas in 2018 a majority were based in Africa. In both years, a majority of respondents were scientists/researchers but there was also a large sample from government sectors (see Appendix Fig. 4).

We compared HECC survey responses 2016 vs. 2018, and we compared responses by location and by occupation. We also conducted significance tests for differences among response categories. We chose two non-parametric tests that are appropriate here. The chi-square test finds the probability (p) of the distribution of answers to a question remaining the same in 2018 as it was in 2016. This assumes the data is categorical with no repeat answers, so we assume those answering the survey are not the same people in 2016 as in 2018. This seems reasonable because a large majority of the participants said they had not been to any previous Adaptation Futures conferences (80% in 2018 and 85% in 2016). The Wilcoxon-Mann-Whitney (WMW) test tests whether there has been a general shift in opinion rather than a change in the proportions of responses within categories. For both tests, we conclude that there is a significant difference between comparison groups if the p value is less than 0.05.

For comparison tests between those based in different geographical regions and working in different occupational roles, we first considered if the number of responses for each category are sufficient for indicative comparison. We investigated statistical differences for: HECC 2018 questions by Location, Africa vs. Other; 2016 HECC questions by Location, Europe vs. Other; combined 2016/2018 data differences between Europe and Africa. In the latter case, we combined data from both surveys on questions where we observed similarity of the responses. This was deemed a valid way to obtain a population with sample size suitable for comparing Africa and Europe for these questions.

Various occupational categories were included (see Appendix Table 1). For the analyses reported in Section 4, we re-categorised the raw data to obtain fewer categories with larger numbers of observations. Respondents belonging to entities 'Government', 'Government agency' and 'Public policy' were re-categorised as 'Gov Related' and are compared to those belonging to the 'Research organization' category.[10] The main results are presented graphically in 'Likert-plots' (stacked bar charts) for ease of comparison of ordinal data across the two surveys and location and occupation. Statistical test results are also noted (see Appendix Table 2 for full results).

3.3 Limitations

We list four main limitations of the methodology presented above:

First, our sample includes only those participating at conferences. A majority of participants were scientists/researchers and from government; fewer of them represented the other roles or sectors that carry out much of the practical adaptation-related decision-making (e.g. civil

[10] In 2016, "Gov Related" was the second largest category. However in 2018, "NGO" was second largest (i.e. larger than "Gov Related"—see Appendix Fig. 4b).

society, NGOs and consultants). On the other hand, some academics have multiple roles, and may well be familiar with the issues.

A second limitation is the lack of a balanced representation of global regions. It is evident that a conference in Europe will attract more Europeans, a conference in Africa will attract more people from that continent; representation of other regions is much lower and therefore we expect results to be affected and views not captured. As previously mentioned, we collected information on where people said they were based and have to some extent analysed these differences.

A third possible limitation is that HECC is still a relatively new term and for many people could be confusing. For those with high technical expertise our use of the term could be confusing because it hides key information about > 2 °C scenarios, their underlying assumptions and the outcomes they portray. Our survey may be found to be imprecise and confusing. For others, different terms might be used more. For example, following the Paris Agreement, it is quite common to refer to 'dangerous climate change' but this is also problematic because it ultimately involves judgements about acceptable risks.

Finally, despite our effort to define terms and use a precise language, one major problem with internet surveys is that people might interpret the questions—and answer categories—very differently. This is in contrast to face-to-face or telephone interviews, where it is possible to ask for clarification for instance. This is a particular problem with interdisciplinary communities that work with very different types of knowledge and know-how such as is the case with climate change adaptation.

4 Results

We first discuss results that consider the international climate governance system response to the climate's signal (i.e. high emissions despite Paris) (statement 1). We then cover results about the information and tools availability for HECC (statements number 2, 3 and 4). Finally, we discuss what respondents say about what is actually happening in practice in terms of their use of scenarios and views about adaptation actions (statements 5, 6 and 7). However, we add the caveat that these results are based on sampling that is not totally representative having several methodological limitations (see 3.3).

4.1 Can the Paris Agreement prevent dangerous climate change?

We asked whether participants agreed with the statement 'The likelihood of high-end climate change now becoming reality has decreased after the Paris agreement'.

Results show that in 2018, compared with 2016, people consider it less likely that HECC can be avoided. We see significant overall opinion shift with the number disagreeing or strongly disagreeing that the likelihood of HECC has been reduced after Paris (reaching 60% of responses in 2018, up from 42% in 2016) (Fig. 1a; $\chi 2$: $p = 1.049e{-}04$, WMW: $p = 2.047e{-}04$). The proportion of people responding neutrally that they 'Neither agree nor disagree' also reduces greatly.

We then compared governmental and researcher participant perceptions about the impact of the Paris Agreement on the likelihood of avoidance of dangerous levels of climate change (Fig. 1b). Interestingly the results from 2016 show that the research community was significantly more sceptical than the government ($\chi 2$: $p = 0.0205$, WMW: $p = 0.0046$). In

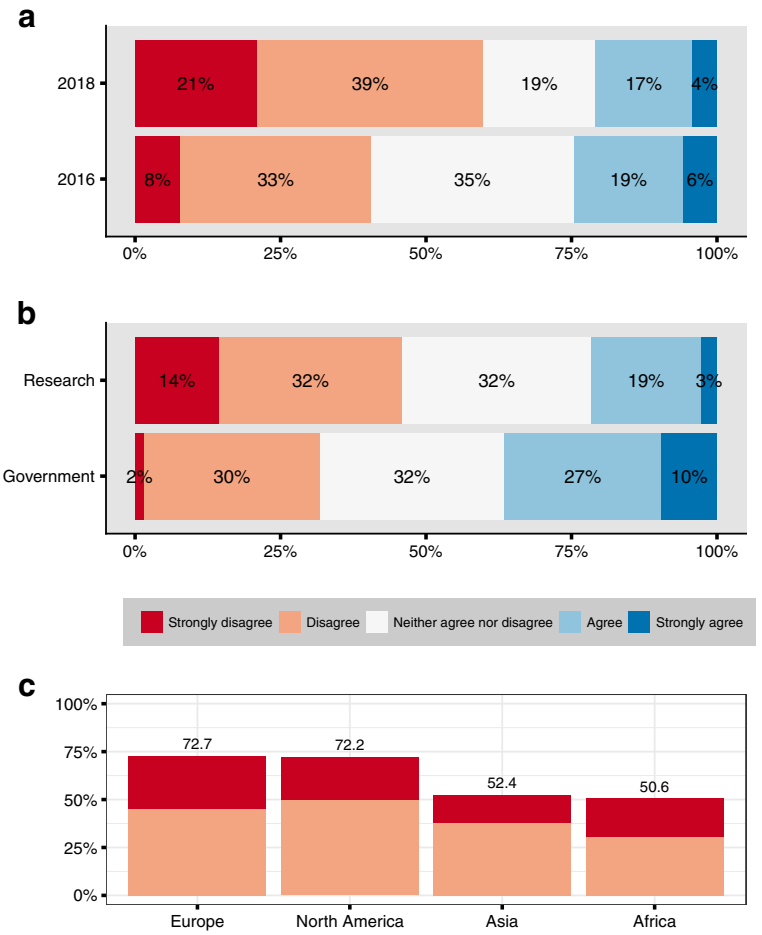

Fig. 1 A comparison of responses to the question about the Paris Agreement **a** for 2016 and 2018, **b** for researcher and government participants in 2016 and **c** percentage of disagree and strongly disagree responses by location of participants in 2016

2016, 46% of researchers and 32% of government professionals disagreed or strongly disagreed (Fig. 1b). In 2018, however, the difference between the two occupational groups on this question was not statistically significant (in fact, in all 2018 questions, there was no evidence that respondents from Governmental and research organisations answered differently). On this particular question about the Paris Agreement in 2018, the overall response was more negative (Fig. 1a) showing the same direction of shift as the researcher response in 2016.

In a final step, we investigated whether there were differences of opinion by location, selecting the most well-represented regions in 2018's survey: Africa, Europe, North America and Asia. We ignored those regions where there were too few responses to give a good indication of opinion (Central and South America, Small Islands, Australasia, Polar regions).

Using 2018 data, we found that Europe and North America both had a very similar level of disagreement, of around 72%, and Asia and Africa had a corresponding figure of around 50–52% (Fig. 1c). Thus, there appear to be some geographical differences of opinion as well as

occupational ones. However, it should be noted that there were insufficient numbers of responses to test significance in this case. Combining categories, we conducted some tests to compare Europe vs. 'Other regions' in 2016 and Africa vs. 'Other regions' in 2018 but the differences were found to be quite minor. Also, because of the shift in opinion on this question, we were not able to combine the datasets from 2016 and 2018 to give a sufficient number of responses to test Europe vs Africa.

4.2 Information on impacts and tools for decision-making under high-end climate change

We enquired about the information and tools availability for HECC through statements 2–4. A striking result was comparative stability of responses between 2016 and 2018 overall (Fig. 2).

First, we asked whether participants agreed with the statement 'It is easy to find information about potential impacts of high-end climate change'. Compared to 2016, in 2018, more people disagreed (30%) with this statement (Fig. 2a), although there was no statistically significant change ($\chi 2$: $p = 0.081$, WMW: $p = 0.4033$). In 2018, only 8% of respondents reported finding this 'Very easy'; therefore, it is clear that there is a lot of room for improvement in this area.

We also asked whether participants agreed with the statement 'It is easy to find information about decision making with respect to impacts, adaptation and vulnerability in the context of high-end climate change'. Around half (46–50%) of respondents found it difficult or very difficult to find information about decision-making in the context of HECC (Fig. 2b). In both surveys, the most common response to the question was 'Difficult' and the least common response was 'Very easy'. Whilst there was no evidence of an opinion shift overall (WMW: $p = 0.8217$), there was a significant change in response ($\chi 2$: $p = 0.0464$) with fewer people selecting 'Neither easy nor difficult' in 2018. These findings suggest that there was no improvement—no progress at all—on ease of finding information either about impacts or about decision-making under HECC.

Finally, we asked participants whether they agreed with the statement 'We, as a society, have tools in place to deal with impacts from high-end climate change'. There were mixed responses to this question across both surveys (Fig. 2c). Compared to 2016, in 2018, fewer people said they agreed; more said they strongly disagreed. However, there were no statistically significant results ($\chi 2$: $p = 0.4564$, WMW: $p = 0.3055$). We also found that in 2016, government-related participants were significantly more in agreement with the statement compared to researchers ($\chi 2$: $p = 0.0241$, WMW: $p = 0.0012$). Overall this question—although in many ways similar to the previous one—revealed more positive responses towards 'tools' than 'information about decision making'. It may suggest that—despite confidence in the availability of suitable tools—accessing decision-relevant information generated by them is a greater challenge.

4.3 Actions on high-end climate change

We looked into what is actually happening on high-end climate change within the climate adaptation community by including statements 5–7.

First we asked whether people agreed with the statement 'In my work I am considering climate changes of more than 2 degrees C'. We find little change between 2016 and 2018 in extent to which people say they are considering HECC in their work. Around 63–65% are considering HECC in their work all the time, or starting to. There was slightly lower use in

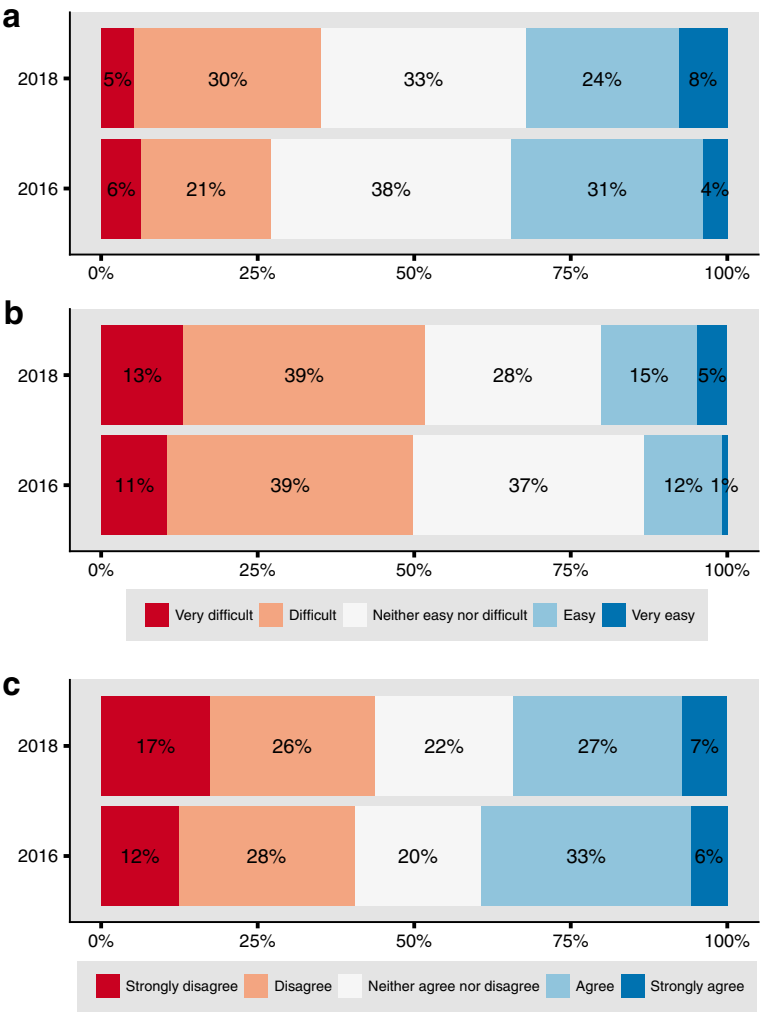

Fig. 2 A comparison of responses in 2016 and 2018 on **a** the ease of finding information about potential impacts of HECC, **b** the ease of finding information about decision-making in the context of HECC and **c** level of agreement with the statement about having tools in place to deal with impacts of HECC

2018 (Fig. 3a) but not significantly lower when tested ($\chi 2$: $p = 0.0902$, WMW: $p = 0.1332$). A small group of people in both surveys said they were not considering HECC. The strong majority for considering HECC seems to be consistent with the earlier finding that people do not think that the likelihood of high-end climate change has decreased with the Paris Agreement.

Due to the similarity of the responses in 2016 and 2018 in the consideration of HECC, we combine results from both years to investigate this same question by location. We find that participants based in Africa consider HECC significantly less frequently overall than those in Europe (Fig. 3b; $\chi 2$: $p = 0.0118$, WMW: $p = 0.0062$). Whereas in Europe around 67% of people are considering HECC in their work all the time, or starting to, in Africa this figure is

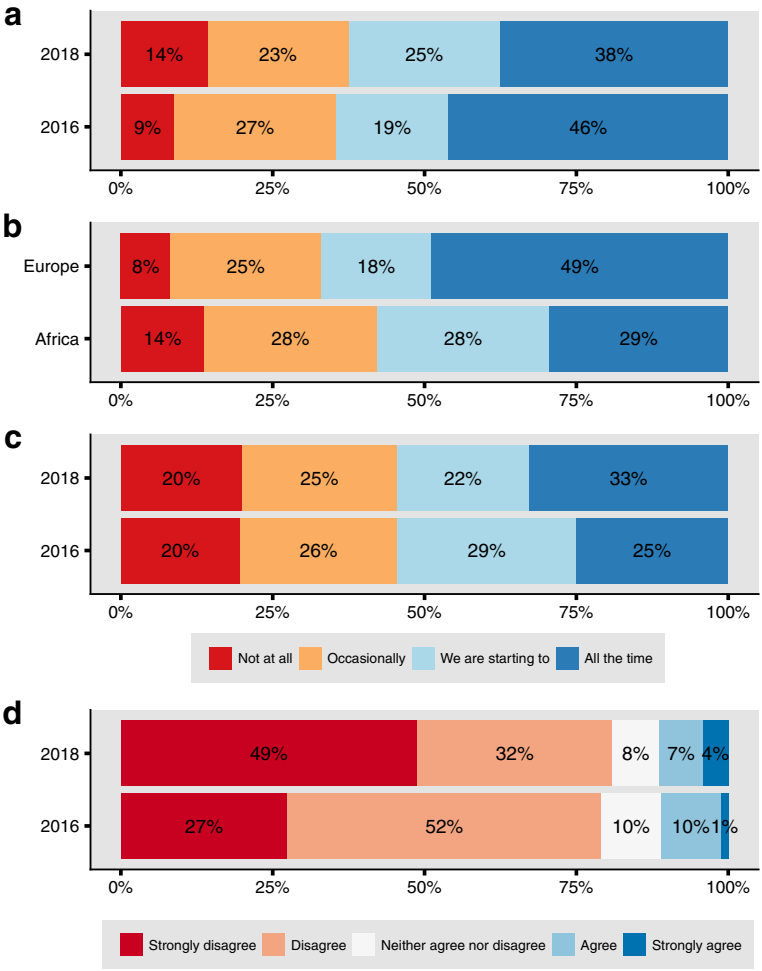

Fig. 3 **a** A comparison of responses in 2016 and 2018 about whether people consider more than 2 °C in their work, **b** comparing the extent to which people based in Europe and Africa consider HECC in their work, **c** comparing responses in 2016 and 2018 about whether people consider HECC scenarios in decision-making and **d** comparing responses in 2016 and 2018 about waiting with large-scale adaptation activities until we have more certainty

around 57%. Those considering HECC 'Not at all' numbered 14% in Africa and 8% in Europe.

Second, we asked whether people agreed with the statement 'I am using high end climate change scenarios for decision-making processes in the context of adaptation/mitigation'.

Fifty-four to 55% of respondents said they were using high-end climate change scenarios for decision-making processes 'all the time' or were starting to, with a share of around 20% saying that they were using them 'not at all'. The responses were quite invariable between the 2016 and 2018 surveys (Fig. 3c) showing no significant differences ($\chi 2$: $p = 0.247$, WMW: $p = 0.4755$).

Our final question concerns perceptions for how society should deal with impacts of HECC. We asked whether people agreed with the statement 'We should wait with large-

scale adaptation activities until we have more certainty about the impacts of high-end climate change'. Results show a strong majority for not waiting for more certain information (Fig. 3d). This sits at around 80% (disagreement or strong disagreement with the statement) in both surveys. However, people disagree more strongly in 2018 than they did in 2016. There was a significant shift in opinion ($\chi 2$: $p = 3.096e{-}05$, WMW: $p = 0.001$). In 2018, 49% of people strongly disagreed. A minority of around 11% agrees or strongly agrees with waiting, and a minority selected the neutral response. However, the majority verdict is quite clear: this rejects the 'Wait and see' approach and recommends immediate action on large-scale adaptation activities in response to the risks of HECC.

4.4 Usage of climate change knowledge platforms

We included a supplementary question to measure participants' use of platforms for climate change information in general: 'Which of the following knowledge platforms do you use in your work?' (Appendix Table 1). Results are included in our supplementary material (ESM). For the 2018 survey we identified 25 platforms through a review of the landscape, including global, regional and community knowledge platforms with online presence (but excluding institutional websites), noting that some of them may not reach beyond a 'niche' of users. Findings revealed low usage of platforms overall. Half of the platforms had never been used by at least 75% of those responding to the survey. Seven of the platforms had been used by at least 50% of respondents; however, most of these users said they were occasional users; a minority described themselves as frequent users. Low use suggests that platforms are not currently as effective in communicating climate information to adaptation professionals as might be desired.

5 Discussion

5.1 Understanding participants' scepticism towards the Paris Agreement

Results reflect a perceived lack of progress on climate goals, in the post-Paris Agreement era. The surveys took place at a time when the legal and scientific ramifications of the Paris Agreement were coming under closer scrutiny and increasing political pressure. The 2016 conference was post-Paris, but before the Trump administration announced that the US would be withdrawing from the agreement, an action that may have had some impact on perceptions.[11] Meanwhile, the science has focused on 1.5 °C. When the 2018 conference took place, the draft summary of the 1.5 °C report was available but the Paris Rulebook, the compilation of the rules and guidelines needed to put the 2015 Paris Agreement into practice, was not yet agreed.

Our result shows that overall opinion can shift quite rapidly on key provisions of the climate governance system. It highlights the fact that confidence and trust in the process is precarious. Many commentators have criticised the Agreement for the lack of a legally binding obligation (e.g. Bawden 2016; Sharma 2017), lack of provision for climate financing and its effectiveness (e.g. Müller 2016; Sharma 2017), for lack of clarity on 'loss and damage' (e.g.

[11] Since the June 1, 2017 announcement, the US State Department have continued to attend negotiations whilst the country remains in the agreement. Meanwhile, US companies, cities and states have vowed to continue to cut emissions.

Sharma 2017), for transparency and comparability of its NDC mechanisms (e.g. Pauw et al. 2018) and for the 'emissions gap' not addressed (e.g. Victor et al. 2017; UNEP 2018). Yet the Paris Agreement was important for raising the profile of adaptation. Research priorities have also shifted. It has been suggested that adaptation research has entered a fourth generation, focused on implementation questions, whilst continuing to build on past areas of inquiry (understanding climate change impacts, defining adaptation's core concepts and interactions and adaptation policy and financing mechanisms) (Klein et al. 2017; Dzebo and Stripple 2015).

Why did researchers have more pessimistic views on the Paris Agreement than government-related participants in the 2016 survey (Fig. 1b)? A conventional explanation is that researchers are trained in different ways to government employees/civil service which might lead them to question such a proposition more critically. On the other hand, it is obvious that the sectors are linked to different sources of information, and they process information through different filters. Scientific and political processes around climate change develop at different rates, but there are many ways in which they affect one another. For instance, research findings can contribute to pressure on governments to revisit their pledges and actions and make them more transparent and accountable, realigning them with what is actually happening, which also would provide a further important role for researchers (Victor et al. 2017). Interestingly in 2018, the scientific and government representatives surveyed were equally sceptical about the Paris Agreement.

5.2 Reviewing information provision and decision relevance

One of the most important questions concerns how well-informed participants feel about HECC and its potential challenges, which imply 'preparing for higher levels of adaptation than we hope are necessary' (Capela Lourenço et al. 2019). With statement 3, we aimed to understand respondents' views on the quality of information for decision-making, considering that not all information about potential impacts under HECC might be directly relevant. The fact that around half of respondents (see Fig. 2b) found it difficult or very difficult to find information about decision-making in the context of HECC is therefore worrying. 'Decision-first' approaches to adaptation have become more important as climate information needs have changed (Watkiss 2015). However, it is also claimed that decision-making under HECC does not imply an extrapolation of decision-making under moderate climate change (Stafford-Smith et al. 2010). For higher levels of adaptation, information about conventional strategies and solutions used in adaptation decision-making is not particularly useful. Thus, one gap is information sources for identifying and comparing long-term interventions that might be needed under HECC.

Around a third of participants said they have difficulty finding information about potential impacts, but a similar number thought the opposite. These differences suggest that information might not be available in a consistent way across different levels of action, sectors and disciplines. However, comparisons based on participant location or occupation show no differences. Detecting patterns in information access merits further investigation. The overall lack of improvement in responses to statements 2–4 are disappointing and underline that the adaptation community needs to better support exchange of information and data between all actors, and to conduct new research to address knowledge gaps. Using more sophisticated, integrated scenarios that include other types of knowledge, providing decision-relevant knowledge specific to HECC, and considering policy responses that include large-scale adaptations will be necessary.

At present, there is very little research about communication of HECC information specifically. According to Tàbara et al. (2017) 'a major difficulty in the assessment and communication of HECC is dealing with potential system discontinuities, abrupt changes and tipping points and their implications for policy'. Our surveys confirm that provision of HECC information is challenging but do not provide insight into why this is the case. Partial answers can be found from smaller, qualitative surveys about limitations to the use of climate change information. Tàbara et al. (2017) found that Spanish knowledge contributors found little actionable use for IPCC information: it was overly complicated, not specified at the local level and not sufficiently oriented towards solutions. Similarly, Capela Lourenço et al. (2019) reported that information is not usable because (i) it is not adequately tailored to the decision-making circumstances (e.g. variables, spatial and timescales), (ii) there is a lack of cross-sectoral information and it is often not presented in a format that is usable (or translated out of 'researcher language'), and (iii) some barriers on the usage of data formats still remain. HECC information—characterised by an unclear terminology, scarce evidence, high uncertainty and potentially profound changes and interactions—may be particularly complicated. To the three reasons above, we add a fourth: (iv) HECC information does not adequately integrate socio-economic factors that determine future vulnerabilities and adaptive capacities (as well as human pressures on the climate system) into assessments of scenarios.

Arguably, information and tools are becoming increasingly available e.g. through 'knowledge brokers' but remain very difficult to find. Hammill et al. (2013) observed that the climate change information landscape is very fragmented and confusing. There is information overload and the sector is overcrowded with different platforms and products. The landscape is also changing fast, and moving from a supply-driven to a climate service-driven production system that takes greater account of participants needs (Capela Lourenço et al. 2016). Climate services are focused on the need for user-centred products and the format of delivery. In this context, it is revealing that participants make scant use of knowledge brokering platforms' services. It suggests that platforms are not currently as effective in communicating climate information to adaptation professionals as might be desired.

The relatively high number of responses to our surveys suggests that the term 'high-end climate change' is meaningful for many in the adaptation community. However, it joins the already crowded field of climate change jargon. In our opinion, it is important to define it more carefully and consistently in relation to other terms like 'dangerous climate change' and more precisely in relation to the use of scenarios in order to avoid confusion.

5.3 Considering action on high-end climate change

Results show that around two thirds of people consulted are considering HECC or using high-end scenarios in their work all the time, or starting to (Fig. 3). However, this is still not done as a matter of course by all. In addition, we recognise that to 'consider HECC' could mean different things to different people. It is also possible that some users of climate data do not actually know whether the scenarios they are using exceed 2 °C or not—particularly given that they are not easily labelled by global averages nor by the term 'high-end climate change'. Responses to statements 5 and 6 show that more people are considering HECC whilst not necessarily building this into decision processes, which suggests it is being used in a more conceptual manner. This ties in with the result that around 20% are 'starting to' consider HECC and around 25% are 'starting to' consider scenarios in decision-making.

It also suggests decisions are relatively 'insensitive' to specific levels of global temperature change and tend to focus more on the impacts and consequences at their respective scales or institutional interests (Capela Lourenço et al. 2019). Many institutions may not currently be considering changes above 1.5–2 °C because the IPCC (2018) has focused on the high ambition outcome of the Paris Agreement whilst omitting higher ranges. In this context, HECC information will likely be ignored, get an indifferent reception or be 'unwelcome' because it runs counter to the '2°C remains feasible' narrative (Rayner and Minns 2015).

A possible explanation for regional differences (Fig. 3b) is that there are different needs and priorities for adaptation decision-making and for research in these regions and hence the way people engage is different. Moreover, there might be an information availability and access gap among regions. For example, model projections of impacts are unlikely to be available to the same extent and at the same resolution everywhere. Research specifically on HECC seems to have developed more rapidly in Europe (e.g. Berry et al. 2017; Capela Lourenço et al. 2019; Harrison et al. 2019b). Differences in access to HECC information and opportunities to do research will vary. Part of the reason for this could be lack of funding. The adaptation community does already recognise inequalities through initiatives such as sponsorship for participants from lower-income countries attending the Adaptation Futures conference.

There is a strong and increasing majority for not waiting for more certain information (Fig. 3d). The shift may imply some feeling of urgency around the need for large-scale adaptation activities.[12] Large-scale activities are often equated with government intervention (such as new infrastructure or planning) and/or activities having long lifetimes (e.g. building irrigation systems or flood protection/barriers). On the other hand, large-scale adaptations can be autonomous (not explicitly planned) for example the regreening of the Sahel (Kates et al. 2012). Interventions require higher budgets compared to 'softer' measures such as institutional or behavioural changes, and might seem riskier (i.e. to risk a waste of resources if climate changes turn out to be manageable in the long term). However, our result suggests that people consider the risks of inaction to be higher. Some people might actually consider some large-scale adaptations to be 'no-regrets' strategies. This could particularly be the case if the activities are synergistic with sustainable development goals. Other studies show that uncertainty is not generally perceived as a barrier to action (Capela Lourenço et al. 2019) and our result is consistent with this.

6 Conclusions and key policy implications

High-end climate change is becoming increasingly plausible, as emissions continue to rise. Society is ill-prepared for the specific threats posed by high-end impacts that many in the adaptation community recognise to be likely to occur. Preparedness must encompass a combination of strategies. Firstly, it requires strengthening research on impacts of HECC, particularly through comparative studies of projections, and on the effects of interactions (including across sectors and across national borders). Impacts research must also include

[12] It is also worth remarking that the 2018 conference took place during the Cape Town water crisis, a time of severe drought, which threatened the water supply at the conference. This first-hand experience of climate risks might have contributed to a growing sense of urgency for adaptation.

the appraisal of adaptation responses to HECC. Secondly, more work needs to be done on improving the applicability of policy support tools—for example by focusing on exploring policy implications of large changes associated with HECC, and by improving support tools' design and delivery. Thirdly, there are gaps in understanding adaptation needs in the context of HECC. These are likely to be considerable—going beyond conventional strategies and solutions. Efforts must focus on understanding large-scale and transformative solutions and providing information about effectiveness of these measures under a wider range of scenarios. Finally, research and tools should be developed in response to these emerging adaptation needs.

One particular gap we identified was information about decision-making in the context of HECC. We suggest prioritising decision-making (i.e. adopt 'decision-first' approaches) in future adaptation assessments. Further assessments are needed to reveal differences between the now relatively well-charted lower end (1.5–2 °C) and HECC scenarios of more than 2 °C, and this information needs to be available to inform decision-making. Crucially, support for adaptation decisions requires that both societal drivers, which determine vulnerabilities and the capacity to cope and adapt, and climate scenarios, which determine changes in temperature and precipitation and show subsequent impacts, be analysed together. In the current scenario framework (Van Vuuren et al. 2014), socio-economic and climate change scenarios are developed in parallel, and then integrated in a subsequent step. Further HECC assessments should employ a combinatory approach in order to express the full complexity of scenarios (Carlsen et al. 2017). HECC information also needs to be better contextualised by representing more relevant scales (i.e. disaggregated resolution) and sectors of action in the assessments, along with considering regional and institutional factors.

Despite the lack of preparedness for responding to potential challenges of HECC, and the noted gaps in information, there is an emerging consensus for the need to take action through large-scale adaptation, without delay. To build on this consensus, those working in this field will need to improve communication about how the specific needs for adaptation change under HECC. This is important because large-scale adaptation concerns everyone, and will require collaboration across a diverse set of actors and sectors for effective implementation. An important step will be to build awareness of the information available on HECC and the capacity within key institutions to use this information. Our survey of the use of climate change knowledge platforms suggests that resources are being invested in platforms that are ultimately used by very few people. This is unsustainable: either we need to advertise and promote these knowledge platforms much more actively or we should not develop them at all. Platforms that work exclusively in an online environment might be far less effective than alternatives that focus mainly on providing offline training on climate change and adaptation.

Acknowledgements The authors would like to thank the organisers of the Adaptation Futures conferences in Rotterdam and Cape Town and would like to thank Yuxun Ling and Ewan Davies at Oxford University for their help with the survey analysis.

Funding information This study was funded by the European Union's Seventh Framework Programme (grant agreement no. 603416) and by Formas – the Swedish Research Council for Sustainable Development (grant number 2017-01144).

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Appendix 1

Table 1 The high-end climate change conference survey

At the COP 21 in Paris world leaders agreed to: 'Holding the increase in the global average temperature to well below 2 °C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5 °C above pre-industrial levels'. However, the legal document does not specify any tools or mechanisms to achieve this goal. The latest estimates by the UN show that a 2.7–3 °C increase in temperature is likely by the end of the twenty-first century based on current mitigation efforts. Furthermore, there are other estimates that the temperature increase can be even higher, possibly up to 4 °C or 5 °C if, for example, the climate system is more sensitive than was originally thought.

This survey aims to assess current views on high-end climate change, here defined as temperature increase exceeding 2 °C at the end of the century.

(Please, note the results of this survey will be treated with anonymity).

* Required

1. In my work I am considering climate changes of more than 2 degrees C

All the time | We are starting to | Occasionally | Not at all | Other

2. The likelihood of high-end climate change now becoming reality has decreased after the Paris agreement

Strongly agree | Agree | Neither agree nor disagree | Disagree | Strongly disagree

3. I am using high end climate change scenarios for decision-making processes in the context of adaptation/-mitigation

All the time | We are starting to | Occasionally | Not at all | Other

4. It is easy to find information about potential impacts of high-end climate change

Very easy | Easy | Neither easy nor difficult | Difficult | Very difficult | Not relevant to my work

5. It is easy to find information about decision making with respect to impacts, adaptation and vulnerability in the context of high-end climate change

Very easy | Easy | Neither easy nor difficult | Difficult | Very difficult | Not relevant to my work

6. We should wait with large-scale adaptation activities until we have more certainty about the impacts of high-end climate change

Strongly agree | Agree | Neither agree nor disagree | Disagree | Strongly disagree

7. We, as a society, have tools in place to deal with impacts from high-end climate change

Strongly agree | Agree | Neither agree nor disagree | Disagree | Strongly disagree

8. Please indicate your gender (optional):

Male | Female

9. Please indicate your age (optional)

20–29 | 30–39 | 40–49 | 50–59 | > 60

10. Where are you based?*

Africa | Europe | Asia | Australasia | North America | Central and South America | Polar Regions | Small Islands

11. Please, select the type of entity:* Please choose the one which is the best description

Public policy | Research organisation | Government | Government agency | Business | Consultancy | NGO | Other

12. What is the geographical focus of your entity/interest?* Please tick as many as are relevant

Local | Municipal | Regional | National | International

S. Which of the following knowledge platforms do you use in your work? (optional) I have never used this platform / I use this platform occassionally / I use this platform frequently.Please tick as many as apply

1. UNFCCC Adaptation Knowledge Portal
2. Africa Adapt
3. India Environment Portal
4. ICIMOD

Table 1 (continued)

5. Gobeshona
6. Tonga ECC
7. The Climate and Development Knowledge Network (CDKN)
8. Adaptation Community
9. Adaptation Learning Mechanism (ALM)
10. Climate Impacts Global and Regional Adaptation Support Platform (ci:grasp)
11. Global Adaptation Network (GAN Adapt)
12. Eldis
13. AdaptationPartnership
14. ClimateTechWiki
15. 100 Resilient Cities
16. Info Amazonia
17. AdaptaCLIMA
18. Asian Cities Climate Change Resilience Network (ACCCRN)
19. Climate-ADAPT
20. weAdapt
21. UNISDR PreventionWeb
22. Caribbean Community Climate Change Centre
23. PANORAMA - Solutions for a Healthy Planet
24. The Adaptation Network
25. Pacific Climate Change Portal

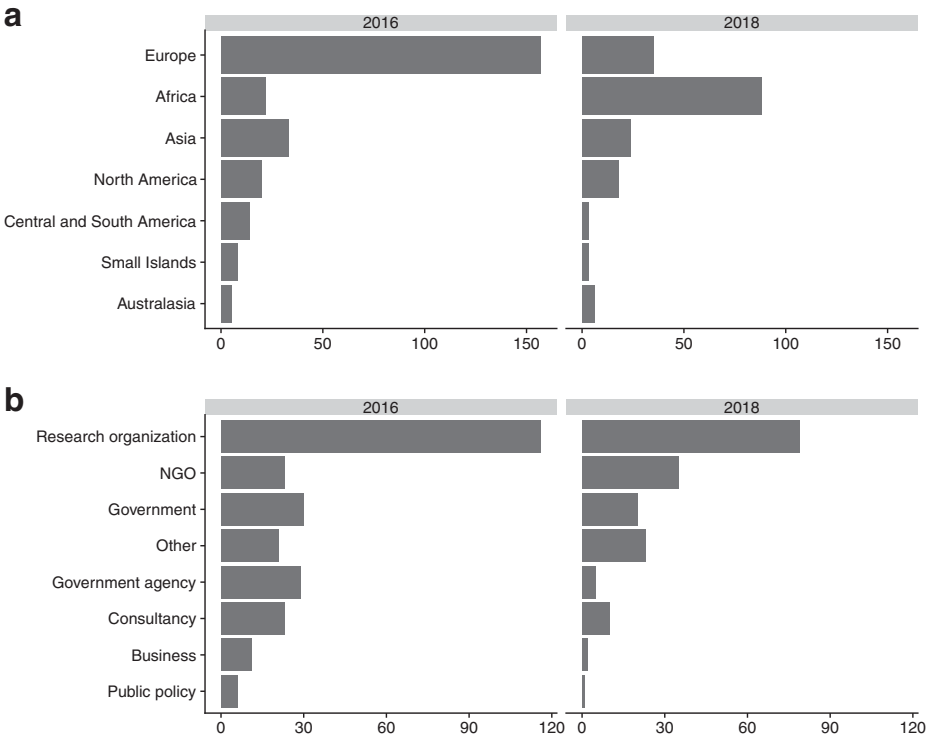

Fig. 4 Number of responses to the surveys **a** by location and **b** by organisational affiliation

Table 2 Results of the comparative tests for significant differences between two samples. We show p values for Pearson's chi-squared test and Wilcoxon-Mann-Whitney tests. The former tests for any significant change in response categories, whilst the latter tests for overall shift in response. Asterisks denote significant results. See Section 4 for discussion of these results

Responses compared	Statement #	χ^2 test	WMW test
2016 and 2018 (see Fig. 1a)	1	1.049e−04*	2.047e−04*
2016 and 2018 (see Fig. 2a)	2	0.0810	0.4033
2016 and 2018 (see Fig. 2b)	3	0.0464*	0.8217
2016 and 2018 (see Fig. 2c)	4	0.4564	0.3055
2016 and 2018 (see Fig. 3a)	5	0.0902	0.1332
2016 and 2018 (see Fig. 3c)	6	0.2470	0.4755
2016 and 2018 (see Fig. 3d)	7	3.096e−05*	0.0010*
'Research' and 'Gov. related' in 2016 (see Fig. 1b)	1	0.0205*	0.0046*
'Research' and 'Gov. related' in 2016	2	0.6513	0.7361
'Research' and 'Gov. related' in 2016	3	0.4758	0.4495
'Research' and 'Gov. related' in 2016	4	0.0241*	0.0012*
'Research' and 'Gov. related' in 2016	5	0.7009	0.4957
'Research' and 'Gov. related' in 2016	6	0.09919	0.8984
'Research' and 'Gov. related' in 2016	7	0.604	0.4459
'Research' and 'Gov. related' in 2018	1	0.9373	0.5817
'Research' and 'Gov. related' in 2018	2	0.5659	0.1748
'Research' and 'Gov. related' in 2018	3	0.4707	0.7217
'Research' and 'Gov. related' in 2018	4	0.4791	0.4755
'Research' and 'Gov. related' in 2018	5	0.4723	0.6624
'Research' and 'Gov. related' in 2018	6	0.1347	0.1347
'Research' and 'Gov. related' in 2018	7	0.5398	0.3968
'Europe' and 'Africa' combining 2016 and 2018 responses (see Fig. 3b)	5	0.0118*	0.0062*
'Europe' and 'Africa' combining 2016 and 2018 responses	6	0.2948	0.5709

References

Alfieri L, Feyen L, Dottori F, Bianchi A (2015) Ensemble flood risk assessment in Europe under high end climate scenarios. Glob Environ Chang 35:199–212. https://doi.org/10.1016/j.gloenvcha.2015.09.004

Bawden T (2016) COP21: Paris deal far too weak to prevent devastating climate change, academics warn. The Independent

Berkhout F, Hertin J, Gann DM (2006) Learning to adapt: organisational adaptation to climate change impacts. Clim Chang 78:135–156

Berry PM, Betts RA, Harrison PA, Sanchez-Arcilla A (2017) High-end climate change in Europe. Pensoft Publishers, Sofia

Capela Lourenço TC, Rovisco A, Groot A (2014) Making adaptation decisions under uncertainty: lessons from theory and practice. In: Adapting to an uncertain climate. Springer International Publishing, Heidelberg, pp 139–162

Capela Lourenço TC, Swart R, Goosen H, Street R (2016) The rise of demand-driven climate services. Nat Clim Chang. https://doi.org/10.1038/nclimate2836

Capela Lourenço T, Cruz MJ, Dzebo A et al (2019) Are European decision-makers preparing for high-end climate change? Reg Environ Chang 19:629–642. https://doi.org/10.1007/s10113-018-1362-2

Carlsen H, Klein RJ, Wikman-Svahn P (2017) Transparent scenario development. Nature Climate Change 7: 613–613. https://doi.org/10.1038/nclimate3379

Collins M, Knutti R, Arblaster J, et al (2013) Long-term climate change: projections, commitments and irreversibility. In: Climate change 2013: the physical science basis. Contribution of Working group 1 to the Fifth Assessment Report of the International Panel on Climate Change (IPCC). Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA

Cooper JAG, Lemckert C (2012) Extreme sea-level rise and adaptation options for coastal resort cities: a qualitative assessment from the Gold Coast, Australia. Ocean Coastal Manag 64:1–14. https://doi.org/10.1016/j.ocecoaman.2012.04.001

de Longueville F, Gemenne F, Ozer P (2015) Perception des changements de précipitation et migration au Burkina Faso. In: Actes du 28e Colloque International de l'Association Internationale de Climatologie. Université de Liège, pp 457–462

Dow K, Berkhout F, Preston BL et al (2013) Limits to adaptation. Nat Clim Chang 3:305. https://doi.org/10.1038/nclimate1847

Dunn M, Rounsevell MD, Carlsen H et al (2017) To what extent are land resource managers preparing for high-end climate change in Scotland? Clim Chang 141:181–195. https://doi.org/10.1007/s10584-016-1881-0

Dzebo A, Stripple J (2015) Transnational adaptation governance: an emerging fourth era of adaptation. Glob Environ Chang 35:423–435

Frantzeskaki N, Hölscher K, Holman IP et al (2019) Transition pathways to sustainability in greater than 2 °C climate futures of Europe. Reg Environ Chang 19:777–789. https://doi.org/10.1007/s10113-019-01475-x

Golledge NR, Kowalewski DE, Naish TR et al (2015) The multi-millennial Antarctic commitment to future sea-level rise. Nature 526:421. https://doi.org/10.1038/nature15706

Hammill A, Harvey B, Echeverria D (2013) Understanding needs, meeting demands: a user-oriented analysis of online knowledge brokering platforms of climate change and development. International Institute for Sustainable Development

Hamilton LC (2018) Self-assessed understanding of climate change. Climatic Change 151:349–362. https://doi.org/10.1007/s10584-018-2305-0

Hamza M, Morinière L, Taylor R, et al (2010) Emerging issues: forced migration by climate change. In: Fujikura R, Kawanishi M (eds) Climate change adaptation and international development: making development cooperation more effective. Earthscan, p 333

Harrison PA, Dunford RW, Holman IP, Rounsevell MDA (2016) Climate change impact modelling needs to include cross-sectoral interactions. Nature Clim Change 6:885–890. https://doi.org/10.1038/nclimate3039

Harrison PA, Dunford RW, Holman IP et al (2019a) Differences between low-end and high-end climate change impacts in Europe across multiple sectors. Reg Environ Chang 19:695–709. https://doi.org/10.1007/s10113-018-1352-4

Harrison PA, Jäger J, Frantzeskaki N, Berry P (2019b) Understanding high-end climate change: from impacts to co-creating integrated and transformative solutions. Reg Environ Chang 19:621–627. https://doi.org/10.1007/s10113-019-01477-9

Hedlund J, Fick S, Carlsen H, Benzie M (2018) Quantifying transnational climate impact exposure: new perspectives on the global distribution of climate risk. Glob Environ Chang. 52:75–85

Hermwille L (2016) Climate change as a transformation challenge. A new climate policy paradigm? GAIA-Ecological Perspectives for Science and Society 25:19–22. https://doi.org/10.14512/gaia.25.1.6

Hölscher K, Frantzeskaki N, Loorbach D (2019) Steering transformations under climate change: capacities for transformative climate governance and the case of Rotterdam, the Netherlands. Reg Environ Chang 19:791–805. https://doi.org/10.1007/s10113-018-1329-3

IEA (2019) Global energy & CO2 status report—the latest trends in energy and emissions in 2018. International Energy Agency, Paris 28 pp

IPCC (2018) Summary for policymakers. In: Global warming of 1.5°C. An IPCC special report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty. World Meteorological Organization, Geneva, Switzerland

Jackson RB, Quéré CL, Andrew RM et al (2018) Global energy growth is outpacing decarbonization. Environ Res Lett 13:120401. https://doi.org/10.1088/1748-9326/aaf303

James R, Otto F, Parker H et al (2014) Characterizing loss and damage from climate change. Nat Clim Chang 4:938. https://doi.org/10.1038/nclimate2411

Jones RN, Preston BL (2011) Adaptation and risk management. Wiley Interdiscip Rev Clim Chang 2:296–308. https://doi.org/10.1002/wcc.97

Kates RW, Travis WR, Wilbanks TJ (2012) Transformational adaptation when incremental adaptations to climate change are insufficient. Proc Natl Acad Sci 109:7156–7161. https://doi.org/10.1073/pnas.1115521109

Klein RJT, Midgley GF, Preston B, et al (2015) Adaptation opportunities, constraints, and limits. in: Climate change 2014: impacts, adaptation, and vulnerability. Part A: global and sectoral aspects. Contribution of

Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, pp 899–943
Klein RJT, Adams KM, Dzebo A et al (2017) Advancing climate adaptation practices and solutions: emerging research priorities. Stockholm Environment Institute (SEI), Stockholm
Koutroulis AG, Papadimitriou LV, Grillakis MG et al (2018) Freshwater vulnerability under high end climate change. A pan-European assessment. Sci Total Environ 613–614:271–286. https://doi.org/10.1016/j.scitotenv.2017.09.074
Lonsdale K, Pringle P, Turner B (2015) Transformative adaptation: what it is, why it matters & what is needed. University of Oxford, Oxford
Magnan AK, Schipper ELF, Burkett M et al (2016) Addressing the risk of maladaptation to climate change. Wiley Interdiscip Rev Clim Chang 7:646–665. https://doi.org/10.1002/wcc.409
Marquart-Pyatt ST, Jorgenson AK, Hamilton LC (2015) Methodological approaches for sociological research on climate change. In: Dunlap RE, Brulle RJ (eds) Climate change and society. Oxford University Press, pp 369–411
Müller B (2016) Finance in Paris: Non à la nouvelle haute couture impériale! In: Oxford Climate Policy Blog. http://oxfordclimatepolicy.com/blog/finance-in-paris. Accessed 30 Mar 2019
Oppenheimer M, Campos M, Warren R, et al (2014) Emergent risks and key vulnerabilities. In: Climate change 2014: impacts, adaptation, and vulnerability. Part A: global and sectoral aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. In: White and LL (ed). Cambridge University Press, Cambridge, pp 1039–1099
Ostberg S, Schewe J, Childers K, Frieler K (2018) Changes in crop yields and their variability at different levels of global warming. Earth Syst Dyn 9:479–496. https://doi.org/10.5194/esd-9-479-2018
Parkes B, Sultan B, Ciais P (2018) The impact of future climate change and potential adaptation methods on maize yields in West Africa. Clim Chang 151:205–217. https://doi.org/10.1007/s10584-018-2290-3
Pauw WP, Klein RJT, Mbeva K et al (2018) Beyond headline mitigation numbers: we need more transparent and comparable NDCs to achieve the Paris Agreement on climate change. Clim Chang 147:23–29. https://doi.org/10.1007/s10584-017-2122-x
Piguet E (2010) Climate and migration: a synthesis. In: Afifi T, Jäger J (eds) Environment, forced migration and social vulnerability. Springer, Berlin, pp 73–85
Portmann FT, Döll P, Eisner S, Flörke M (2013) Impact of climate change on renewable groundwater resources: assessing the benefits of avoided greenhouse gas emissions using selected CMIP5 climate projections. Environ Res Lett 8:024023. https://doi.org/10.1088/1748-9326/8/2/024023
Rayner T, Minns A (2015) The challenge of communicating unwelcome climate messages. Tyndall Centre for Climate Change Research Working Paper, pp 162
R Core Team (2019) R: a language and environment for statistical computing
Reeder T, Ranger N (2011) How do you adapt in an uncertain world? Lessons from the Thames Estuary 2100 project. World Resources Institute, Washington DC
Rogelj J, den Elzen M, Höhne N et al (2016) Paris Agreement climate proposals need a boost to keep warming well below 2 °C. Nature 534:631–639. https://doi.org/10.1038/nature18307
Schewe J, Heinke J, Gerten D et al (2014) Multimodel assessment of water scarcity under climate change. Proc Natl Acad Sci 111:3245–3250. https://doi.org/10.1073/pnas.1222460110
Sharma A (2017) Precaution and post-caution in the Paris Agreement: adaptation, loss and damage and finance. Clim Pol 17:33–47. https://doi.org/10.1080/14693062.2016.1213697
Sherwood SC, Huber M (2010) An adaptability limit to climate change due to heat stress. Proc Natl Acad Sci 107:9552–9555. https://doi.org/10.1073/pnas.0913352107
Stafford-Smith M, Horrocks L, Harvey A, Hamilton C (2011) Rethinking adaptation for a 4°C world. Phil Trans R Soc A 369:196–216. https://doi.org/10.1098/rsta.2010.0277
Steffen W, Rockström J, Richardson K et al (2018) Trajectories of the Earth System in the Anthropocene. Proc Natl Acad Sci 115:8252–8259. https://doi.org/10.1073/pnas.1810141115
Stevanović M, Popp A, Lotze-Campen H et al (2016) The impact of high-end climate change on agricultural welfare. Sci Adv 2:e1501452. https://doi.org/10.1126/sciadv.1501452
Tàbara JD, Miller D (2012) Reframing public opinion on climate change. In: Hasselmann K, Jaeger C, Leipold G et al (eds) Reframing the problem of climate change: from zero sum game to win-win solutions. Routledge, pp 68–96
Tàbara JD, St. Clair AL, Hermansen EAT (2017) Transforming communication and knowledge production processes to address high-end climate change. Environ Sci Pol 70:31–37. https://doi.org/10.1016/j.envsci.2017.01.004
Tàbara JD, Jäger J, Mangalagiu D, Grasso M (2019) Defining transformative climate science to address high-end climate change. Reg Environ Chang 19:807–818. https://doi.org/10.1007/s10113-018-1288-8
UNEP (2018) The emissions gap report 2018. United Nations Environment Programme, Nairobi
UNFCCC (2015) Adoption of the Paris agreement. UNFCCC, Bonn
van Vuuren DP, Kriegler E, O'Neill BC et al (2014) A new scenario framework for Climate Change Research: scenario matrix architecture. Climatic Change 122:373–386. https://doi.org/10.1007/s10584-013-0906-1

Victor DG, Akimoto K, Kaya Y et al (2017) Prove Paris was more than paper promises. Nat News 548:25
Watkiss P (2015) Mainstreaming climate information into sector development plans: the case of Rwanda's tea and coffee sectors. Climate and Development Knowledge Network
Zickgraf C (2015) "The fish migrate and so must we": the relationship between international and internal environmental mobility in a Senegalese fishing community. San Diego, CA