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COP21 climate negotiators' responses to climate model forecasts

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Policymakers involved in climate change negotiations are key users of climate science. It is therefore vital to understand how to communicate scientific information most effectively to this group[1]. We tested how a unique sample of policymakers and negotiators at the Paris COP21 conference update their beliefs on year 2100 global mean temperature increases in response to a statistical summary of climate models' forecasts. We randomized the way information was provided across participants using three different formats similar to those used in Intergovernmental Panel on Climate Change reports[2,3]. In spite of having received all available relevant scientific information, policymakers adopted such information very conservatively, assigning it less weight than their own prior beliefs. However, providing individual model estimates in addition to the statistical range was more effective in mitigating such inertia. The experiment was repeated with a population of European MBA students who, despite starting from similar priors, reported conditional probabilities closer to the provided models' forecasts than policymakers. There was also no effect of presentation format in the MBA sample. These results highlight the importance of testing visualization tools directly on the population of interest.

Climate change policy whether at a local, national or international scale requires dealing with the presence of uncertainty on many dimensions[4]. These uncertainties may be grouped into two broad categories: those associated with socio-economic, demographic, geo-political and technological drivers; and those associated with the science of climate itself and, in particular, the response of the climate system to increases in CO_2 concentration in the atmosphere. Scientists and advisory bodies such as the Intergovernmental Panel on Climate Change (IPCC) handle and report these uncertainties in different ways. Uncertainties about both categories are typically dealt with by means of multi-model ensembles, either of integrated assessment models[5] or of climate models[6]. These comparison exercises generate distributions of variables of interest, which incorporate model and parametric uncertainty. They are routinely represented and summarized in reports such as the ones produced by the IPCC (see Supplementary Fig. 4 for examples of formats used to represent these uncertainties).

Studies that examine people's response to, and use of, probabilistic information suggest that individuals may treat uncertainty from distinct sources differently[7], and that the communication format can affect how they use this information[1,8]. Concerns have been raised about the implications of uncertainty and its presentation format on their use in climate change decisions[1,3,9–11]. However, little is known about the way policymakers, directly involved in climate negotiations, process and react to the data and projections presented in written discussions and graphical displays (as, for example, in the IPCC summaries for policymakers).

Our goal in this experiment is to investigate climate negotiators' reactions to climate scientific uncertainty and the way it is presented. We address this problem by centring the experiment on a central issue in climate change policymaking: global climate models' projections of global temperatures increase by the year 2100 as a result of current and future greenhouse gas emissions. To make our experiment relevant to the policy debate, we use an emission scenario that builds on the pledged 'nationally determined contribution' (NDC). Our respondents are a unique sample of 217 policymakers attending the Paris COP21 conference, more than half of them being active negotiators (including eight heads of delegations). To investigate the specificities of this population, we compare policymakers' responses with those of 140 European MBA students, trained to play a country role in a climate negotiation simulation.

Our results provide insights into climate negotiators' expectations of future global warming and their reaction to scientific forecasts. Specifically, our experiment enables us to answer four research questions in a real world setting: What are climate policymakers' expectations of future temperature increases? How do climate models' predictions change their expectations? How is the effectiveness of climate models' predictions affected by the way model information and its associated uncertainty is presented? Are climate policymakers different (in their beliefs and use of model predictions) from informed members of the general public?

Related to the first question, Fig. 1 depicts policymakers' *ex ante* beliefs (or priors) about the effects of NDCs on long-term global temperature increase, elicited for four (mutually exclusive and exhaustive) temperature increase intervals. (Only 18% of respondents reported probabilities for the four ranges of temperature increases that summed up to 100%. For the purpose of our analyses we normalized the four subjective probabilities given Q.2 by each individual to add up to 100% (ref. 12)). The respondents Q.3 were not given any information about the emission pathway in the period 2030–2100. Thus, they were free to report probabilities that reflected both their beliefs about future emissions and about the resulting evolution of the temperature. The future deemed most likely is that of 2100 temperature increases of 2–3 °C, followed closely by the 3–4 °C scenario. These scenarios are in line with the debate preceding the Paris conference, with estimates ranging between 2.7 °C and 3.5 °C, as provided by the United Nations Framework Convention on Climate Change (UNFCCC)[13] and Climate Interactive[14] respectively. The median judged probability of 2100 temperature increase below 2 °C is 8%. Although the distribution of probability assigned to this scenario is wide, most respondents did not assign more than a 20% probability to this

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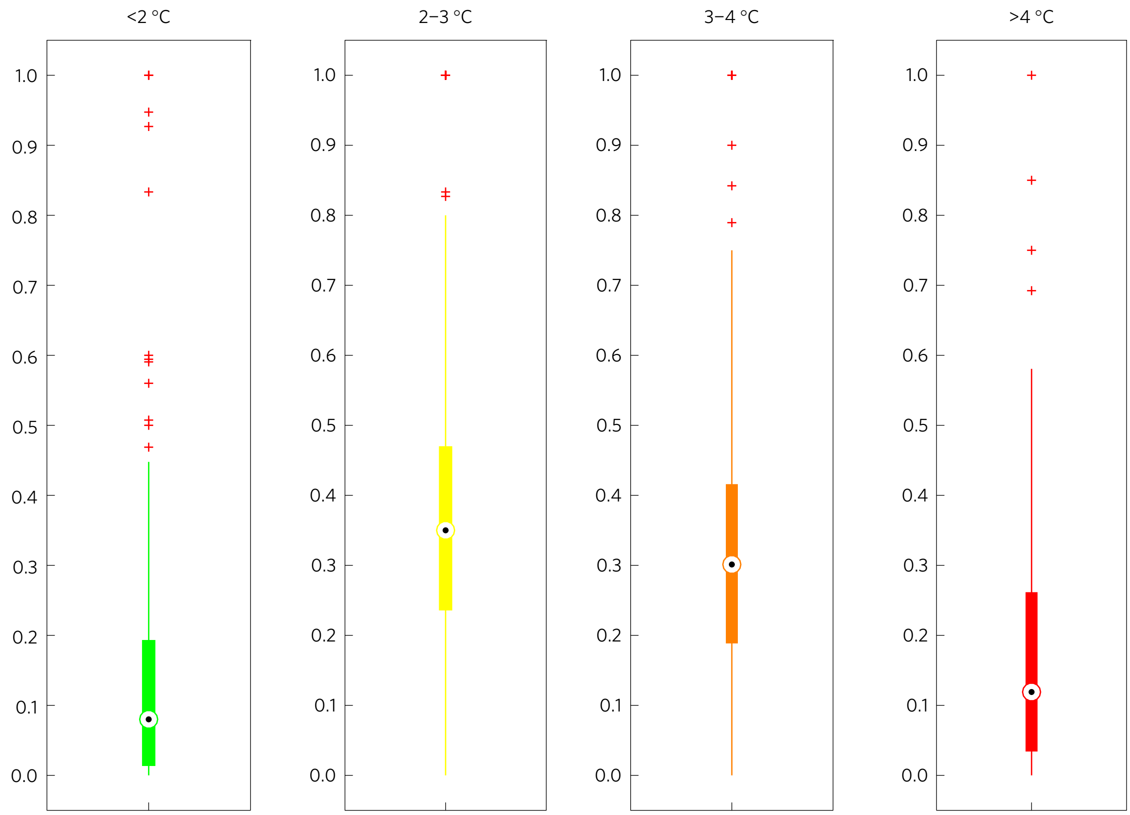

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Figure 1 | Distribution of prior probabilities across temperature bins. The box line shows the median, and the edges are the 25th and 75th percentiles of the sample. Whiskers are 1.5 times the interquartile range away from the top or bottom of the box (covering 99% of the data if normally distributed). Outliers are displayed with a red plus sign. See Supplementary Fig. 5 for the same figure for the student sample.

event. This low probability assigned to the <2 °C scenario is in stark contrast with the stated goal of the Paris agreement that emphasized the need to limit temperature increases to be 'well below 2 °C'. MBA students reported similar prior distributions (Supplementary Fig. 5).

The prior beliefs do not differ for climate negotiators directly involved in the negotiation process versus non-negotiator policymakers present at the Paris conference, and are not associated with other individual characteristics such as age or gender. However, there is evidence of regional differences. We classified respondents into five groups of countries (not mutually exclusive) that are relevant to climate negotiations: vulnerable (countries/regions vulnerable to consequences of climate changes); emerging economy (countries/regions experiencing economy booming); energy exporter (countries/regions that are major exporters of fossil fuels); high emitters (seven highest greenhouse gas emitters); and OECD (Organisation for Economic Co-operation and Development) members (see Supplementary Information 2 for a detailed description of country clusters). Representatives of vulnerable and emerging economies assign a lower probability to the 2–3 °C bin, and a higher one to the high temperature outcome of >4° (see Supplementary Table 1).

To answer our second question, we assess how COP21 policymakers use climate models' predictions when being asked for the probability distribution of 2100 global temperature increase based on a specific emission pathway. Before providing their estimates, policymakers received the range of predictions made by major climate models associated with this specific emission pathway. The projected temperature was shown by means of Q.5 boxplot, displayed in three different formats (see Fig. 3 hereafter). Reported conditional probabilities move clearly in the direction of the climate models' forecasts (19% of the COP21 sample adopt the provided forecasts, almost exactly, while 61% move in the direction of that information). However, policymakers' probability estimates of temperature increases conditional on the specific emission pathway adhere more closely to their unconditional priors than to the forecasts provided (see Supplementary Information 3).

Figure 2 shows the joint distributions of priors and probabilities conditional on the given emission pathway. Respondents with no private information on the validity of alternative climate models' projections could adopt the provided model forecasts, while study participants who are aware of some of the controversies over the forecast could reasonably have given more weight to their own views. Observations along the horizontal black line represent individuals who completely adopt the provided model forecasts as their conditional probabilities. Observations along the diagonal line represent individuals who did not move from their priors at all (respectively 28%, 20%, 24% and 30% of respondents for the four temperature categories, and 18% for all four of them). These figures include those respondents whose prior was right on the mark (1 in the <2 °C scenario and 3 in the >4 °C scenario); hence, they had no reason to change their prior. Confirming previous research[15], more than 80% of respondents did not treat the scientific information as a posterior probability, but rather used it as additional information to update their prior beliefs, mostly in a very conservative fashion (see Supplementary Tables 3 and 4 in Supplementary Information 4 and Supplementary Discussion). Interestingly, in the follow-up experiment with MBA students conditional probabilities are much less close to prior beliefs on average, 25% of the sample almost exactly reporting the provided information (see Supplementary Fig. 6).

Different mechanisms might make respondents anchor on their unconditional priors, when being asked to report the probabilities of the given emission scenario. These mechanisms might furthermore have different impacts on different individuals.

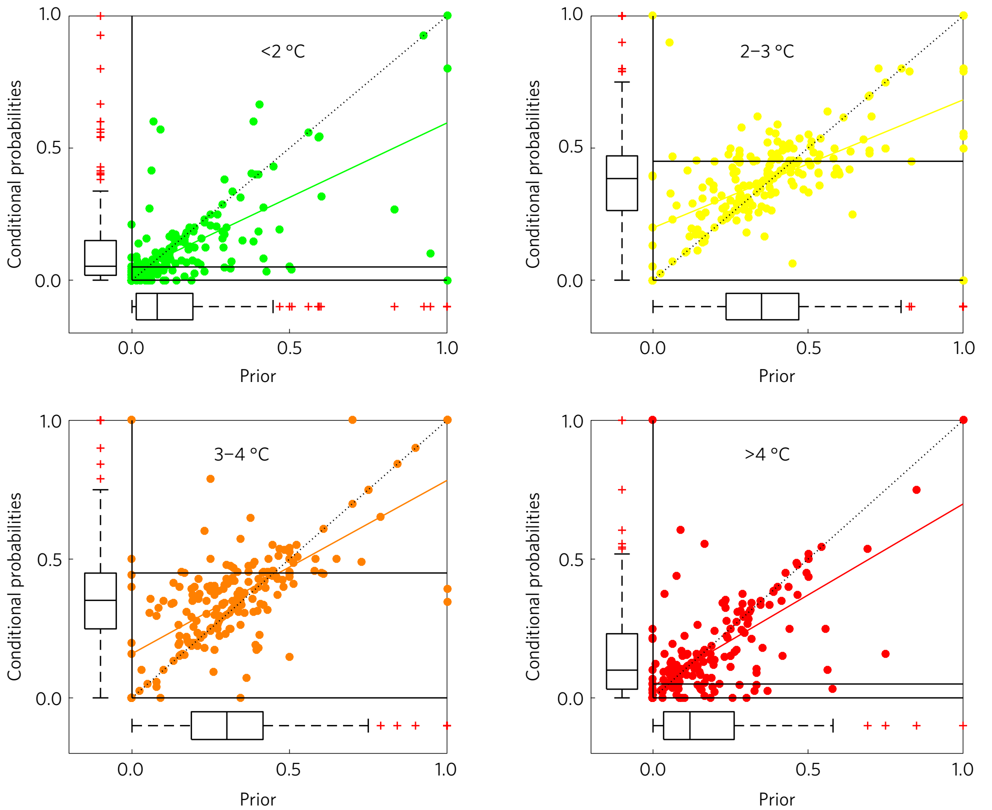

Figure 2 | Scatter plot of the prior and conditional probabilities across temperature bins. Each dot is an observation, the coloured lines represent a linear fit to the data and the black lines represent the scientific information. The bisector line is dotted. Boxplots show the distribution of the prior and conditional probabilities, as in Fig. 1. See Supplementary Fig. 6 for the same Figure for the Student sample.

The first mechanism relates to the confidence respondents have in their priors[16]. We find that reported confidence in the prior (on a 7-point scale) for policymakers (median = 5.00, iqr = 1.75) is higher (Wilcoxon p value = 0.02) than for MBA students (median = 4.0, iqr = 2), with active negotiators and other COP21 participants reporting similar levels of confidence ($p = 0.82$, Wilcoxon test). The difference in confidence could be the result of different perceptions of expertise and power, as confidence in one's own judgement has been shown to negatively affect advice taking[17,18]. For COP21 non-negotiator policymakers, high confidence in the prior is associated with large distances between their reported conditional probabilities and the provided scientific information. In contrast, active negotiators' and MBA students' distance between conditional probabilities and scientific information is independent of their confidence level (see Supplementary Fig. 1).

The negotiators reported conditional probabilities that were more distant from the scientific information than the non-negotiator policymakers in Paris (this is a result robust to the different tests presented in Supplementary Information 4) as well as than the MBA students (Supplementary Table 8). A second possibility is that negotiators (consciously and/or unconsciously) may be more cautious in reporting conditional probabilities that differ from their country's (or block of countries') negotiation position, which is in turn possibly reflected in their priors.

In summary, our data show that, in answer to the second question posed, the policymakers' reported conditional probabilities failed to fully incorporate the scientific information they received. Future research is needed to identify the exact mechanism(s) at play.

Our third question addresses the way uncertain forecasts extracted from scientific models are interpreted as a function of the presentation format. Figure 3 shows different ways of communicating the uncertainty in predictions across climate models (these formats are commonly used in the IPCC 5th Assessment Report and examples are provided in Supplementary Information). Participants were randomly assigned one of the three formats. Format 1 presents the mean and the central 90% of the predictions across scientific models. Formats 2 and 3 provide additional information about model uncertainty, that is, the fact that different models generate different estimates. Format 2 highlights those models whose estimates fall outside the 90% uncertainty range, while Format 3 presents all models' estimates. These formats thus provide information on similarities between models, clustering of predictions, and outliers.

Since the three formats provide increasing details about the underlying scientific uncertainty, we are interested in their relative effectiveness in influencing reported conditional probabilities. Figure 4 shows the proportion of respondents whose conditional probability is closer to scientific information across the four temperature bins for each of the three presentation formats. Providing policymakers with the individual model estimates in addition to the statistical range (Format 3) increases the likelihood of reporting conditional probabilities closer to the scientific information (further analysis is provided in Supplementary Table 7). The >4 °C scenario is the only one where Format 3 is not outperforming the other formats. The respondents judged the three formats to be equally credible (on average 4.6 on a 1–7 scale). However, scientific information provided using Format 3 was perceived as marginally more informative than Format 1 (see Supplementary Table 6 for details). Interestingly, the effect of format is not significant in the MBA student sample (see Supplementary Table 8). These results highlight the importance of testing visualization tools directly on the population of interest.

Although the scientific understanding of the response of the climate system to increases in CO_2 concentration will improve over time, significant uncertainty and disagreements across climate and

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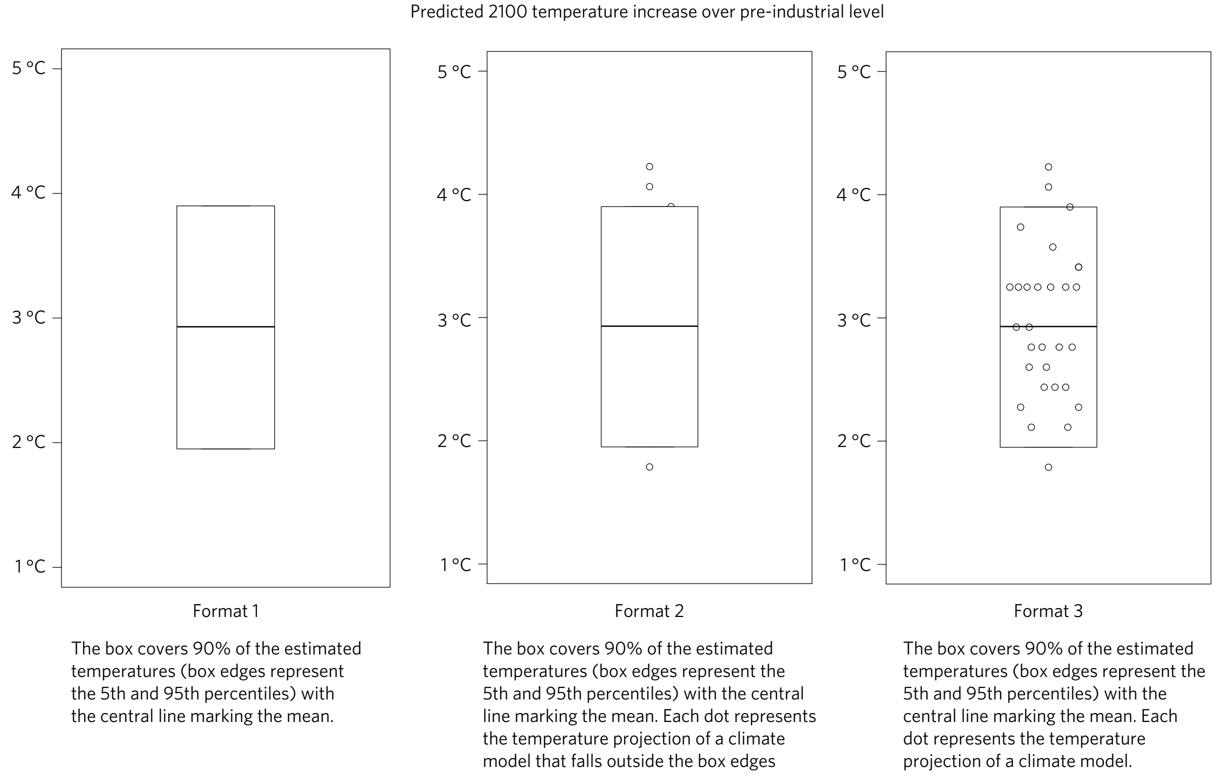

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Figure 3 | Different formats employed across subjects in the presentation of model forecasts.

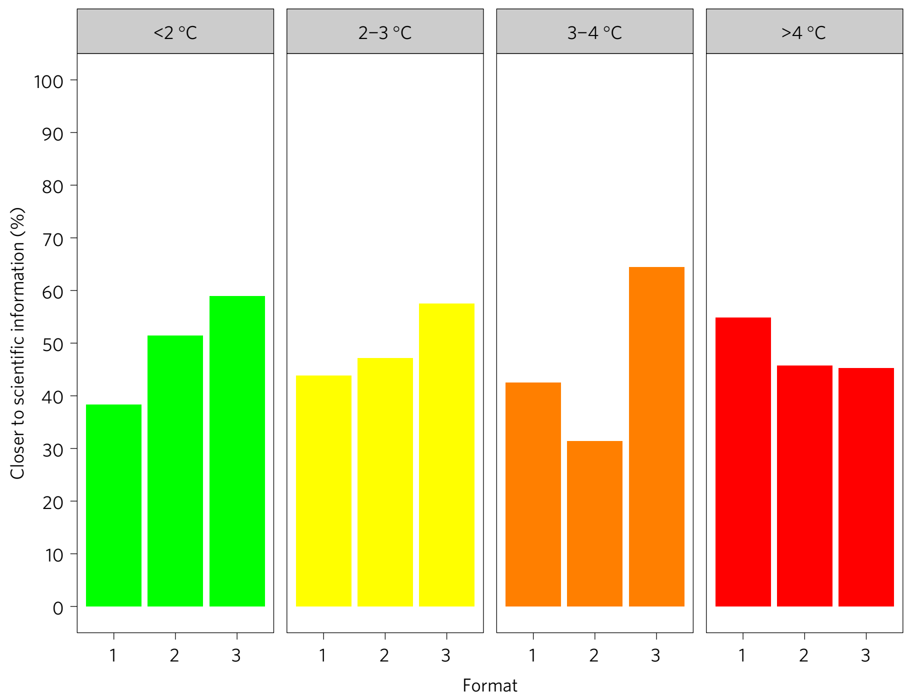

Figure 4 | Proportion of respondents whose conditional probability is closer to scientific information. See Supplementary Fig. 7 for the same figure for the student sample.

economic models are likely to persist[19]. Science communication (and particularly uncertainty communication) will be increasingly relevant in climate change and science-based policymaking. Our results point to the importance of testing behavioural effects targeting the population of interest. Greater efforts need to be devoted to the understanding of how policymakers perceive and react to scientific uncertainty in light of the multiplicity of goals and constituencies and how they are affected by the way it is presented[20] to tailor the communications to the specific problem at hand and the relevant target populations.

Our study provides a unique glimpse at COP21 policymakers' beliefs and responses to climate models' forecasts. The comparison between their responses and those of a climate-educated MBA student population answers our fourth question and reveals two striking behavioural phenomena. The first is a notable anchoring effect[21] of prior beliefs, which is much more pronounced for policymakers. Policymakers, though not distinguishable in their priors from the student sample, were less likely to revise their conditional probabilities in the direction of the model's forecasts (Supplementary Fig. 5 and Supplementary Table 8). The second result, particularly important for future communication of uncertainty to key users, is that the gap between initial beliefs and scientific evidence can be partially reduced by using an adequate presentation format (see Supplementary Table 7). Our results reinforce recent calls for the incorporation of behavioural (in addition to normative) models of judgement and choice into public policy[22] and suggest a more effective, and relatively easy to implement, format to visually communicate scientific information to policymakers. In that sense, application of our results could naturally take place for example in the next assessment report of the IPCC.

Methods

Methods, including statements of data availability and any associated accession codes and references, are available in the online version of this paper.

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Author contributions

All authors were involved in planning the research and designing the experiments. V.B., E.W., L.B. and M.T. carried out the experiment. V.B., M.T. and N.L. analysed the results. All authors contributed to the writing of the paper.

Additional information

Supplementary information is available in the online version of the paper. Reprints and permissions information is available online at www.nature.com/reprints. Correspondence and requests for materials should be addressed to V.B.

Competing financial interests

The authors declare no competing financial interests.

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Methods

We conducted a framed field experiment[23] at the 2015 United Nations Climate Change Conference, COP21, held in Paris. We recruited 217 participants, representing more than 100 countries (the sample composition is described in Supplementary Table 9) and elicited their expectations for global temperature increases by 2100 before testing their responses to climate models' projections. More than half of our respondents were climate negotiators, including eight heads of delegations. The others were non-negotiator policymakers from different communities.

In individual in-person interviews, we prompted policymakers for their prior probability distribution of four different intervals of year 2100 global temperature increases ($<2\,^{\circ}$C, 2–3 °C, 3–4 °C, $>4\,^{\circ}$C), following implementation of current NDCs. We provided policymakers with response scales using the IPCC numeric–verbal format (see Supplementary Information 8).

After eliciting policymakers' prior distributions, we presented them with a specific extrapolation of the NDCs beyond 2030, where global emissions remained roughly constant throughout the century. We then presented policymakers with predicted 2100 temperature increases given that specific emission trajectory that were based on the transient climate response of all 30 climate models included in the 5th Assessment Report of the IPCC, WGI (Table 9.5)[24]. We presented policymakers with the results, shown in either one of the three boxplot formats in Fig. 3. These were introduced as follows: 'the projections (in °C) as estimated by all climate models whose results on transient climate response are reported in the IPCC latest assessment report'. We then elicited the policymakers' projections of long-term temperature conditional on the specified emission scenario ('Based on the projections we have just shown you, and for each of the 4 ranges presented in the table below, could you please indicate the probability (or probabilities) that the temperature will be in that range.'). For this second round, we used again the response template shown in Supplementary Information 1 (in Supplementary Information 8 we report the full questionnaire used in the survey).

Figure 3 shows different ways of communicating the uncertainty in predictions across climate models. Subjects were randomly assigned to one of the three formats. This provides greater accuracy but lower treatment effects than a within-subjects design. When we asked policymakers for the second round of estimates of the probability distribution over possible 2100 temperature increases, we instructed them to consider the specified emission pathway as given, to isolate the impact of climate uncertainty alone. In both rounds of probability elicitation, we asked policymakers to report their level of confidence in their estimates.

In May 2016, a two-day simulation of a post-COP21 climate change negotiation (Climate Change Strategy Role Play held through CEMS - The Global Alliance in Management Education) took place in Erasmus University Rotterdam. This event involved MBA students from seven major European business schools who had received briefings in climate change science and UNFCCC climate negotiations. MBA students were playing the role of delegates to the COP21 process for a representative set of countries. These students had been preparing for this event for several months with documents including detailed background papers. We replicated the key portions of the experiment with a sample of 113 respondents. This MBA student sample is far more knowledgeable, in the content matter of the study, than any usual sample of students, or online survey subjects (because of their selection and preparation for the meeting). However, the students are less driven/influenced in their beliefs by national needs/agendas than actual climate negotiators, as they only play/act or simulate national roles.

For both the Rotterdam and Paris experiments, informed consent was obtained from participants, consistent with procedures of a protocol approved by the Institutional Review Board at Columbia University.

Analysis of priors. We used the STATA command 'sureg' to perform the seemingly unrelated regression[25]. Demographic controls in the regressions are gender, age, number of children, and education (dummy for each category), as responses to questions 1, 2, 3 and 7 in the questionnaire (see Supplementary Information 8).

Description of regional coding. The coding of country/region clusters is based, primarily, on self-reported country represented. Of the 217 subjects, 84 did not provide enough information to allow us to code the country they represent, reporting 'None', 'UN', 'University' or simply nothing. We coded those who did not fill in information according to their reported nationality. In this way, we coded the country/region cluster for 21 more observations.

The sample size is smaller than the total sample as some respondents did not fill either the country they represented or their demographic information.

Vulnerable countries/regions in our sample are: Afghanistan, Antigua and Barbuda, Bangladesh, Barbados, Bhutan, Burkina Faso, Central African Republic, Chad, Comoros, Congo RDC, Equatorial Guinea, Ethiopia, Fiji, Gabon, Ghana, Guatemala, Kenya, Latvia, Lebanon, Maldives, Marshall Islands, Mongolia, Morocco, Mozambique, Myanmar, Nepal, Pakistan, Palau, Panama, Papua New Guinea, Philippines, Somali, Salvador, Sudan, Swaziland, Tunisia, Togo, Tonga, Uganda, Vanuatu, Vietnam and Zambia.

Emerging economy countries/regions in our sample are: Argentina, Bangladesh, Brazil, Chile, China, Colombia, Hungary, India, Indonesian, Malaysia, Mexico, Pakistan, Panama, Peru, Philippines and Poland.

Energy exporter countries/regions in our sample are: Algeria, Australia, Brazil, Canada, China, Colombia, Georgia, Iraq, Latvia, Lebanon, Mongolia, Norway, Netherlands, Qatar, Russia, South Africa, Vietnam and United States of America.

High-emitter countries/regions in our sample are: Brazil, China, European Union, India, Japan, Russia and United States of America.

OECD members in our sample are: Australia, Austria, Belgium, Canada, Chile, Denmark, Finland, France, Germany, Hungary, Ireland, Israel, Italy, Japan, Korea, Luxembourg, Mexico, Netherlands, New Zealand, Norway, Poland, Switzerland, United Kingdom and United States of America.

Analysis of conditional probabilities. We consider four metrics to quantify the difference between reported conditional probabilities and the scientific information. The metrics used in the analyses performed are based on two factors: whether they are based on the differences bin-by-bin or aggregated across the four temperature bins (Overall); and whether they measure the magnitude of change (Continuous) or its direction (Dichotomous).

The following are the four metrics we used as dependent variables in the regressions, the first two continuous, the last two dichotomous.

Overall_dis (continuous, overall): Euclidean distance between overall probability distributions.

Bin_dis (continuous, bin-by-bin): Bin-by-bin absolute distance between probabilities.

Overall_closer (dichotomous, overall): Dummy variable indicating whether the Euclidean distance between the overall distribution of conditional probability and information is smaller (or greater) than the Euclidean distance between the overall distribution of prior and information.

Bin_closer (dichotomous, bin-by-bin): Bin-by-bin dummy variable indicating whether the absolute distance between conditional probability and information is smaller (or greater) than that between prior and information.

Raw versus normalized probabilities. Only 18% of respondents reported probabilities for the four ranges of temperature increases that summed up to 100%.

A large literature has studied 'binary additivity', that is, testing whether $P(\text{Event}) + P(\text{Not Event}) = 1$. In most cases, and on average, this condition is satisfied. However, studies that have looked at partitions of discrete distributions with more than two outcomes, as in our case, all find a different behaviour. Indeed, results from Tversky and Koehler[26] show that additivity in such cases is much harder to Q.12
achieve and in fact quite rare, while subadditivity is more common. Redelmeier *et al.*[27] find evidence of subadditivity in judgements made by doctors. Fox and Birke[28] showed it on lawyers. Fox, Rogers and Tversky[29], on option traders. Finding that $n>2$ events sum to a probability >1 may be driven by a bias toward the 'case partition' ignorance prior of 1/2 for each event (see Fox and Rottenstreich[30]).

We found no significant differences between the COP21 and MBA students' samples in terms of the additivity of their probability estimates of either distributions (priors and conditional probabilities).

For the purpose of our analyses we normalized the four subjective probabilities given by each individual to add up to 100%. Our main findings are robust to the exclusion of subadditive observations for either priors or conditional probabilities. For more information, see Supplementary Table 5, where we test the robustness of results presented to the use of raw data rather than normalized data.

Difference across formats. Figure 4 and Supplementary Fig. 7 report for each temperature bin the proportion of respondents whose reported conditional probability is closer to the scientific information than the corresponding prior.

Respondents were asked to judge the provided information along two dimensions, credibility and informativeness. The range of scales for both variables credibility and informativeness associated with each format is from 1 to 7. There is no difference in credibility across formats (Kruskal–Wallis $\chi^2 = 2.99$, df $= 2$, p value $= 0.22$). Informativeness, however, is marginally different across the formats (Kruskal–Wallis $\chi^2 = 5.00$, df $= 2$, p value $= 0.08$).

Post hoc Dunn's test with Bonferroni correction for two tests reveals that Format 3 is marginally more informative than Format 1 ($p = 0.08$) but there is no difference between Format 1 and Format 2 ($p = 1.00$) or between Format 2 and Format 3 ($p = 0.16$). Note that credibility and informativeness are measured in a between-subject design, so the identified difference in perceptions across formats could be bigger had the subjects been able to see multiple formats. Results are presented in the Supplementary Information (Supplementary Table 6).

Data availability. The authors declare that data supporting the findings of this study are available online. Further information regarding the code used and the data produced are available from the corresponding author on request.

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Query 12:
According to style, author names should be avoided in the text, unless the significance of an author's contribution must be emphasized, or (for readability) where the results of more than one author are being compared. Please check/amend this paragraph (and if the names are to be retained, please note 'Koehelr' changed to 'Koehler' here, to match the reference list. OK?

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Query 13:
Please provide final page number of the range for refs 26 and 28 (if the numbers already provided are article numbers, no action is required).