Gauging Economic Consensus on Climate Change

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Executive Summary

Thousands of economists have spent years or decades studying the interaction between climate change and the economic systems that underlie modern life. The views of these experts can help clarify how climate change will likely affect our society and economy, and how policymakers should approach greenhouse gas emission reduction efforts.

We conducted a large-sample global survey on climate economics, which we sent to all economists who have published climate-related research in the field's highest-ranked academic journals; 738 responded. To our knowledge, this is the largest-ever expert survey on the economics of climate change. The results show an overwhelming consensus that the costs of inaction on climate change are higher than the costs of action, and that immediate, aggressive emissions reductions are economically desirable.

Respondents expressed striking levels of concern about climate impacts; estimated major climate-related GDP losses and a reduction in long-term economic growth; and predicted that climate impacts will exacerbate economic inequality both between countries and within most countries. The economists surveyed also expressed optimism about the viability and affordability of many zero-emissions technologies. And they widely agreed that aggressive targets to reach net-zero emissions by mid-century were likely to be cost-benefit justified.

Survey Details

This project expands on similar surveys conducted by the Institute for Policy Integrity in 2015 and 2009, but uses a larger and more geographically diverse sample. Expert-elicitation projects like this one have recently played an influential role in climate economics, helping establish consensus on such topics as the appropriate "discount rate" to use when evaluating climate policies, and the expected magnitude of climate damages.

We invited 2,169 Ph.D. economists to take a 15-question online survey focused on climate change risks, economic damage estimates, and emissions abatement. Of this pool, 738 participated, a response rate of 34% (not all respondents submitted a response to every survey question, so the sample for some questions is smaller). These economists have all published an article related to climate change in a leading economics, environmental economics, or development economics journal, and their areas of expertise cover a wide range of issues in climate economics. The survey design and related analysis sought to minimize selection bias, response bias, and anchoring bias.

Growing Concern About Climate Change

When asked about their professional opinions on climate change, an overwhelming majority of respondents (74%) said that "immediate and drastic action is necessary." In sharp contrast, less than 1% believe that climate change is "not a serious problem." Compared to our 2015 survey, a significantly larger share of respondents now believe that drastic action is needed, while far fewer believe that more research is needed before action is taken.

Nearly 80% of respondents also self-report an increase in their level of concern about climate change over the past five years, underscoring the high level of overall concern among this group. This broad majority suggests that even respondents who have characterized the situation as urgent in the past may feel that the nature of the climate change challenge is rapidly escalating. When asked to identify items that most affected their views on climate change in recent years, the most common answer by a significant margin was "observed extreme weather events attributed to climate change." The next most influential factors identified were new research findings, both in climate science and in climate economics and the social sciences.

A Threat to Economic Growth

Economists have traditionally modeled climate damages by focusing on changes to GDP in a specific year (i.e., a level impact), but some research has suggested evidence of reduced economic *growth* as a result of current climate impacts. In total, 76% of survey respondents think it is likely or very likely that climate change will negatively affect global economic growth rates. Maybe more notable is the dearth of respondents who find this prospect unlikely (3%) or extremely unlikely (2%).

Increasing Inequality Between Countries and Within Countries

The vast majority (89%) of respondents believe that climate change will exacerbate income inequality between high-income and low-income countries (the upper third of countries by per-capita income versus the lower third). This could create enormous difficulties for many countries that already face profound economic challenges and high rates of poverty.

Approximately 70% of economists also believe it is likely or extremely likely that climate change will exacerbate inequality within most countries (between the lower third of households by household income and the upper third).

The Promise of Zero-Emissions Technologies

Over the last decade, the costs of solar and wind energy technologies have dropped rapidly (-7% annually for solar photovoltaic systems and -4% annually for onshore wind). When asked whether a similar pattern is likely to be replicable for some other emerging zero-emission and negative-emission technologies, 65% of respondents said this is likely or very likely, while less than 3% disagreed.

Economists predict rapid expansion of clean energy technologies, estimating that more than 50% of the global energy mix will consist of zero-emission technologies by 2050—the current share is roughly 10%. They are also bullish about negative-emissions technologies eventually becoming viable, with a majority predicting this during the second half of this century (though a very high percentage of "No Opinion" responses underscores the uncertainty of this projection).

Climate Damages Will Be Very Costly

Respondents were asked to estimate the economic impacts of several different climate scenarios. They project that economic damages from climate change will reach $1.7 trillion per year by 2025, and roughly $30 trillion per year (5% of projected GDP) by 2075 if the current warming trend continues. Their damage estimates rise precipitously as warming intensifies, topping $140 trillion annually at a 5°C increase and $730 trillion at a 7°C increase. As expected, experts believe that the risk of extremely high/catastrophic damages significantly increases at these high temperatures.

Consistent with the view that society can better adapt to climate change if the rate of warming is slower or if society is wealthier, the economists project somewhat lower climate damages in scenarios with slower rates of warming or higher global income. However, even these damage estimates are high, with a loss of at least 4% of GDP expected in each future climate scenario presented (and a 6% GDP loss expected in a scenario with faster warming).

To provide context, another survey question asked respondents to estimate the GDP change in 2020 (this information was not available at the time of the survey, in early February 2021). Respondents' GDP loss estimates for 2020, when a pandemic devastated the global economy, are far smaller than their estimates for annual damages from climate change under a 3°C warming scenario (-3% of GDP vs. -5 %). And unlike the pandemic-related downturn, the climate impacts projected by survey respondents would recur annually (on average) and worsen over time.

The Costs of Inaction Outweigh the Costs of Reducing Emissions

The survey findings reveal a clear consensus that ambitious emissions reductions are likely to cost less than the expected damages from climate change. Respondents overwhelmingly agree that the benefits of reaching net-zero emissions by 2050 would likely outweigh the costs—66% view this as likely or very likely, compared to only 12% who disagree. Respondents' abatement cost projections are higher than estimates from some other sources (roughly 3-4% of GDP in some scenarios). Yet they still clearly indicate that aggressive emissions reduction efforts in line with the Paris Agreement targets are economically justified, as projected economic damages from climate change are far higher.

Costs are often cited as a reason to delay or avoid strong action on climate change, but this survey of hundreds of expert economists suggests that the weight of evidence is on the side of rapid action.

These results can be useful to both policymakers and economic researchers. In particular, economic modelers who calibrate "Integrated Assessment Models" (which calculate the Social Cost of Carbon for use in policy analysis) could use these findings to help ensure that key model assumptions align with the consensus views of experts. The U.S. government is currently reviewing the methodology used for this modeling, and these survey findings could inform improved calibration of several model parameters.

This survey reveals a clear consensus that immediate and meaningful efforts to reduce emissions are needed to limit the enormous economic risks of climate change. Policymakers should heed these findings.

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Why Survey Economists?

Economists whose research focuses on climate change are uniquely qualified to provide insights on the economic risks of climate damages and the appropriate policy responses.[1] Thousands of economists have spent years or decades developing expertise on the interaction between climate change and the economic systems that underlie modern life. Since the 1990s, an entire sub-field of economics has developed to research these issues, with thousands of articles published in peer-reviewed academic journals. Experts in this area are well suited to provide context on such issues as:

- The speed, severity, and regional distribution of climate change's potential economic impacts;
- The dynamics and costs of reducing emissions in key economic sectors;
- The ability of populations to adapt to the impacts of climate change;
- The nature of low-probability climate risks with potentially catastrophic consequences;
- The costs and benefits to both current and future generations of climate policies;
- The dynamics of international cooperation related to climate change.

The consensus views of economists with expertise on climate change can provide valuable insights for policymakers who must weigh the benefits and costs of various climate strategies. Expert-elicitation research has been cited in some important past policy decisions.[2] Additionally, the views of experts can also help advance economic research, including the modeling used to evaluate climate policies.

In order to gauge the views of economists with expertise on climate change, we conducted a large-sample survey of individuals who have published articles about climate change in highly ranked economics journals since 1994. To our knowledge, this is the largest-ever survey of economists' views on climate change. The results of this survey help clarify consensus on some key economic issues related to climate change.

This project expands on a similar survey we conducted in 2015 as well as a 2009 survey conducted by other researchers at the Institute for Policy Integrity (Holladay et al., 2009; Howard & Sylvan, 2015; Howard & Sylvan, 2020).Those surveys revealed widespread consensus that climate change poses dramatic economic risks, that immediate actions to reduce emissions are economically justified regardless of whether other countries have agreed to act, and that the discount rate currently used to evaluate climate policies is inappropriately high, among other findings.

This 2021 survey samples a larger pool of experts than the past surveys. The pool was expanded because many new articles on climate change have been published since 2015, and because we chose to include authors who published in highly ranked development economics journals as well as mainstream economics journals and environmental economics journals. We included development journals in order to help diversify the sample, as these journals generally feature publications that originate from and focus on a broader range of geographic regions (in part because they are less skewed toward scholars from rich countries).

Beyond the direct policy implications of these survey findings, the results provide a useful resource for modelers who estimate climate damages. Economists have developed integrated assessment models (IAMs), which capture various steps in the climate and economic processes that translate an additional ton of carbon dioxide emissions into economic damages. These models are used to estimate the "Social Cost of Carbon" (SCC)—the marginal damage of a ton of carbon dioxide emissions. The SCC is an essential metric in U.S. government cost-benefit analyses of actions that affect greenhouse gas emissions. However, IAMs and the results derived from them, including the SCC, are highly sensitive to modelers' assumptions, which do not necessarily reflect the consensus views of experts. Research based on our 2015 survey shows that when an IAM is recalibrated to use the discount rate and damage function preferred by respondents to an expert survey, the SCC value increases more than tenfold (Howard & Sylvan, 2020).

This survey and other expert elicitations can help establish the appropriate assumptions to be used in IAMs, and could play a role in the U.S. government's current review of this modeling methodology. The Biden administration is presently working to update the models underlying the U.S. federal government's SCC value (IWG, 2021). This process will rely in part on recommendations from the National Academies of Sciences, Engineering, and Medicine, including a call to use expert elicitation in the development of several IAM components (NAS, 2017). The results from this survey and others like it can be used to help calibrate IAM parameters including climate damage functions; adaptation assumptions; emissions scenarios; technology availability assumptions; abatement cost functions; and discount rates. Calibrating these parameters to match the consensus views of experts (as revealed through expert elicitations like this survey) will likely lead to a more comprehensive account of likely climate impacts. Based on related recalibration efforts, the result would likely be a significant increase in the SCC value (Howard & Sylvan, 2020).

The Value of Expert Elicitation

Eliciting the views of experts in a field can improve understanding of complex topics and highlight prevalent points of view that might not otherwise stand out. Clarifying these consensus views can help inform the public and provide insights for policymakers. Expert elicitation is distinct from public opinion polling, which is useful for gauging widespread sentiments and political views.

Policymakers and researchers regularly use expert elicitation to improve understanding of climate change-related topics. In an effort to determine consensus on climate issues, the United Nations established the Intergovernmental Panel on Climate Change (IPCC) and tasked it with providing a consensus-based, scientific view on the current understanding of climate change and related consequences. Through the IPCC's deliberative review process, thousands of climate experts from across the globe assess the most recent scientific, technical, and socio-economic information, and then synthesize their findings.

The IPCC reviews the research of economists and solicits their expertise to help develop the consensus viewpoint. In particular, economists participate in the Working Group on "Impacts, Adaptation, and Vulnerability," which has explored the consensus view on the SCC and other topics.

However, there are drawbacks to the deliberative process used by the IPCC (and others) to identify consensus. Group deliberations can lead to "groupthink," sometimes causing deliberation processes to suffer from censorship and uniformity (Sunstein, 2005). Indeed, the IPCC has been criticized for moving too slowly and adopting only the "lowest-common denominator" conclusions, leading to overly conservative results that ignore more up-to-date viewpoints (McKibben, 2007). In fact, actual measures of sea-level rise have tracked the high end of the IPCC's projections, and the IPCC's past temperature predictions were shown to be low (Rahmstorf et al., 2007; Rahmstorf et al., 2012). In other words, the IPCC has tended to underestimate the rate of climate change, and the results of its deliberative process perhaps only indicate the minimal consensus in the scientific community—the *least* we can expect (Oreskes et al., 2019).

Besides deliberation, an alternate method for identifying the consensus opinion of experts is to use surveys and find a group's median or mean answer. Well-developed theories on "the wisdom of crowds" explain why the average answer from a group is likely to be more accurate than the answers of most individuals in that group, and why large groups perform better than small groups.[3] For example, groups of experts have been shown to significantly outperform individual experts on predicting such uncertain (and climate change-related) quantities as the annual peak rainfall runoff of various countries or changes in the U.S. economy (Armstrong, 2001). By comparison, deliberating groups tend only to do about as well as their average members on making accurate predictions, and not as well as their best members (Gigone & Hastie, 1997).

Compared to deliberation, surveys and statistics can often produce a more nuanced understanding of expert consensus, and help reveal the full range of opinions in a group. Deliberation tends to reduce variance, since deliberations can amplify cognitive errors and overemphasize common knowledge, causing a group to converge on a common—though not necessarily accurate—answer. By showing the diversity of opinion, surveys can indicate where debate still exists on an issue and where a consensus might emerge in the future. Surveys can also measure the level of uncertainty on a topic, which can be especially important for policymakers who are risk-averse or who seek to maximize future policy flexibility.

Past Surveys on Climate Economics

Researchers focusing on climate economics have shown a renewed interest in expert elicitation in recent years. Until 2015, the most prominent surveys on climate damages (Nordhaus, 1994; Schauer, 1995) and discount rates (Weitzman, 2001) were decades old. Many existing estimates suffered from shortcomings including small sample size (and related selection bias); reduced variance due to uniformity or censorship (from using deliberation and consensus building); and/or respondent bias (from using informal, open web surveys). Beginning in 2015, some scholars began to call for new expert elicitation efforts, and a number of researchers soon undertook such projects.

Economist Robert Pindyck argued in a 2015 working paper (later published in 2017) that IAMs are over-reliant on the assumptions of the modeler,[4] such that these climate-economic models represent the modeler's informed opinion (on climate science, economics, and policy) rather than the scientific consensus. Pindyck proposed using expert opinion from "a range of economists and climate scientists" to calibrate these models, rather than relying on modelers to independently set parameter values. In 2016, Oppenheimer et al. (2016) also called for the use of formal expert elicitation in the climate change context due to the inevitable need for expert judgment in long-run numerical models.

Around this time, several expert elicitations were conducted on climate damages and discount rates, aiming to overcome past survey shortcomings. From May 2014 to April 2015, Drupp et al. (2018) conducted an expert elicitation on social discount rates and the related parameters. Critically, the authors found strong support for a median discount rate of 2%, with a strong consensus for a range of 1% to 3%.

Second, building on a 2009 Policy Integrity survey, Howard and Sylvan (2015; 2020) conducted an expert elicitation on climate economics and policy. The survey revealed high levels of concern about climate change and support for immediate action using market-based policies. It also showed a strong disparity between the general views of experts publishing on climate economics and the output of IAMs, as theorized by Pindyck. Specifically, the survey found substantially higher estimated climate damages (mean and median estimates of -9.2% and -5% of global GDP, respectively, for a 3°C increase) and strong support for median discount rate of 2%, consistent with Drupp et al. (2018).

Finally, Pindyck (2019) conducted a survey on climate damages, emissions, and discount rates. His respondents also provided relatively high climate damage estimates (slightly higher than Howard and Sylvan (2020)), and a low discount rate.

Taken together, these three studies provided strong evidence that the current expert consensus on key economic parameters strongly differed from past survey findings and current IAM assumptions, implying support for lower intergenerational discount rates and higher climate damages.

In 2016 and 2017 the National Academies of Sciences, Engineering, and Medicine (NAS) published two reports on the SCC. Critically, NAS (2017) called for the use of expert elicitation in the development of key components of IAMs, including socio-economic and emission scenarios, though the report cautions against its use for estimating climate damages. Resources for the Future has begun conducting some of the updates laid out in NAS (2017), including the use of expert elicitation to develop long-run socio-economic and emission scenarios.[5]

This 2021 expert elicitation survey builds on these recent efforts and introduces questions on long-run climate damages, distributional impacts, adaptation, and abatement technology and costs.

Survey Methodology

In an attempt to gauge expert consensus on key economic issues related to climate change, we surveyed 2,169 of the world's leading experts on climate economics. We sent each respondent a link to a 15-question online survey with questions focused on climate change risks, economic damage estimates, and emissions abatement. Of this pool, 738 economists participated, for a response rate of 34%. (Not all respondents submitted a response to every survey question, so the sample for some questions is smaller; see Appendix C.)

Survey Design

Our survey was designed to accomplish several objectives. We sought to determine the extent of expert consensus on critical economic questions related to climate change; understand how experts' views of climate change have evolved over time (in part by comparing these findings with the results of past surveys); and solicit specific estimates of the economic impacts of climate change and the likely costs of emissions abatement. We surveyed respondents on the following topics:

- Their specific areas of expertise and the subjects on which they have published;
- Their professional views on climate change, including the level of risk that climate change poses to the economy; the general policy responses that are most appropriate; and how and why their views have shifted over the past five years;
- The distributional impacts of climate damages, including the effect on inequality both between countries and within countries;
- Estimated trends and costs for emissions abatement, including projections for some low-emissions technologies, and the overall costs for various levels of abatement;
- Estimates for the economic impacts of various climate scenarios, and expected levels of adaptation;
- The expected benefits/costs of reaching net-zero emissions targets by mid-century;
- Estimates for changes in GDP and emissions during the Covid-19 pandemic; for purposes of comparison.

Because we sought to compare our respondents' views to the opinions expressed in other surveys, some of our questions mirrored those from a 2015 Institute for Policy Integrity survey. The full text of our survey is included as Appendix A. Before distributing the survey, we conducted a series of internal and external tests to help ensure that the questions were unambiguous, and we made several changes to improve question clarity.

Discount Rates and Expert Consensus

We chose not to include a question about the social discount rate in this survey, given that recent studies (including our previous survey of a similar sample) have already established a clear consensus that a rate of 2% or less is appropriate in the climate change context.

There are two views on the best way to determine discount rates: observing market interest rates (the descriptive approach) and applying ethical/philosophical arguments (the normative approach). Historically, the descriptive approach has suggested higher rates than the normative approach, particularly in the inter-generational context. However, this is no longer true due to developments in both approaches.

In the descriptive context, recent research indicates that consumption discount rates are appropriate in the climate change context, while capital discount rates, which are higher, are not (IWG, 2010; NAS, 2017; Li & Pizer, 2021). Recent research also demonstrates that the consumption discount rate has declined over the last several decades to a rate below 2% (U.S. Council of Economic Advisers, 2017; Bauer & Rudebusch, 2020).

In the normative context, recent research by Heal and Millner (2014) demonstrated that a voting procedure is an efficient, time-consistent way to select a social discount rate when a wide range of views are held over the appropriate rate. As mentioned above, two recent surveys that elicited these views found median rates of 2% (Drupp et al., 2018; Howard & Sylvan, 2020). Given this consensus, we decided to focus our survey questions on other critical climate-economic issues.

Respondent Criteria

We sought to identify a pool of respondents with demonstrated expertise in the economics of climate change. Building on the approach used in prior surveys by the Institute for Policy Integrity, we compiled a list of all Ph.D. economists who had published an article related to climate change in a leading economics, environmental economics, or development economics journal since 1994.[6] We included all papers that discussed climate change and had implications for the climate change debate, even if that was not their primary focus.

We defined leading journals as those ranked in the top 25 economics journals, top seven environmental economics journals, and top seven development economics journals, according to rankings published in peer-reviewed publications. Given that the rankings of various journals have changed during this time frame, we used rankings from multiple time periods and included any journal that met the criteria in any time period. In total, our final list included 45 economic journals.[7] The list of journals is available in Appendix B.

We conducted a thorough search of each journal for articles that mentioned "climate change" or "global warming" and significantly discussed related issues. The articles published by the economists in our sample tended to have an academic focus on issues related to climate change; they were not political pieces, and most cannot be easily classified as advocating either for or against climate change policies.

After removing experts who had died and individuals for whom we could not locate a working email address, our review revealed 2,169 authors who fit our selection criteria.[8] From this group, 738 economists participated in the survey, for a response rate of 34%.

This sample is significantly larger than our survey from 2015, for which we invited 1,103 experts and had 365 participants (a response rate of 33.1%).[9] The larger sample stems from the publication of hundreds of new relevant articles since 2015, as well as our inclusion of development economics journals and two new environmental and resource economics journals, which were not included in the prior survey.[10]

Survey Administration and Response Rate

We conducted our survey online using Qualtrics software, with the survey open from February 1, 2021 through February 11, 2021. We sent each expert an email message that described the nature of this project, informed them of the reason for their selection, and requested their participation through an embedded hyperlink to the survey.

The survey included 10 multiple-choice questions and five quantitative forecasts. Respondents were told that the survey would take roughly 15 minutes to complete, and that individual responses would be anonymous (the survey did not ask for any identifying information or track individual responses). Respondents were sent two reminder emails that included deadline details. These emails were sent to the entire pool since we could not determine who had already completed the survey.

Our overall response rate was 34%, which is consistent with the average response rate for online surveys of this type.[11] Not all respondents answered every question. Unsurprisingly, fewer people answered the more complex forecast questions that asked for multiple quantitative estimates of conditions under various climate scenarios. These questions had samples ranging from 212 to 342 responses (see Appendix C).

Addressing Possible Biases

Our methodology for choosing respondents could potentially suffer from selection bias, given that highly ranked academic journals might not publish articles encompassing the entire spectrum of thought on climate change economics. However, we believe our approach adequately identified a large sample with demonstrated expertise in the economics of climate change. Furthermore, our respondents were representative of a wide range of opinions, based on the diverse and often conflicting arguments made in their published articles.[12]

Response bias could be a concern for our open-ended questions on damage and abatement forecasts, which were answered by a smaller number of respondents. However, we analyzed response rates for different respondent subgroups and found that the rates were generally balanced and our results are robust across groups.[13] Using stratification weights to adjust for different response rates by subgroups in order to ensure our sample is representative of our population, we found the results to be relatively similar. We also tested whether open-ended responses differed based on timing of responses relative to our reminder e-mails (this assumes late responses are a phenomenon related to non-responses); we do not find evidence of responses differing by timing.[14] Finally, given our large sample size, even a smaller response rate of around 10% for some questions encompasses over 200 economists' views.

Finally, we designed our survey to minimize anchoring bias (whereby respondents rely disproportionately on information provided recently). In the fourth question of the survey we presented respondents with a list of possible influences on their views about climate change. We included a wide range of examples, some of which related to emissions increases and climate damages while others related to emissions reductions and climate policy development. These options were intended in part to encourage respondents to consider a variety of factors in their later responses. Additionally, we asked respondents to answer forecast questions by providing their 5th and 95th percentile estimates before providing their 50th percentile estimates, in order to avoid anchoring on these responses. Lastly, just before asking respondents whether mid-century net-zero-emissions goals are cost-benefit justified, we asked them to complete forecasts of both the costs and benefits of emissions abatement.

Survey Results and Analysis

Our survey results reveal several areas of consensus with implications for climate change policy. The survey was divided into ten thematic sections. The findings from questions in each section are discussed below.

Throughout this report, Figure numbers correspond to the question numbers from the survey. The full survey text is available in Appendix A.

Respondents' Expertise

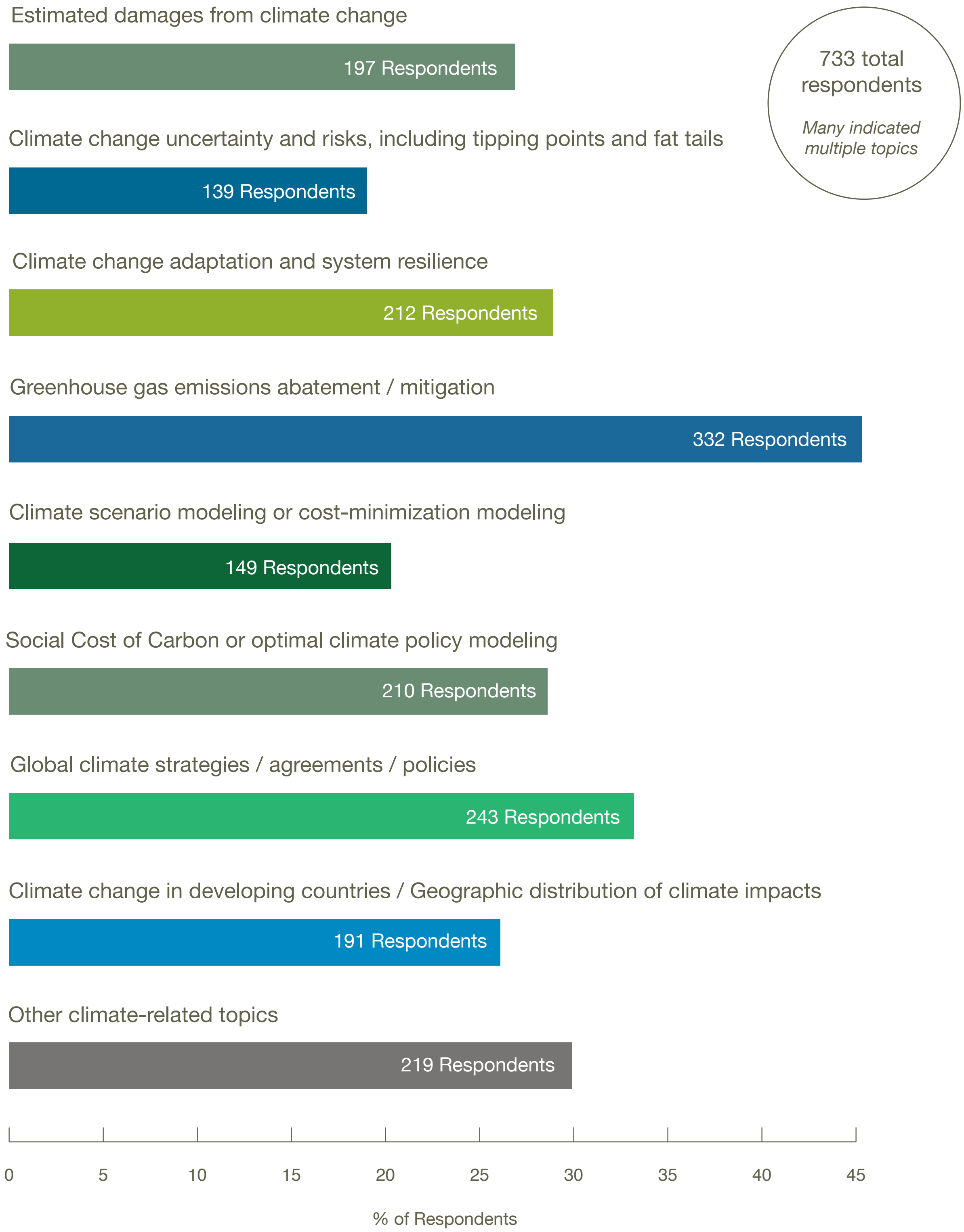
In the first survey question, we asked respondents to indicate their area(s) of expertise and topics on which they had published, from the following list:

- Estimated damages from climate change
- Climate change uncertainty and risks, including tipping points and fat tails
- Climate change adaptation and system resilience
- Greenhouse gas emissions abatement / mitigation
- Climate scenario modeling or cost-minimization modeling
- Social Cost of Carbon or optimal climate policy modeling
- Global climate strategies / agreements / policies
- Climate change in developing countries / Geographic distribution of climate impacts
- Other climate-related topics

The respondent group reported a diverse mix of expertise, with at least 139 respondents (19% of the full group) identifying expertise within each of the listed topic areas. In total, 733 of the 738 respondents answered this question.

Figure 1

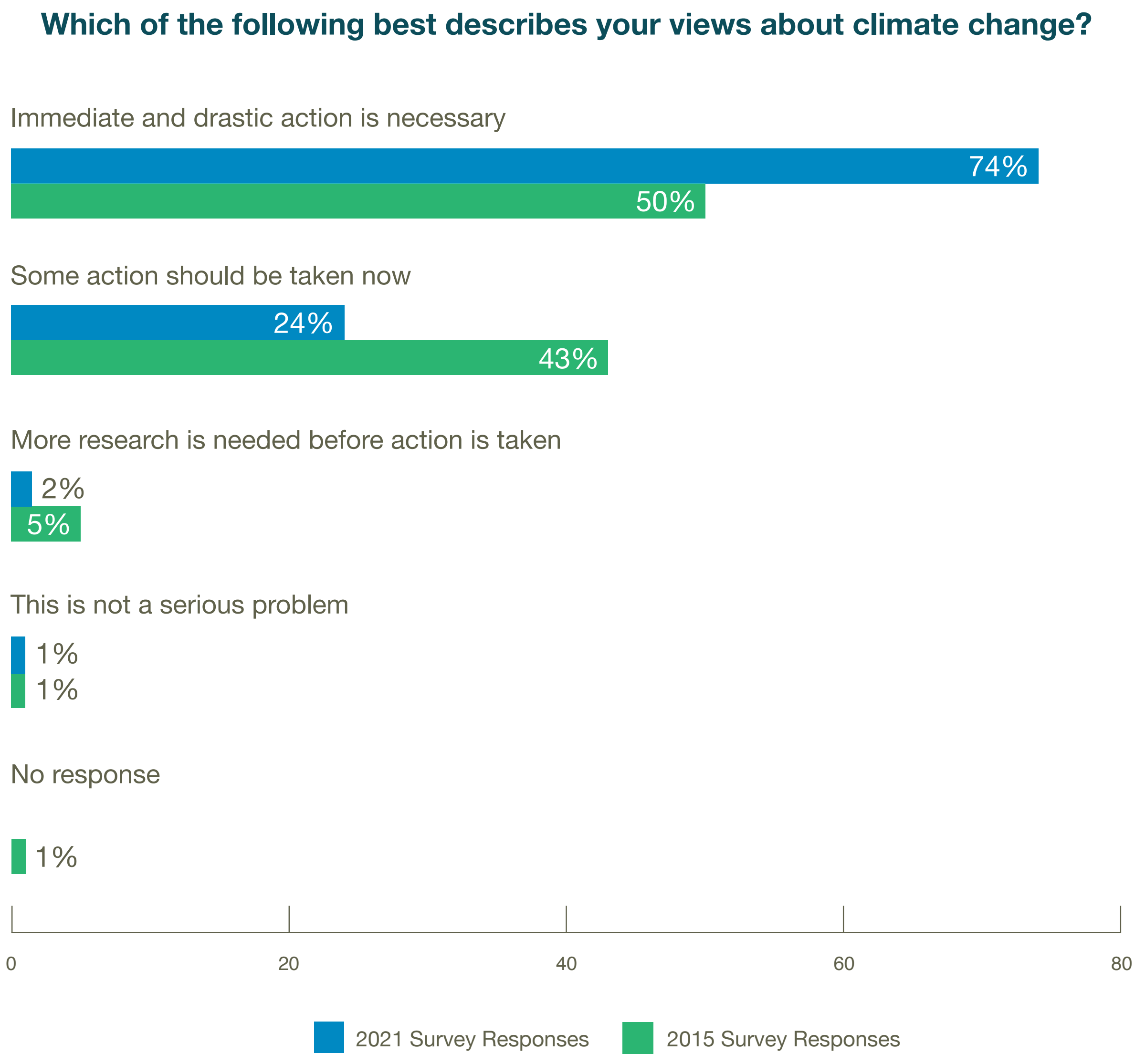
Respondents' Areas of Expertise/Publication Topics



Professional Opinions on Climate Change

Our questions in this category attempted to gauge general views on climate change, based on respondents' research. The first question was also included in our 2015 survey; it uses wording from an MIT/Harvard public opinion survey that was conducted on several occasions beginning in 2003 (Ansolabehere & Konisky, 2014).

Figure 2

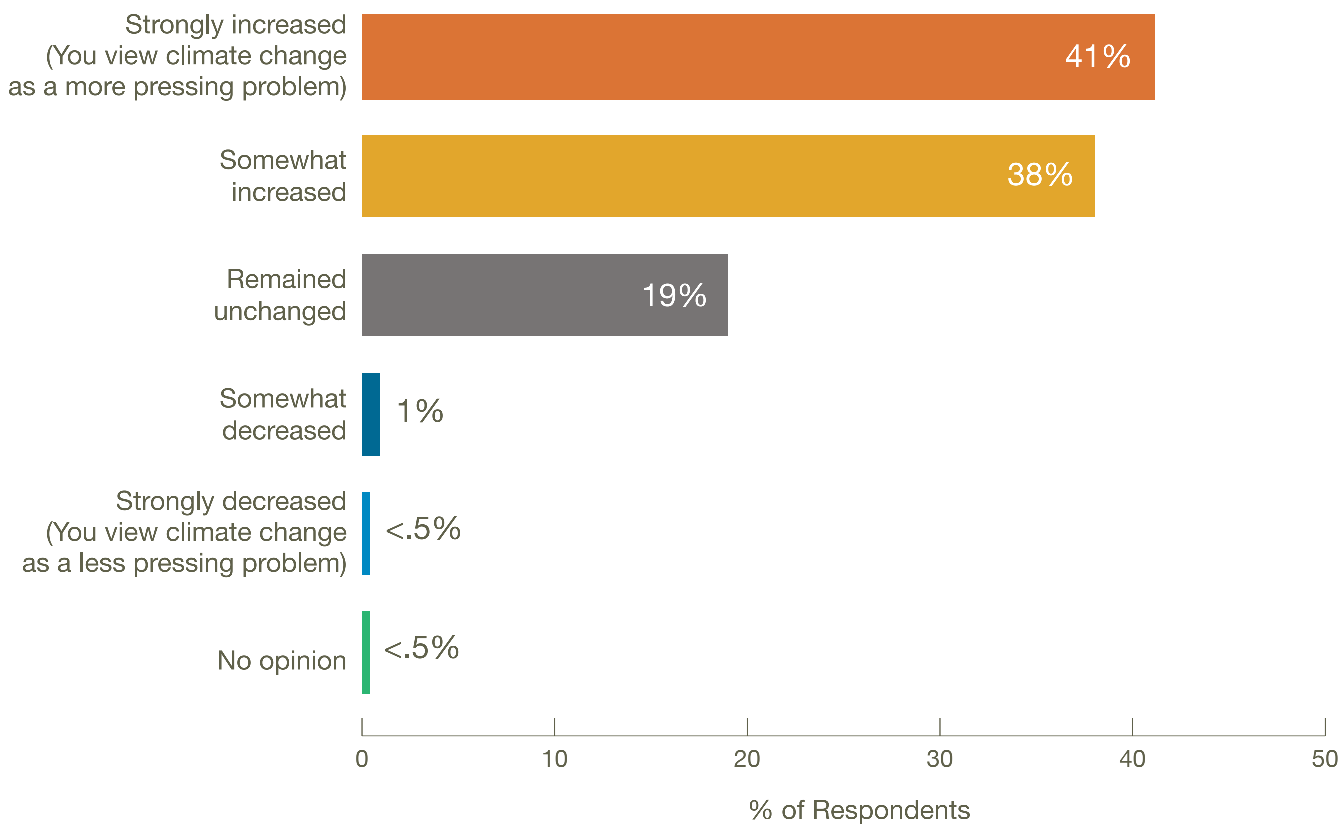


A clear consensus is evident on this question, as an overwhelming majority of respondents (nearly three quarters) believe that "immediate and drastic action is necessary" to address climate change. In sharp contrast, less than 1% (five total respondents) believe that climate change is "not a serious problem."

Compared to our 2015 survey, a significantly larger share of respondents now believe that drastic action is needed. Far fewer respondents believe that more research is needed before action is taken, relative to the 2015 survey. The responses to the following question appear to confirm this escalating level of concern.

Figure 3

As informed by your research, how has your level of concern about climate change shifted over the past five years?

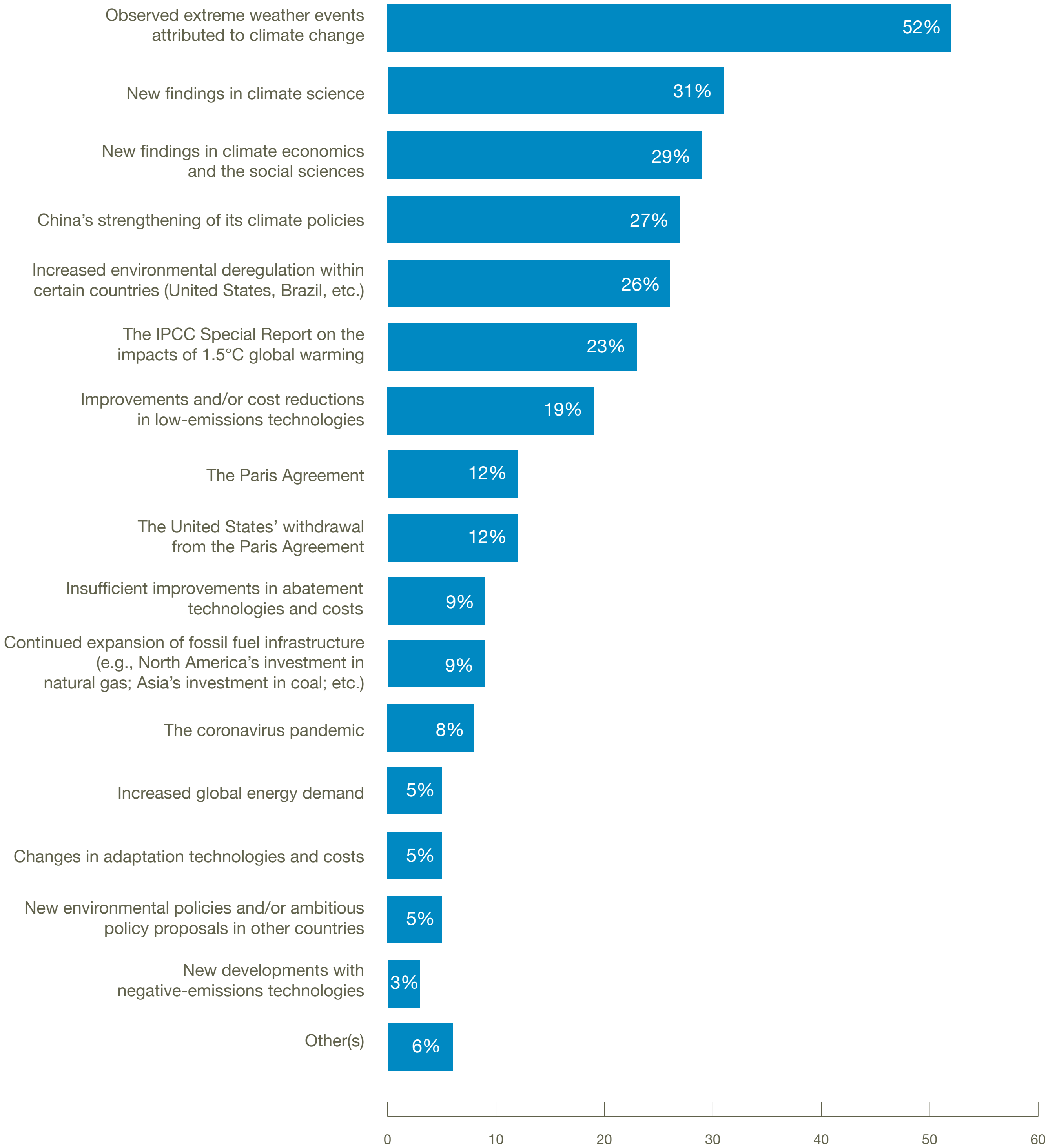


Nearly 80% of respondents self-report an increase in their level of concern about climate change over the past five years, underscoring the high level of overall concern among this group. This broad majority suggests that even respondents who have characterized the situation as urgent in the past may feel that the nature of the climate change challenge is rapidly escalating.

Respondents whose level of concern remained unchanged over the past five years still emphasized the need for urgent action in the prior question. Of the 140 respondents who selected this option, 60% believe that "immediate or drastic action is necessary" and another 37% believe "some action should be taken now."

Figure 4

Which items had the greatest effect on your views about climate change over the past five years?
Respondents could select up to three choices



In an effort to understand some of the key factors driving respondents' views on climate change, we asked them to select up to three items that had the greatest effect on their views over the past five years. We included a wide range of choices, roughly split between factors related to increasing emissions/climate impacts and those linked to emissions reductions. We included this range of choices in part to minimize anchoring effects for later questions.

While a wide spectrum of factors seems to have informed respondents' views, the most common answer by a significant margin was "observed extreme weather events attributed to climate change."

These empirical observations of climate impacts appear to have had an outsize role in shaping economists' views, perhaps due to the high level of damage caused by recent extreme weather events (such as wildfires in Australia and the Western United States, heatwaves in Europe, and historically large numbers of hurricanes). Such events may also have stood out to economists because many projections anticipated that the current levels of temperature increase and climate-linked extreme weather would take longer to manifest than they have (Diffenbaugh, 2020). Extreme weather events also frequently elevate the general public's level of concern about climate change (Sisco et al., 2017).

The next most influential factors identified by survey respondents were new research findings, both in climate science and in climate economics and the social sciences. Relatedly, nearly a quarter of respondents highlighted the influence of the IPCC special report on the impacts of 1.5°C global warming. This report discussed research on the high level of climate damages projected to occur even if global emissions are rapidly reduced and temperature increases are halted quickly.

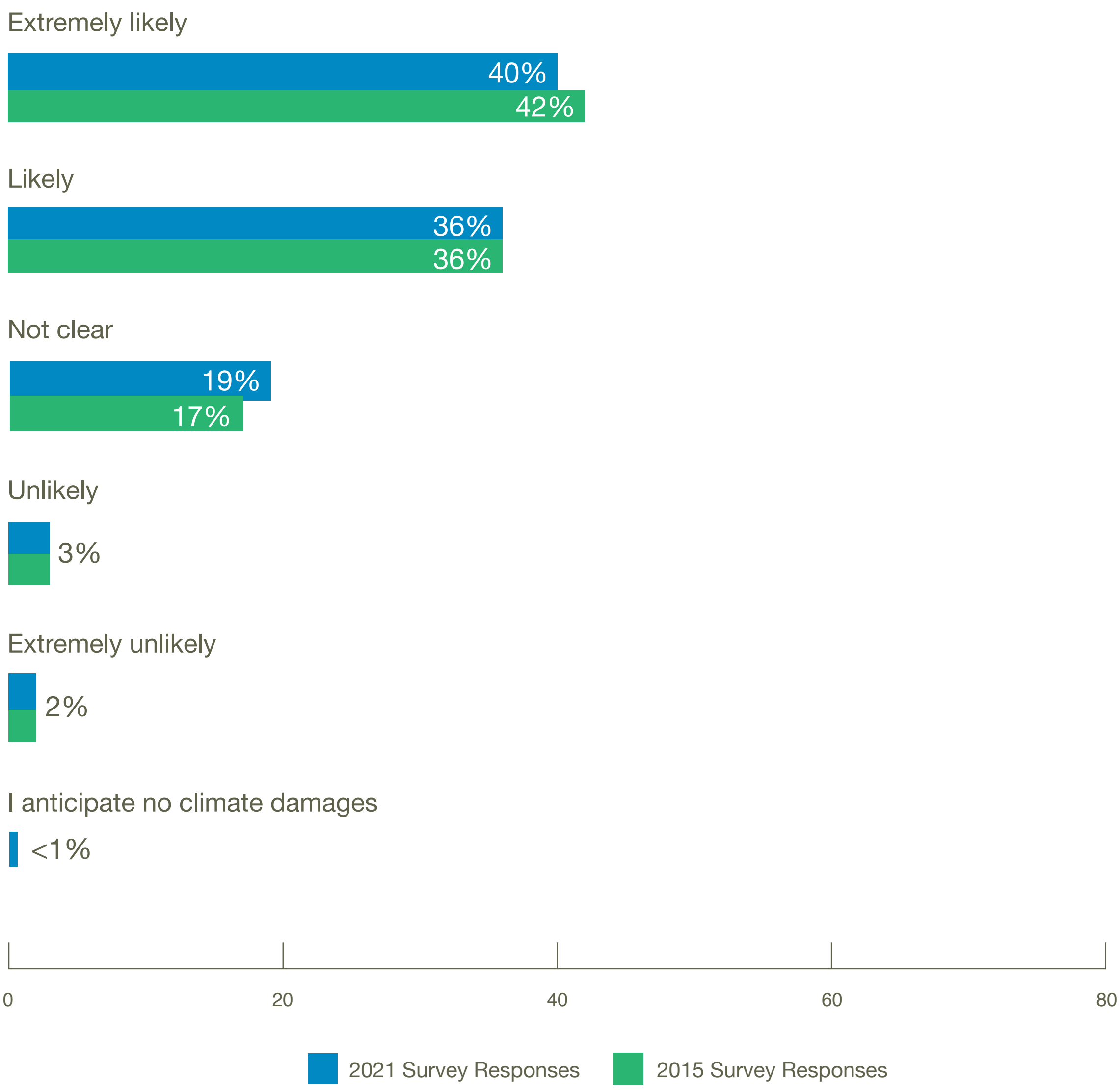
Many respondents also said their views were shaped by policy changes in high-emitting countries, including both environmental deregulation in the United States and Brazil, and the strengthening of climate policies in China. While the former examples have exacerbated the climate challenge by allowing for increased emissions, China's policy changes had the opposite effect. But it is possible that respondents saw China's policy change as evidence of the enormous risks presented by climate change. Additionally, respondents may have concerns about the robustness of China's climate policies, though few highlighted Asia's recent and planned expansion of coal power plants as a major influence on their views.

Climate Change and Economic Growth

Our next survey question focused on one potential channel through which climate change might affect the global economy.

Figure 5

What is the likelihood that climate change will have a long-term, negative impact on the growth rate of the global economy?



In the 2021 survey, 3% of respondents (24 total) selected "No Opinion." They are removed from the sample shown above.

Economists have traditionally modeled climate damages by focusing on changes to GDP in a specific year (i.e., a level impact), rather than changes to the growth rate of the economy. Recent empirical research (such as Burke et al. (2015)) has shown evidence of reduced economic *growth* as a result of current climate impacts, though some researchers have questioned the assumptions behind these findings, while others have found growth rate declines only in lower-income countries. [15]

To clarify the nature of the survey question on growth rates, we included a note under the question text that read:

> *"This is distinct from an impact on the level of GDP in a given year (i.e., climate damages measured as % of GDP)."*

Our survey findings show significant consensus for the idea that climate change will negatively affect global economic growth. Maybe more notable is the dearth of respondents who find this prospect unlikely (3%) or extremely unlikely (2%).

Our 2015 survey, which was conducted before many of the major publications on this topic, found very similar results, suggesting that these views stem from additional factors beyond the influence of recent empirical research. Despite several publications and working papers being released since 2015, the results are nearly identical after dropping respondents who selected "no opinion" and those who "anticipate no climate damages" (these responses were unavailable in the previous survey).

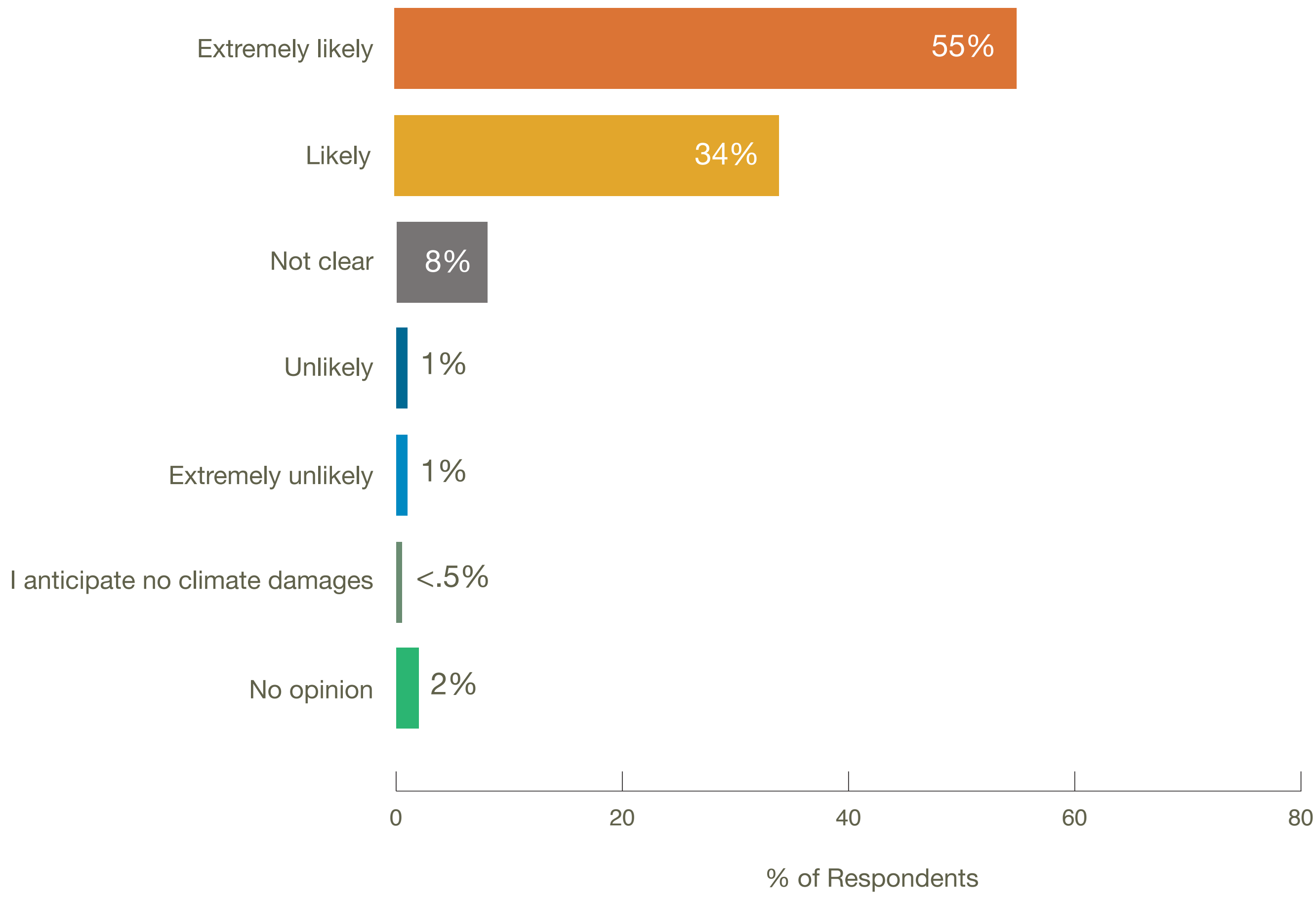
Based on the damage estimates provided in other survey questions (discussed below) it appears that many of the economists in our survey may believe that climate change could damage the global economy *both* by reducing economic growth *and* by reducing GDP through level impacts in specific years.

Distributional Impacts

Two survey questions sought to gauge consensus on the relationship between climate impacts and economic inequality, at both the international and national levels.

Figure 6

What is the likelihood that climate change will increase economic inequality between low-income and high-income countries (the lower third of countries by per-capita income versus the upper third of countries by per-capita income)?

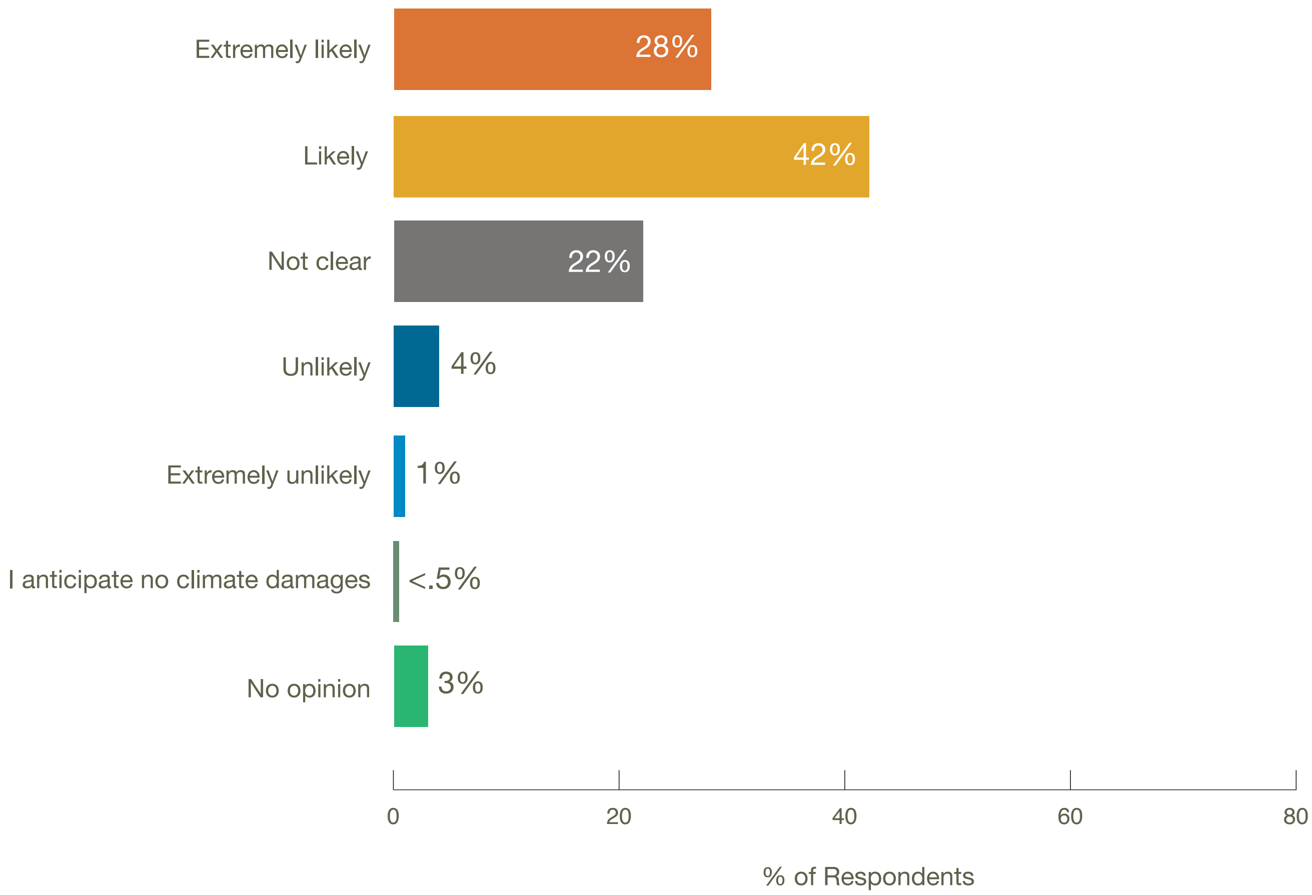


The vast majority of respondents believe that income inequality will be exacerbated between high-income and low-income countries as a result of climate change. This view aligns closely with the economic literature.[16] Specifically, as indicated in the literature, poorer countries are generally expected to be more vulnerable to climate impacts due to their reliance on agriculture and other outdoor activities, initial hotter temperatures, and smaller budgets available for adaptation (see Tol, 2018).

If this prediction is true, it would counteract recent trends—average incomes in developing countries have increased at a faster rate over the past 25 years (United Nations, 2021). The results could be highly problematic for many countries that already face profound economic challenges and high rates of poverty.

Figure 7

What is the likelihood that climate change will increase economic inequality within most countries, between the lower third of households by household income and the upper third of households by household income?



Approximately 70% of economists also believe it is likely or extremely likely that climate change will exacerbate inequality within most countries. Given that every country has a unique combination of economic structures, existing inequality dynamics, and climate-related risk, this finding suggests that many economists expect to see broadly regressive patterns in climate impacts and/or adaptation measures. The views expressed in our survey are consistent with recent economic findings for the United States (Hsiang et al., 2017).

Our findings regarding inequality both between and within countries have significant implications, especially given recent calls to address environmental justice and climate justice concerns. Policymakers may need to devote additional focus to remedies for inequality. These anticipated effects could also increase the cost of climate change, including the SCC, if damage estimates account for inequality aversion via equity weights (Anthoff et al., 2009). The expansion of national, regional, and global inequality also raises serious questions about the use of GDP per capita (i.e., a mean estimate where total GDP is divided by total population) as a proxy for welfare in IAMs.

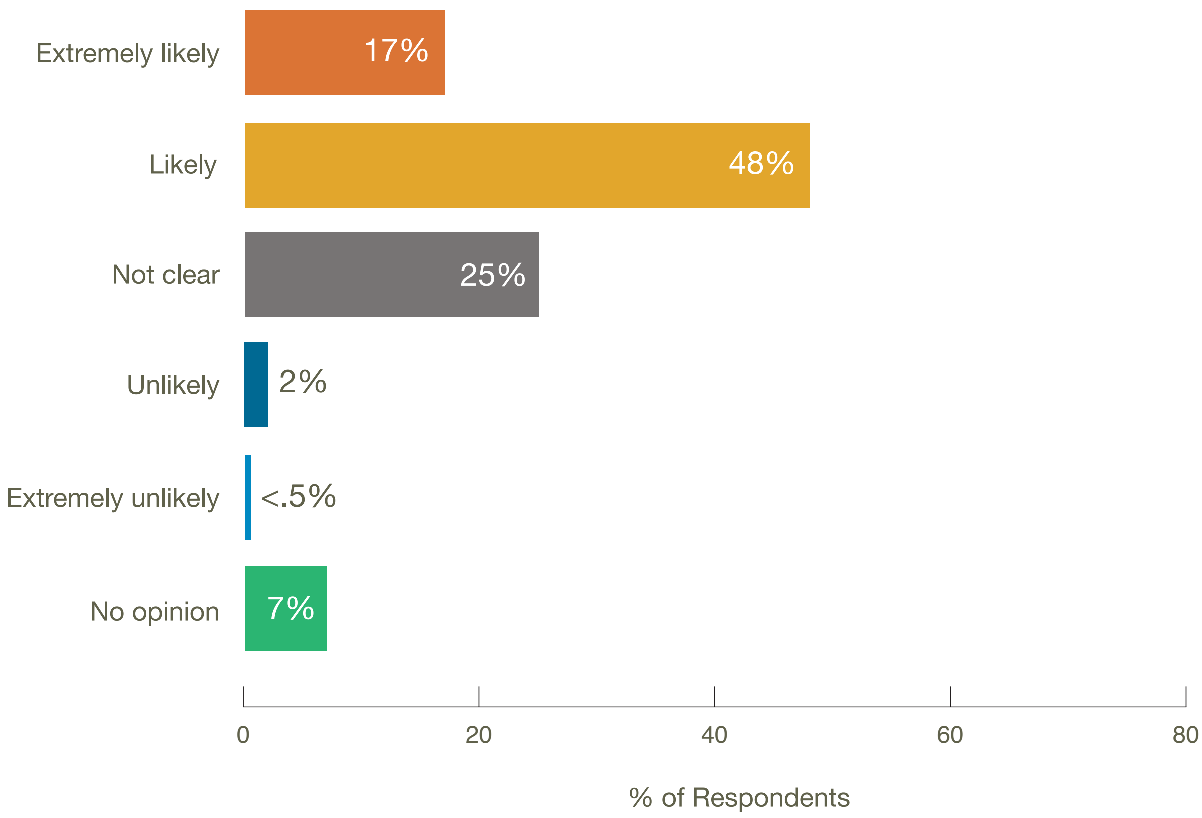
Emissions Abatement

Three of our survey questions focused on predictions related to major technologies that can reduce emissions.

Figure 8

Over the last decade, the costs of solar and wind energy technologies have dropped rapidly (-7% annually for solar PV and -4% annually for onshore wind).

Do you think a similar pattern is likely to be replicable for some other emerging zero-emission and negative-emission technologies?



Costs for some low-emissions energy technologies have dropped substantially in recent years (IRENA, 2019; Lazard, 2019). In many cases, these technologies have become cost-competitive with dominant fossil-fuel energy sources more rapidly than expected (IEA, 2020). Economists have highlighted several factors that have contributed to these declining costs, including the effects of learning, the increased maturity of supply chains and production processes, and an increasingly favorable policy landscape (Kavlak et al., 2018).

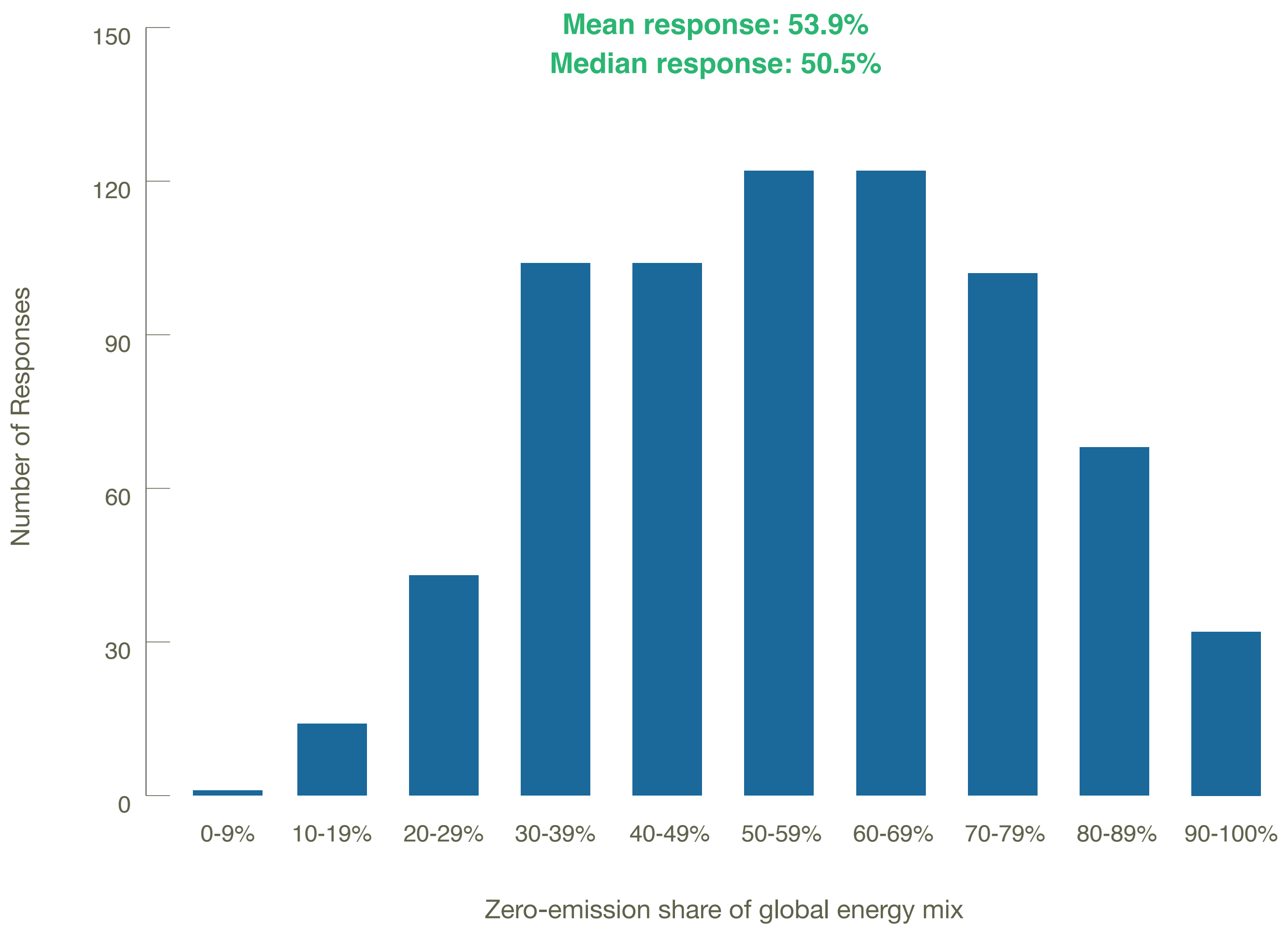
In total, 65% of respondents believe that these patterns are likely or very likely to be replicable for some other emerging clean technologies. We chose to phrase this question broadly to focus on general trends rather than specific technologies or timeframes. It is noteworthy that even when asked to make a broad prediction about a diverse category of technology, very few respondents (less than 3%) seem to view the recent reductions in solar and wind costs as anomalous.

Compared to our results, DICE (one of the most prominent IAMs, which is used to calculate the U.S. government's Social Cost of Carbon) appears to be relatively conservative on the availability of abatement technologies. DICE-2016R2 does not explicitly model the cost of zero-emission or negative-emission technologies. However, it does show the price of the backstop technology (i.e., the price of the marginal technology when 100% of emissions are abated), which declines by approximately 0.5% annually (Nordhaus, 2018). As this technology could be a zero-emission or negative-emission technology (Nordhaus & Sztorc, 2013, p. 13), this rate may be insufficient if price declines in clean technologies can be maintained near the 4% to 7% annual rate observed recently for wind and solar.

Figure 9

In 2050, what share of the global energy mix do you think will consist of zero-emission technologies (e.g., solar, wind, nuclear, green hydrogen, bioenergy with carbon capture and storage, etc.)?

For context, zero-emission sources make up roughly 10% of the current energy mix according to the International Energy Agency.

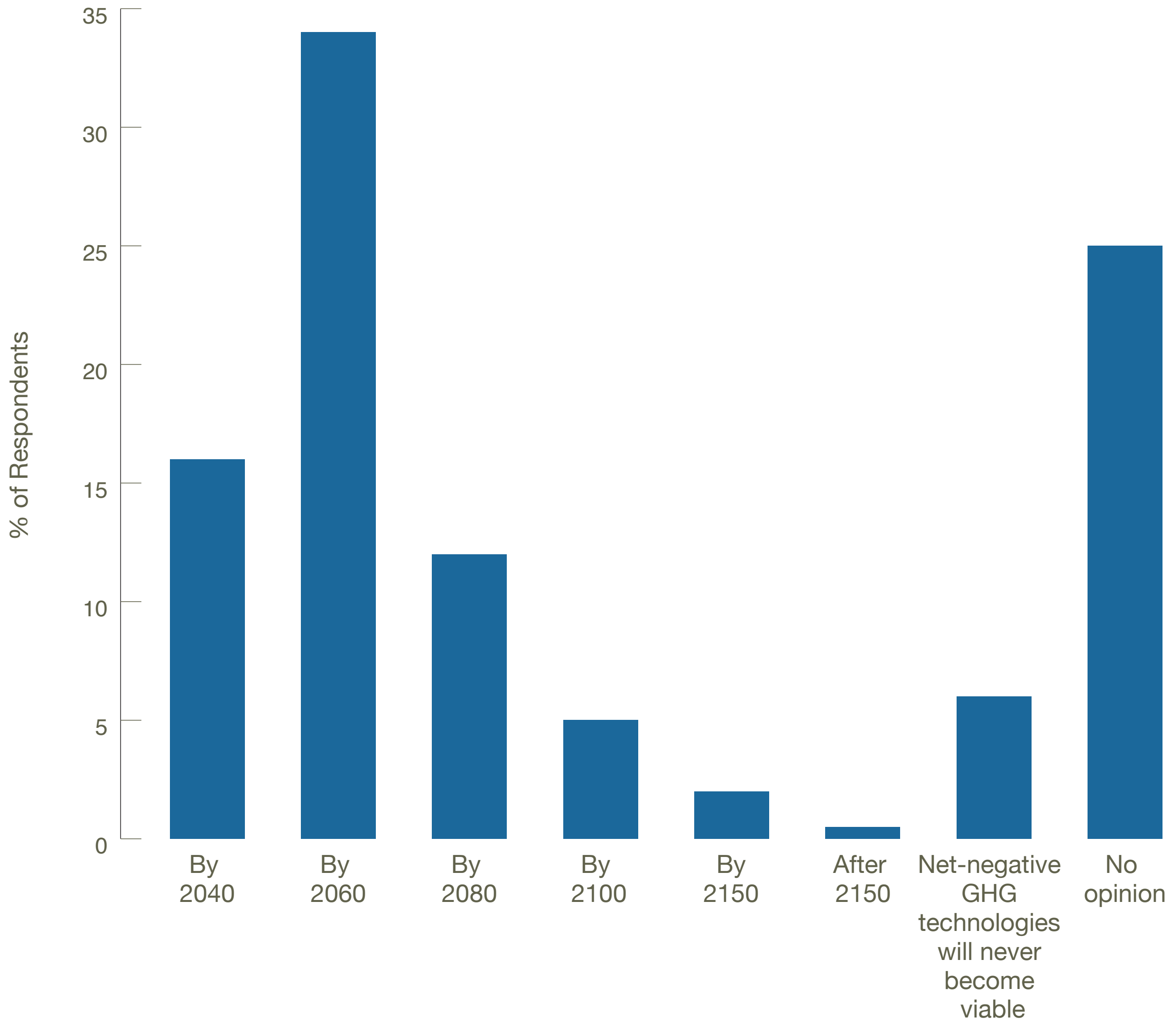


On average, respondents estimate that just over half of the global energy mix will consist of zero-emission sources in 2050. The responses to this question essentially follow a normal distribution, with a nearly identical mean and median of slightly over 50%.

Respondents believe that growth in zero-emissions energy will be prolific, as expanding the share of global primary energy supplied by these sources from roughly 10% to 50% in three decades would represent a monumental shift. However, even this enormous increase is likely insufficient for a 1.5°C or 2°C temperature pathway, according to prominent projections (which would require net-zero economywide emissions by 2050 or soon after).[17]

Figure 10

During what time period do you believe that net-negative greenhouse gas emission technologies, such as direct air capture and carbon capture/utilization/storage (CCUS), will become viable and reliable at a low-enough cost to be adopted on a large scale (i.e., to significantly change the global emissions path)?



Respondents appear to be relatively bullish on the viability of negative-emissions technologies, given that few large-scale projects exist today.[18] Roughly 25% of respondents chose the "No Opinion" option, suggesting a high level of uncertainty for this question. Still, 542 experts did offer a prediction, and a sizeable majority expects negative-emissions technologies to be viable at a large scale by 2060 or 2080 (the median response is between 2040 and 2060). These findings are roughly consistent with the IPCC (Hansel et al., 2020).[19]

This result could suggest confidence in the ability of research-and-development efforts and other climate policies to accelerate these technologies and reduce costs. The level of government support and the climate policy landscape could ultimately determine the level of success and pace of progress for these technologies.

Most scenarios for meeting a 1.5°C or 2°C limit require extensive use of negative-emissions technologies by soon after 2050.[20] According to our survey, economists seem to believe this timeline is viable. However, the optimism of these results should be tempered somewhat, as engineers and other categories of experts may have equally (or more) relevant insights on these issues than economists, and their views may differ. Many researchers who focus on the energy transition advise a "precautionary approach" with respect to negative-emissions technologies, given that they are unproven and overreliance on these technologies could deter necessary emissions reductions in the near term (Rogelj et al., 2019).

The timeline suggested by our survey findings is significantly faster than the one projected by some major IAMs, including DICE. DICE does not specify when negative-emissions technologies will become economically viable on a large scale. However, Nordhaus assumes that net-negative emissions (i.e., abatement of more than 100%) will occur in 2240 on DICE's business-as-usual emissions path. This only occurs by 2160 on the optimal emissions path (Nordhaus, 2018).

Taken together, the findings from our series of survey questions on emissions abatement paint a more positive picture for affordable, effective emissions reductions than does DICE.

Climate Damage and Emissions Abatement Estimates

We next asked questions soliciting forecasts of expected economic impacts under various climate scenarios. The initial scenarios approximate a business-as-usual warming trend, carried forward to four future time periods.

The scenarios we provided included the year, level of temperature change since the pre-industrial era, average rate of temperature change over the prior 30 years, and estimated global GDP (based on scenario assumptions from DICE). The full scenario details provided in the survey are available in Appendix A. The scenario details for our damage estimate questions originate from the baseline DICE-2016R2 scenario.

We asked respondents to "Please consider the level of global GDP and rate of temperature change, in addition to overall temperature change (some researchers theorize that society is more capable of adapting to climate change with slower rates of temperature change and/or higher levels of global economic output)."

In climate economics, economic damages (measured as a percentage of GDP) are represented as functions of temperature change, the rate of temperature change, and income. Temperature change is used as a proxy variable for other climate drivers, including increased storm frequency and sea-level rise. As temperatures increase, the economic literature suggests that there may be initial benefits (an empirical question), though the global economy will eventually suffer economic damages at some level of temperature increase (Howard & Sylvan, 2020; Howard & Sterner, 2017; Tol, 2018).

Since we asked experts to provide their projection of net damages (i.e., damages minus adaptation and its costs), slower rates of temperature increase (that increase the time it takes to reach a particular temperature level) should decrease damages, as society has more time to adapt. With respect to income, damages could decrease or increase depending on the relative effects of increased adaptability and relative prices (i.e., the value of non-market goods increases as market goods become less scarce). Our adaptation scenarios were designed to provide measurements of these effects.

To avoid overconfidence and anchoring biases in these questions, we asked respondents to provide their 5th and 95th percentile estimates before providing their median/50th percentile estimates. We also asked respondents to include both non-market and market impacts, and factor in adaptation to climate change and its corresponding costs.

Figure 11

Climate Damage Estimates

Year	2025	2075	2130	2220
Temperature increase (relative to pre-industrial era)	**1.2°C**	**3°C**	**5°C**	**7°C**
Economic damages (% of global GDP) - Median estimate	**-1%**	**-5%**	**-10%**	**-20%**
Economic damages (trillions of 2019 USD) - Median estimate	**-$1.7**	**-$29.8**	**-$143.0**	**-$730.9**
Economic damages (% of global GDP) - Mean estimate	-2.2%	-8.50%	-16.10%	-25.20%
Economic damages (trillions of 2019 USD) - Mean estimate	-$3.8	-$50.6	-$230.3	-$920.9
Standard deviation	2.9	7.6	13.3	20.7

Results above reflect the trimming of outlier estimates below the 5th percentile or above the 95th percentile of total responses.

We believe the median estimate best reflects expert consensus due to the skewness of the results, which arises from outlier responses (see below for more detail). When expert survey responses include significant outliers or focus on a belief rather than a testable forecast, the median result can often be more useful than the mean (Lorenz et al., 2011). Our analysis of the forecast questions therefore focuses primarily on the median results.

Respondents project that economic damages from climate change will reach $1.7 trillion per year by 2025, and roughly $30 trillion per year (5% of projected GDP) by 2075 if the current warming trend continues. Damage estimates rise precipitously as warming intensifies, topping $140 trillion annually at a 5°C increase and $730 trillion at a 7°C increase. These damage estimates exceed those in DICE and other commonly cited IAMs, though they are consistent with past surveys (Howard & Sylvan, 2020; Pindyck, 2019). We also asked questions about impacts at higher temperatures and income levels than some past surveys. Like Nordhaus (1994), we found that climate damages do not appear to follow a quadratic path in the long run, providing some support for the earlier DICE damage function that limits climate damages to 100% of GDP.

Trimming and the Median Response

We use a two-pronged approach to ensure that outliers in our data set do not overly influence the results. First, we trim the overall results to eliminate responses below the 5th percentile and above the 95th percentile. Second, we focus primarily on the median rather the mean estimate. We selected this approach in part because the near-term forecasts that result from this method approximate the range of estimates in the literature, while the inclusion of outlier responses produced vastly larger damage estimates.

In our 2015 survey and the corresponding academic paper (Howard & Sylvan, 2020), we used a different two-part approach to address outliers in damage estimates. First, we trimmed responses at the 99th percentile; we selected the 99th percentile to eliminate only the most extreme responses. Second, in addition to reporting the mean damage estimates, we conducted sensitivity analysis by reporting median damage results. The mean is generally the appropriate central estimate (i.e., wisdom of the group) if experts' responses are forecasts, as the mean minimizes forecast error. However, if results are highly skewed and/or if elicited damages are more representative of beliefs than forecasts, then the median may better reflect expert consensus (Lorenz et al., 2011; Freeman & Groom 2015; Colson & Cooke, 2018). We believe the median is appropriate in this context.

Our 2021 survey responses on this topic are highly skewed, as the mean differs considerably from the median. In this survey, we asked respondents for estimates of impacts in the near future (i.e., a 1.2°C increase in 2025) when uncertainty is considerably lower relative to a 3°C increase in 2075 (given that it is much closer to our current state). Using our previous method of trimming at the 99th percentile would imply a range of damages of +2% to -45% of GDP for a 1.2°C in 2025. The upper end of this range is far above the range in the literature: DICE-2016R's 0% to -0.7% (Nordhaus, 2017), Howard and Sterner (2017)'s range of -0.5% to -2.7% for non-catastrophic and total impacts; and Burke et al. (2015)'s range of approximately -1.7% to -6.8% for market-only impacts.[21]

To address outlier estimates and avoid putting our fingers on the scale, we apply a 95th percent confidence interval trimming methodology, implying a damage range of 0% to -18% in 2025. However, as the upper end of this range implies a permanent catastrophic event with a magnitude akin to the Great Depression occurring in under five years, we also conducted 90th percentile trimming to analyze the median estimate. As the median is relatively stable across various trimming ranges, we focus our analysis primarily on the median estimate after 95th percentile trimming.

Comparing Our Results to Other Estimates

Economists' primary focus in the climate damage literature is on the economic impact of a doubling of CO_2 emissions from pre-industrial levels. Based on the central estimate of the "equilibrium climate sensitivity parameter" (i.e., the amount of long-run warming from a doubling of CO_2 emissions), the bulk of climate damage estimates fall around 3°C.

Focusing on our 95th percentile trimming results, we find that mean and median damage estimates for a 3°C increase in 2075 are -8.5% and -5% in GDP losses, respectively. This estimate is in line with our 2015 survey results.[22] Both estimates are significantly higher than DICE-2016R2, which implies a central estimate of only -2.1% of GDP for damages under a 3°C increase in 2075 (Nordhaus, 2017). Our survey findings are however within the range characterized by Howard and Sterner (2017), which forms the basis of the alternative damage function in Nordhaus (2019). Compared to Burke et al. (2015), our survey findings appear to be relatively conservative.

For a 1.2°C increase by 2025, we find mean and median losses of -2.2% and -1%, respectively, indicating that most economists believe that initial benefits from climate change are no longer (or maybe never were) present; this is consistent with our 2015 survey. Again, this estimate is far above DICE-2016R and is more consistent with Howard and Sterner (2017). However, only the median estimate is consistent with the DICE 95th percent confidence interval for non-catastrophic damages, though the mean estimate is relatively consistent with Burke et al. (2015).

We also asked respondents to provide damage estimates for higher temperature increases of 5°C and a 7°C. These estimates imply a damage function with less curvature than the standard quadratic damage function of DICE, potentially more consistent with earlier DICE damage functions that limit damages to below 100% of GDP; these results are consistent with Nordhaus (1994)'s survey results (Roughgarden & Schneider, 1999).

Figure 12

Climate Damage Estimates: Adaptation Scenarios

Changes in Economic Damage Due to Different Rates of Temperature Change or Income

Scenario	Scenario 1: Baseline	Scenario 2: 10% Higher GDP	Scenario 3: Faster Warming	Scenario 4: Slower Warming
Year	**2075**	**2075**	**2050**	**2100**
Temperature increase (relative to pre-industrial era)	**3°C**	**3°C**	**3°C**	**3°C**
Economic damages (% of global GDP) - Median estimate	**-5%**	**-5%**	**-6%**	**-4%**
Economic damages (trillions of 2019 USD) - Median estimate	**-$29.8**	**-$32.7**	**-$20.8**	**-$36.1**
Economic damages (% of global GDP) - Mean estimate	-8.5%	-7.40%	-9.90%	-6.60%
Economic damages (trillions of 2019 USD) - Mean estimate	-$50.6	-$48.4	-$34.3	-$59.5
Standard deviation	7.6	7.3	8.8	6.4

Results above reflect the trimming of outlier estimates below the 5^{th} percentile or above the 95^{th} percentile of total responses.

Comparing our "Adaptation Scenario" results to the prior question, we find evidence that higher income and slower rates of warming result in lower climate damages. This is consistent with the widespread view that society can better adapt to climate change if the rate of warming is slower or if society is wealthier. However, even in the scenarios with slower warming or higher GDP, damage estimates are high, with a loss of at least 4% of GDP expected in each scenario (and a 6% loss expected if warming is faster than the baseline). It is also worth noting that respondents expect higher GDP to provide only a minor adaptation benefit: the median damage estimate for this scenario is nearly identical to the baseline, though the mean estimate is less severe than the baseline mean estimate (the higher GDP scenario results in losses of 7.4% of GDP rather than 8.5%). In terms of actual dollars, the monetary impacts look quite similar, indicating that a wealthier society might save slightly in relative terms but the costs of climate change remain consistently high.

As DICE ignores potential impacts from divergent GDP levels and warming rates in its specification of the damage function, our results further indicate that it likely underestimates the benefits of climate action. This is particularly true when the DICE model deviates from its central calibration point (which is around 3°C for most of the damage estimates that underlie its calibration), as when it solves for the socially optimal temperature increase.

Figure 13

Estimated Cost of Emissions Abatement

Scenario	Abatement Scenario A - 2075	Abatement Scenario A - 2130	Abatement Scenario B - 2075
Year	2075	2130	2075
Temperature increase (relative to pre-industrial era)	2.5°C	3.5°C	2°C
Abatement level (% of emissions controlled) relative to RCP8.5-like pathway	68%	97%	88%
Abatement cost (% of global GDP) - Median estimate	**3%**	**4%**	**4%**
Abatement cost (trillions of 2019 USD) - Median estimate	**$17.5**	**$55.8**	**$25.3**
Abatement cost (% of global GDP) - Mean estimate	4.3%	5.9%	6.2%
Abatement cost (trillions of 2019 USD) - Mean estimate	25.0	82.4	39.2
Standard deviation	4.5	6.2	6.7

Results above reflect the trimming of outlier estimates below the 5th percentile or above the 95th percentile of total responses.

This question focuses on the cost of reducing emissions below a business-as-usual path (such as the RCP 8.5 scenario) at different times and levels of abatement. In the question text, we asked respondents to factor in all costs, including opportunity and general-equilibrium costs.

These abatement cost projections are higher than estimates from the IPCC and some other sources. However, the survey findings reveal a clear belief that reducing emissions by a meaningful amount is likely to cost less than the expected damages from climate change. These abatement cost estimates cannot be directly balanced against the damage estimates from the prior questions since they measure different outcomes under different scenarios and represent dynamic paths, but the underlying message is clear. Respondents already estimated that warming of 3°C by 2075 would lead to a loss of roughly 5% of GDP and a risk of even more catastrophic damages. But investing roughly 3-4% of GDP in emissions abatement by 2075 could cut that warming significantly, to 2.5°C or even 2°C, avoiding a great deal of damages in 2075 and later. As discussed below, the same respondents who made these abatement costs estimates also expressed widespread agreement that the costs of reaching net-zero emissions targets by mid-century were outweighed by the benefits.

Additionally, abatement costs are generally assumed to encompass investments in clean technologies, which entail upfront costs but offer benefits over a longer duration. By contrast, climate damage estimates are often projected to recur annually (on average) and worsen over time. As a reference point, respondents estimated that a continuation of the same 3°C warming trend until it reached 5°C would result in an annual GDP loss of 10% ($143 trillion in damages in 2130).

These abatement cost estimates are on the high end of the literature, though they are still roughly consistent with some IAM results.[23] Several factors could be contributing to the disparity between our survey estimates and the literature. Unlike responses to the prior questions, the median abatement cost estimate is sensitive to 95th percentile trimming, indicating that a lower cost estimate of 2.75% of GDP (to achieve a target of 2.5°C by 2075) may in fact be more accurate.[24] Additionally, if we focus on respondents with potentially more relevant expertise, i.e., those self-identifying as publishing on emissions abatement or those with multiple publications that meet the survey criteria, the resulting abatement cost projections drop to be more in line with the IPCC estimates (see Appendix D). Even then, the central estimates of these subgroups exceeds both DICE and the median IPCC estimates.[25]

On the other hand, this disparity is partially the result of the IPCC potentially underrepresenting abatement cost uncertainty, possibly leading to an underestimate of abatement costs. Specifically, the IPCC uses cost estimates from "idealized implementation scenarios," which assume a ubiquitous price on carbon and other GHGs is applied across the globe in every sector of every country and rises over time."[26]

A clear advantage of expert elicitation is that experts can account for difficult-to-model factors. When estimating damages, survey respondents can account for non-market, socially contingent, and tipping point impacts of climate change in ways that models might not. The same likely applies for abatement costs, and our relatively high estimates might reflect assumptions that emissions reductions will occur in a manner that is not perfectly efficient, due to either technological or political reasons. If we assume that our results represent the wisdom of the crowd (i.e., are asymptotically efficient), then a key advantage of our expert elicitation is that we implicitly capture these considerations to the extent that respondents consider and weigh them.

Despite the higher cost estimates from our survey, the cost trends for more aggressive mitigation are lower than some other projections. We find that the percentage increase in costs from Scenario A to Scenario B is lower than that of DICE-2016R2, implying that an extrapolation of our results would eventually show equal or lower costs to reach even more aggressive mitigation targets than DICE.[27]

Net-Zero Emission Targets

After earlier survey questions asked respondents to think through both the costs and benefits of climate action and inaction, we directly asked whether a net-zero emissions target by mid-century was likely to be cost-benefit justified.

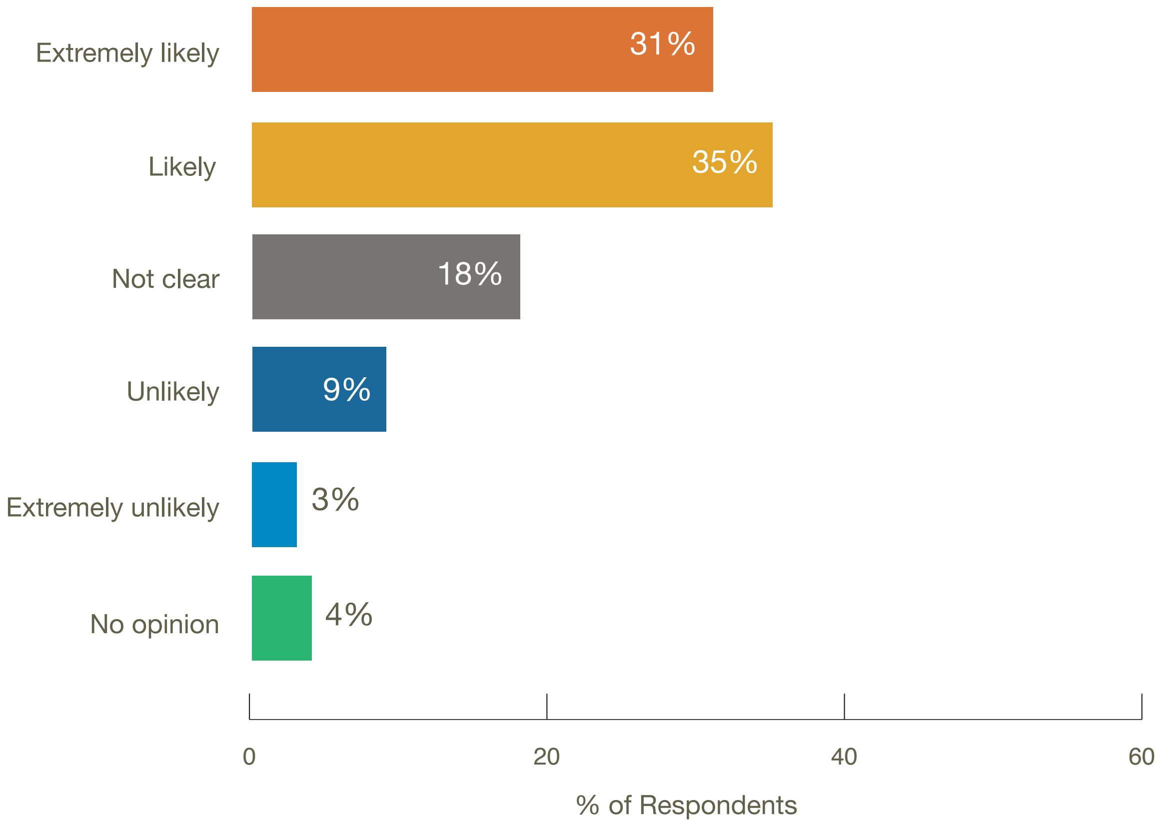
Mid-century net-zero targets have recently been adopted by some European countries and a small number of U.S. states (Energy & Climate Intelligence Unit, 2021; Center for Climate and Energy Solutions, 2021). These are the most aggressive emissions-reduction targets adopted by governments to date, and they align generally with the aims of the Paris climate agreement, to limit temperature increases to less than 2°C.

Figure 14

Many government entities have set goals to reach net-zero GHG emissions by roughly mid-century (this would be consistent with a global average surface temperature limit of 1.5° to 2°C according to many projections).

Are the expected benefits of mid-century net-zero GHG targets likely to outweigh the expected costs?

Please account for any relevant co-benefits and co-costs in your implicit present-value estimates.



The survey results suggest that economists with climate expertise believe that aggressive mitigation measures are warranted given the expected damages from climate change. Before answering this question, economists were asked to make specific forecasts about the costs of emissions abatement and the expected damages from climate impacts, ideally leading them to think through this high-level cost-benefit analysis in a somewhat detailed manner. Given this context, the findings are especially striking.

Nearly two-thirds of respondents believe that these net-zero goals are "likely" or "very likely" to be cost-benefit justified, despite the aggressive timeline and the anticipated abatement costs highlighted in the prior question. Meanwhile, only 12% of respondents think the goals are "unlikely" or "extremely unlikely" to be net-beneficial.

Likely due to the uncertainties involved, more than 18% chose the "Not Clear" option while an additional 4% expressed "No Opinion." But of the remaining respondents, economists that believed strong climate action was economically justified outnumbered their counterparts almost six to one.

These findings stand in contrast to models such as DICE, which estimates an "optimal" temperature (where benefits and costs are balanced) of 3.5°C in 2100 and a maximum of 4.1°C in 2165. These results and other past research suggest that DICE does not align with the consensus views of experts on a number of key issues, including expected damages/ damage functions, abatement costs, discount rates, and negative-emission technology availability.

Context from the Pandemic

Our final question focused on estimated changes to GDP and greenhouse gas emissions in 2020, in order to provide some context about how estimated climate impacts might compare to the impacts from the Covid-19 pandemic.

At the time of the survey, in early February 2021, official estimates of GDP and greenhouse gas emissions for 2020 were not yet available, so respondents would not have been able to find reliable anchors for their estimates (the question also stipulated not to use outside sources like the internet).

We included this question partially as a "seed question"—once respondents' answers can be empirically verified, we can use their relative accuracy to weight responses to other questions. (This analysis will be undertaken in future research. As of this publication, official estimates of the change in GDP and greenhouse gas emissions remain unavailable.)

Figure 15

Given the unprecedented events of 2020, please estimate the % change in global GDP and global greenhouse gas emissions (CO_2e) from 2019 to 2020, without using outside sources like the internet.

	Global GDP (% change from 2019 to 2020)	Global Greenhouse Gas Emissions (% change from 2019 to 2020)
Median estimate	**-3%**	**-3.5%**
Mean estimate	-2.9%	-3.1%
Standard deviation	4.1	4.7

Results above reflect the trimming of outlier estimates below the 5th percentile or above the 95th percentile of total responses.

These findings underscore the severity of respondents' climate damage forecasts from earlier in the survey. Respondents' GDP loss estimates for 2020, when a pandemic devastated the global economy, are far smaller than their estimates for annual damages from climate change under a 3°C warming scenario (-3% of GDP vs. -5 %). And unlike the pandemic-related downturn, which will presumably be followed by a rebound, the climate impacts are projected to recur and worsen.

Implications for Economic Modeling

The findings from this survey and other expert elicitation projects can help improve policy-relevant modeling of climate damages. One of the Biden administration's first acts was to reconvene the Interagency Working Group on the Social Cost of Greenhouse Gases (IWG) that had developed the official U.S. social cost of carbon estimates during the Obama administration (IWG, 2021). The Biden administration asked the IWG to develop interim estimates for the social cost of greenhouse gases within one month and then to comprehensively update the estimates by 2022 to reflect the best available scientific information.

Much of this update will likely correspond to recommendations from the National Academies of Sciences, Engineering, and Medicine, which published two reports on updating the SCC modeling methodology in 2016 and 2017. NAS (2017) called for the use of expert elicitation in the development of several IAM components, including socio-economic and emission scenarios. Expert elicitation can help modelers understand the current consensus, or lack thereof, on a number of key climate-economic parameters that are highly uncertain, so that they can make appropriate changes.

The results from this survey and others like it can be used to help calibrate IAMs. The methodology laid out in Howard and Sylvan (2020) demonstrates how to calibrate key parameters in a prominent IAM (DICE). Specifically, findings from our 2021 and 2015 surveys can be used to calibrate:

- **Climate damage functions –** Modelers can use elicited damage estimates from the survey to calibrate impacts under various potential temperature increases. As the baseline version of DICE-2016R2 models temperature increases of 1°C to 7.2°C, our survey elicits damage estimates for 1.2°C, 3°C, 5°C, and 7°C to allow for a flexible functional form. We ask about general damages and specifically ask respondents to consider non-market effects, to allow for a full consideration of impacts. More generally, by asking for 5th and 95th percentile estimates, we capture the overall risk of climate damages, finding a higher likelihood of severe damages than small damages (i.e., positive skewness).
- **Adaptation and its costs –** Modelers can use survey estimates to calibrate the impact of the rate of temperature change and per-capita income on net damages, using alternative damage scenarios. We ask respondents to consider adaptation and its costs when estimating damages, in order to reflect these values. By asking for the 5th and 95th percentile estimates, we also represent the impact of adaptation on the overall risk profile of climate damages.
- **Technological availability and adoption –** When calibrating the emissions scenario and the availability of negative-emissions technology, modelers can use survey estimates of the percent of zero-emissions energy in 2050 and the period when negative-emissions technology will become scalable.
- **Mitigation costs –** When calibrating the abatement cost function, modelers can use survey estimates for abatement costs in several climate scenarios. This will help capture the magnitude of abatement costs, how they change over time, and how they change with mitigation levels. Our question design allows respondents to consider imperfect implementation and technological constraints. Again, by asking for 5th and 95th percentile estimates, we also represent the small but real probability of higher-than-expected abatement costs.
- **Discount rate –** Modelers can calibrate the discount rate using the median rate provided by survey respondents (representing the normative quality of discount rates). This is based on a voting procedure. Other methods are also available, as discussed in Howard and Sylvan (2020).

By using survey data to calibrate existing IAMs or a modular IAM (as recommended by NAS (2017)), the IWG can provide the public with transparent estimates of these parameters along with a full representation of their likely values. This will allow the IWG to fully characterize the range of SCC estimates.

Expert elicitation may or may not be the proper tool for all these parameters. One NAS (2017, p. 149) recommendation advises against using "top-down" expert elicitation for climate damage function calibration, instead focusing on its use to quantify specific, hard-to-measure impacts (such as the impact and probability of crossing specific tipping points). However, modelers could generate more robust results by developing several damage function modules that use different approaches, as the magnitude of damage estimates varies significantly by estimation methodology (Howard & Sterner, 2017; Howard, 2019).

Bottom-up approaches that include expert elicitation on focused impacts may be better suited to tracing damages to specific pathways, as noted by NAS (2017). However, this comes at a cost. Specifically, bottom-up estimates generally omit certain impacts, such as inter-sectoral impacts and feedbacks.

As risk and ambiguity (i.e., unknown unknowns) are critical parts of climate change economics, it is important to account for a wide range of impacts and possibilities, particularly to meet the NAS (2017) goal of fully representing the SCC range. Given the multitude of potential climate impacts (Howard, 2014), formal expert elicitation cannot be applied for all categories. However, the top-down expert elicitation approach is critical for fully understanding the risk that society faces, and it is a good barometer of the potential biases inherent to other damage-estimation strategies. Furthermore, developing a full set of bottom-up damage estimates will likely take decades. Top-down elicitation can be useful as the IWG conducts its review in a one-year timeframe.

We believe the respondent criteria used for this survey is appropriate for informing model calibration. NAS (2017, p. 225) interprets the literature to suggest that elicitation should focus on a handful of experts (five to 10) identified by their number of citations or recognized expertise. But research suggests that reputation, peer rankings, and individual citations are uncorrelated with an individual's predictive performance (Aspinall, 2010; Colson & Cooke, 2018). Instead, the application of consistency checks (Howard & Sylvan, 2020) and performance weights, based upon responses to "seed questions"—related questions whose responses can be verified after the survey is conducted—can improve predictive performance relative to equal weighting (Cooke & Goossens, 2008; Howard & Sylvan, 2020). The application of these techniques to a large sample offers some clear benefits over small-sample expert surveys, which can suffer from selection bias and whose limited sample size can reduce estimate efficiency.

In future research, we plan to re-calibrate DICE using our survey results as discussed above. Specifically, we plan to recalibrate the DICE damage and abatement cost functions (including technological availability). In doing so, we will also allow the damage function to vary with the rate of temperature change and income per capita, in addition to overall temperature change, to capture the impacts of adaptation. We will also recalibrate the DICE discount rate to match the expert consensus found in Drupp et al. (2018) and Howard and Sylvan (2020). Finally, we will recalibrate the DICE climate model, which currently suffers from some calibration issues (Howard & Sylvan, 2020). This recalibration will better represent the full range of climate uncertainty. In doing so, we will aim to elucidate the full range of SCC estimates.

Conclusions

Economists with expertise on climate change can provide unique insights into the risks from climate impacts and the appropriate policy strategies. Our survey findings suggest that economic experts are increasingly alarmed about the threat that climate change poses to the global economy, even compared to significant levels of concern expressed five years ago.

Respondents in our survey predict a number of problematic impacts from climate change, including increased inequality both between and within countries, a reduction in the global economic growth rate, and significant economic damages under all climate scenarios presented.

These experts also believe that low-emissions technologies have significant economic promise, projecting that some emerging technologies are likely to replicate the dramatic cost reductions seen in solar and wind energy, and that negative-emissions technologies are likely to be viable in the coming decades. This survey reveals a strong consensus that bold climate mitigation strategies (including mid-century net-zero GHG targets) are likely to be economically justified.

These findings help clarify the level of consensus on key climate issues among economic experts. The results can be useful to both policymakers and economic researchers; both groups should heed the clear call for immediate and meaningful efforts to reduce emissions and limit the enormous economic risks of climate change.

Appendix A. Survey Questions

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SURVEY ON CLIMATE CHANGE ECONOMICS AND POLICY

The Institute for Policy Integrity at New York University School of Law is conducting a survey to examine the professional opinions of expert economists on climate change economics and policy. This survey is being sent only to economists who have published a climate change-related article in a top economic journal. The survey should take roughly 15 minutes to complete and consists of 10 multiple-choice questions and five forecasts. The aggregate results of this survey will be used in academic research and potentially distributed to journalists, but individual responses will be anonymous and confidential.

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Q1. You have published and consider yourself an expert on the following topics (check all that apply):

- O Estimated damages from climate change
- O Climate change uncertainty and risks, including tipping points and fat tails
- O Climate change adaptation and system resilience
- O Greenhouse gas emissions abatement / mitigation
- O Climate scenario modeling or cost-minimization modeling
- O Social Cost of Carbon or optimal climate policy modeling
- O Global climate strategies / agreements / policies
- O Climate change in developing countries / Geographic distribution of climate impacts
- O Other climate-related topics

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Professional Opinions on Climate Change

Q2. Which of the following best describes your views about climate change?

- O This is not a serious problem
- O More research is needed before action is taken
- O Some action should be taken now
- O Immediate and drastic action is necessary

Q3. As informed by your research, how has your level of concern about climate change shifted over the past five years?

- O Strongly increased (You view climate change as a more pressing problem)
- O Somewhat increased
- O Remained unchanged
- O Somewhat decreased
- O Strongly decreased (You view climate change as a less pressing problem)
- O No opinion

Q4. Please check <u>up to three items</u> that had the greatest effect on your views about climate change over the past five years.

- O The coronavirus pandemic
- O The Paris Agreement
- O The United States' withdrawal from the Paris Agreement
- O The IPCC Special Report on the impacts of 1.5°C global warming
- O Increased global energy demand
- O Continued expansion of fossil fuel infrastructure (e.g., North America's investment in natural gas; Asia's investment in coal; etc.)
- O Increased environmental deregulation within certain countries (United States, Brazil, etc.)
- O China's strengthening of its climate policies
- O New environmental policies and/or ambitious policy proposals in other countries
- O Observed extreme weather events attributed to climate change
- O New findings in climate science
- O New findings in climate economics and the social sciences
- O Improvements and/or cost reductions in low-emissions technologies
- O New developments with negative-emissions technologies
- O Insufficient improvements in abatement technologies and costs
- O Changes in adaptation technologies and costs
- O Other(s) ____

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Climate Change and Economic Growth

Q5. What is the likelihood that climate change will have a long-term, negative impact on the growth rate of the global economy? *This is distinct from an impact on the level of GDP in a given year (i.e., climate damages measured as % of GDP).*

- O Extremely likely (80% to 100% probability)
- O Likely (60% to 80%)
- O Not clear (40% to 60%)
- O Unlikely (20% to 40%)
- O Extremely unlikely (0% to 20%)
- O I anticipate no climate damages
- O No opinion

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Distributional Impacts

Q6. What is the likelihood that climate change will increase economic inequality <u>between low-income and high-income countries</u> (the lower third of countries by per-capita income versus the upper third of countries by per-capita income)?

- O Extremely likely (80% to 100% probability)
- O Likely (60% to 80%)
- O Not clear (40% to 60%)
- O Unlikely (20% to 40%)
- O Extremely unlikely (0% to 20%)
- O I anticipate no climate damages
- O No opinion

Q7. What is the likelihood that climate change will increase economic inequality within most countries, between the lower third of households by household income and the upper third of households by household income?

- O Extremely likely (80% to 100% probability)
- O Likely (60% to 80%)
- O Not clear (40% to 60%)
- O Unlikely (20% to 40%)
- O Extremely unlikely (0% to 20%)
- O I anticipate no climate damages
- O No opinion

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Emissions Abatement

Q8. Over the last decade, the costs of solar and wind energy technologies have dropped rapidly (-7% annually for solar PV and -4% annually for onshore wind). Do you think a similar pattern is likely to be replicable for some other emerging zero-emission and negative-emission technologies?

- O Extremely likely (80% to 100% probability)
- O Likely (60% to 80%)
- O Not clear (40% to 60%)
- O Unlikely (20% to 40%)
- O Extremely unlikely (0% to 20%)
- O No opinion

Q9. In 2050, what share of the global energy mix do you think will consist of zero-emission technologies (e.g., solar, wind, nuclear, green hydrogen, bioenergy with carbon capture and storage, etc.)?

For context, zero-emission sources make up roughly 10% of the current energy mix according to the International Energy Agency.

% of global energy mix

0 10 20 30 40 50 60 70 80 90 100

Zero-GHG Technologies

Q10. During what time period do you believe that net-negative greenhouse gas emission technologies, such as direct air capture and carbon capture/utilization/storage (CCUS), will become viable and reliable at a low-enough cost to be adopted on a large scale (i.e., to significantly change the global emissions path)?

- O By 2040
- O By 2060
- O By 2080
- O By 2100
- O Between 2100 and 2150
- O After 2150
- O Net-negative GHG technologies will never become viable
- O No opinion

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Climate Damage Estimates

Q11. Please provide your best estimates for how the following climate scenario would affect global GDP over time.

Please enter your median/50th percentile estimate and your 95th percent confidence interval of the impact on global output. To avoid (over)confidence and anchoring biases, please fill out the 95th percent confidence interval before selecting the 50th percentile.

Please include *non-market* and *market* impacts, and factor in *adaptation* to climate change and its corresponding costs. Please also consider the *level of global GDP* and *rate of temperature change*, in addition to overall temperature change (some researchers theorize that society is more capable of adapting to climate change with slower rates of temperature change and/or higher levels of global economic output).

Please provide your answer as a % of global GDP. If you believe these impacts will increase GDP rather than decrease it, please indicate this with a (+).

Scenario	Scenario 1 - 2025	Scenario 1 - 2075	Scenario 1 - 2130	Scenario 1 - 2220
Year	2025	2075	2130	2220
Temperature increase (relative to pre-industrial era)	1.2°C	3°C	5°C	7°C
Average annual temperature increase over previous 30 years	0.03°C	0.04°C	0.03°C	0.01°C
Estimated global GDP without climate change (trillions in 2019 USD)	173.3	595.1	1430.4	3654.5

	Scenario 1 - 2025 Climate Damage (% of GDP)	Scenario 1 - 2075 Climate Damage (% of GDP)	Scenario 1 - 2130 Climate Damage (% of GDP)	Scenario 1 - 2220 Climate Damage (% of GDP)
5th Percentile				
50th Percentile				
95th Percentile				

Adaptation Estimates

Q12. Please provide your best estimates of how adaptation could alter the level of climate damages, based on different rates of temperature change and anticipated levels of adaptation.

Some researchers theorize that society is more capable of *adapting* to climate change with *slower rates of temperature change* and/or *higher levels of global economic output*.

We are interested in your best guess (median/50th percentile estimate) and your 95th percent confidence interval of the impact on global output, as a percentage of GDP, of three alternative climate scenarios to **Scenario 1 - 2075** (provided earlier in column 2 of Question 11). To avoid (over)confidence and anchoring biases, please fill out the 95th percent confidence interval before selecting the 50th percentile.

Please include *non-market* and *market impacts*, and factor in *adaptation* to climate change and its corresponding costs. **Please provide your answer as a % of global GDP. If you believe these impacts will increase GDP rather than decrease it, please indicate this with a (+).**

Scenario	Scenario 2 - 10% Higher GDP Relative to Scenario 1 - 2075	Scenario 3 - Faster Warming Relative to Scenario 1 - 2075	Scenario 4 - Slower Warming Relative to Scenario 1 - 2075
Year	2075	2050	2100
Temperature increase (relative to pre-industrial era)	3°C	3°C	3°C
Average annual temperature increase over previous 30 years	0.04°C	**0.06°C**	**0.02°C**
Estimated global GDP without climate change (trillions in 2019 USD)	**654.61**	**346.6**	**901.5**

	Scenario 2 Climate Damage (% of GDP)	Scenario 3 Climate Damage (% of GDP)	Scenario 4 Climate Damage (% of GDP)
5th Percentile			
50th Percentile			
95th Percentile			

Abatement Cost Estimates

Q13. Please provide your best estimates of global abatement costs (as a percentage of GDP) for different climate scenarios.

We are interested in your best guess (median/50th percentile estimate) and your 95th percent confidence interval of the total cost of greenhouse gas *abatement*, as a percentage of GDP, for three emission scenarios.

Please factor in all costs, including opportunity and general-equilibrium costs. If you believe that low-carbon options are cheaper than conventional technologies, such that abatement costs are negative rather than positive, please indicate this with a (-).

To avoid (over)confidence and anchoring biases, please fill out the 95th percent confidence interval before selecting the 50th percentile.

Scenario	Abatement Scenario A - 2075	Abatement Scenario A - 2130	Abatement Scenario B - 2075 Higher Mitigation
Year	2075	2130	2075
Temperature increase (relative to pre-industrial era)	2.5°C	3.5°C	2°C
Abatement level (% of emissions controlled) relative to RCP8.5-like pathway	68%	97%	88%

	Abatement Scenario A - 2075 Abatement Cost (% of GDP)	Abatement Scenario A - 2130 Abatement Cost (% of GDP)	Abatement Scenario B - 2075 Abatement Cost (% of GDP)
5^{th} Percentile			
50^{th} Percentile			
95^{th} Percentile			

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Net-Zero Emission Targets

Q14. Many government entities have set goals to reach net-zero GHG emissions by roughly mid-century (this would be consistent with a global average surface temperature limit of 1.5° to 2°C according to many projections).

Are the expected benefits of mid-century net-zero GHG targets likely to outweigh the expected costs? Please account for any relevant co-benefits and co-costs in your implicit present-value estimates.

- O Extremely likely (80% to 100% probability)
- O Likely (60% to 80%)
- O Not clear (40% to 60%)
- O Unlikely (20% to 40%)
- O Extremely unlikely (0% to 20%)
- O No opinion

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Recent Impacts

Q15. Given the unprecedented events of 2020, please estimate the % change in global GDP and global greenhouse gas emissions (CO2e) from 2019 to 2020 without using outside sources like the internet. Answers to this question will provide context for survey results on climate change. To avoid (over)confidence and anchoring biases, please fill out the 95th percent confidence interval before selecting the 50th percentile. **Indicate a decline with a (-) and an increase with a (+).**

	Global GDP (% Change from 2019 to 2020)	Global Greenhouse Gas Emissions (% Change from 2019 to 2020)
5th Percentile		
50th Percentile		
95th Percentile		

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We thank you for your time spent taking this survey.

Your response has been recorded.

Appendix B. List of Journals Used to Assemble Survey Respondent Pool

Journals	Included in 2015 Survey
Economics	
American Economic Review	Yes
Econometric Theory	Yes
Econometrica	Yes
Economic Journal	Yes
Economic Theory	Yes
Economics Letters	Yes
European Economic Review	Yes
Games and Economic Behavior	Yes
International Economic Review	Yes
Journal of Applied Econometrics	Yes
Journal of Business and Economic Statistics	Yes
Journal of Development Economics	Yes
Journal of Econometrics	Yes
Journal of Economic Dynamics and Control	Yes
Journal of Economic Literature	Yes
Journal of Economic Perspectives	Yes
Journal of Economic Theory	Yes
Journal of Financial Economics	Yes
Journal of Human Resources	Yes
Journal of International Economics	Yes
Journal of Labor Economics	Yes
Journal of Monetary Economics	Yes
Journal of Money, Credit, and Banking	Yes
Journal of Political Economy	Yes
Journal of Public Economics	Yes
Journal of the European Economic Association	Yes
NBER Macroeconomics Annual	Yes
Quarterly Journal of Economics	Yes
Rand Journal of Economics	Yes
Review of Economic Studies	Yes

Journals	Included in 2015 Survey
Environmental and Resource Economics	
American Journal of Agricultural Economics	Yes
Ecological Economics	Yes
Environment and Resource Economics	Yes
Journal of Environmental Economic Management	Yes
Land Economics	Yes
Resource and Energy Economics	Yes
Review of Environmental Economics and Policy	No
Journal of the Association of Environmental and Resource Economists	No
Development Economics	
Journal of Development Economics	Yes
World Development	No
World Bank Economic Review	No
World Bank Research Observer	No
Journal of Development Studies	No
Economic Development and Cultural Change	No
Development Policy Review	No

Appendix C. Response Data by Survey Question

Question	Responses	Response Rate (Based on 2,169 Survey Invitations)	% of Total Respondents (Based on 738 Submitted Surveys)
1	733	33.8%	99.3%
2	738	34.0%	100.0%
3	736	33.9%	99.7%
4	727	33.5%	98.5%
5	733	33.8%	99.3%
6	731	33.7%	99.1%
7	730	33.7%	98.9%
8	726	33.5%	98.4%
9	712	32.8%	96.5%
10	725	33.4%	98.2%
11*	276 to 301	12.7% to 13.9%	37.4% to 40.8%
12*	224 to 229	10.3% to 10.6%	30.4% to 31%
13*	212 to 222	9.8% to 10.2%	28.7% to 30.1%
14	571	26.3%	77.4%
15*	340 to 342	16.7% to 15.8%	46.1% to 46.3%

Question numbers correspond to the numbering used in the survey questions (see Appendix A) as well as the numbering of figures in the report.

**These questions solicited multiple forecasts under various scenarios. Some respondents submitted estimates for only a subset of the scenarios, so we present a range of response rate data.*

Appendix D. Additional Forecast Analysis

The analysis below provides additional context for the survey questions that asked for quantitative forecasts of climate damages and abatement costs.

Examining 95th Percentile Results

There are several relevant takeaways from respondents' 95th percent confidence intervals of damages and abatement costs. First, net-negative climate damages are decisively predicted this decade, as 0% damages lies outside the 95th percent confidence interval for a 1.2°C increase in 2025. This is consistent with findings from our 2015 survey of 0% climate damages at approximately a 1°C increase in 2020 (Howard & Sylvan, 2020). Second, we find a 5% probability of a GDP loss of -10% (median) or -17% (mean) for a 3°C increase in 2075. This implies slightly lower catastrophic risks compared to our previous survey results, which found probabilities of 10% (median) and 22% (mean) that a -25% GDP loss would occur.[28] Third, we find that there is approximately a 5% chance of a 40% or more loss of GDP for a 7°C increase. This is unsurprising, as we find that damage uncertainty increases with temperature. Last, we find some evidence that increases in income and slower rates of temperature change decrease the risk of catastrophic climate change. Since the GDP path and equilibrium climate sensitivity are highly uncertain in the long run (though temperature and income are specified as certain in our scenario), catastrophic risks for 5°C and 7°C by 2130 and 2220 are greatly understated. Calibrating a model like DICE to our results, similar to the approach used in Howard and Sylvan (2020), will be necessary to fully specify the implied catastrophic risks.

Focusing on the 95th percentile results for abatement, we find that respondents generally believe that emissions mitigation cannot be accomplished at a negative cost (i.e., "free lunch" where companies act irrationally) as implied by some research (Gillingham & Stock, 2018). Similar to damages, we find that abatement costs are positively skewed. This corresponds to the empirical findings of Lemoine and McJeon (2013). Finally, we find that the range of mitigation costs increases with mitigation levels as indicated by the empirical literature (IPCC, 2014).

Topic Expertise and Forecasts

While the criteria for our survey sample is designed to identify experts in climate economics, one could potentially argue that knowledge of more specific topics is needed to make accurate forecasts. To address this concern, in the first question of our survey we requested that respondents self-identify the topics on which they have published and consider themselves an expert. Thus, we can test whether economists with self-identified expertise on damages provide different climate damage forecasts than others, and we can conduct similar tests for abatement cost experts on abatement forecasts, etc. Additionally, we sent separate but identical surveys to economists based on the number of qualifying publications they authored (one or multiple) and the type of journal in which they published (economics, environmental, and development). Thus, we can test whether economists with multiple qualifying publications provide different estimates than other groups.

Damage forecasts are relatively similar between the full sample and those who self-identify as publishing on climate damages. At low levels of warming, these experts believe that damage estimates are higher than the full sample, but after temperatures rise past 3°C the damage experts predict lower levels of damage than the full group. This may stem from a belief that adaptation is particularly sensitive to both income and the rate of temperature increase, given that global income grows substantially over time along with temperature (the latter of which slows down over time).

However, damage forecasts are higher for economists who self-identify as publishing on climate adaptation, relative to the full sample. These economists appear to be more pessimistic about society's ability to adapt to climate change, particularly for lower temperature increases.

Finally, economists with multiple qualifying publications forecast a slightly lower magnitude of damages than the full sample. Thus, there is no consistent direction by which relevant expert subgroups differ in their damage forecasts from the full sample.

A brief analysis of subgroup differences for our abatement cost forecasts can be found in the main report text.

Table D1. 95th Percent Confidence Intervals for Damage, Abatement, and Pandemic Questions

Question	Scenario	5th percentile				50th percentile				95th percentile			
		Obs	Mean	Median	Std. Dev.	Obs	Mean	Median	Std. Dev.	Obs	Mean	Median	Std. Dev.
11	S.1 - 2025	268	-1.0	-0.5	2.3	279	-2.2	-1	2.9	265	-5.2	-3	5.5
11	S.1 - 2075	260	-3.5	-2	3.8	270	-8.5	-5	7.6	265	-17.4	-10	15.2
11	S.1 - 2130	244	-7.5	-5	7.6	253	-16.1	-10	13.3	250	-31.0	-22	24.0
11	S.1 - 2220	240	-12.2	-7	13.5	251	-25.2	-20	20.7	249	-45.1	-40	30.7
12	S.2 - 2075	202	-3.0	-2	3.6	210	-7.4	-5	7.3	201	-14.6	-10	13.2
12	S.3 - 2075	205	-4.9	-3	5.8	203	-9.9	-6	8.8	201	-18.7	-12	16.1
12	S.4 - 2075	199	-2.4	-1.3	2.7	204	-6.6	-4	6.4	199	-13.2	-8.5	12.5
13	S.A - 2075	203	1.5	1	2.7	203	4.3	3	4.5	197	8.2	5	7.5
13	S.A -2130	192	2.4	1	3.7	192	5.9	4	6.2	193	12.2	8	11.8
13	S.B - 2075	197	2.9	2	4.6	197	6.2	4	6.7	193	11.2	8	10.4
15	GDP	297	-0.1	-1	4.0	310	-2.9	-3	4.1	310	-6.0	-6	5.6
15	GHG	280	0.1	-1	4.2	307	-3.1	-3.5	4.7	297	-6.6	-7	6.1

Table D2. Responses to Damage, Abatement, and Pandemic Questions by Self-Reported Expertise

Question	Scenario	Damage Expertise				Adaptation Expertise				Abatement Expertise			
		Obs	Mean	Median	Std. Dev.	Obs	Mean	Median	Std. Dev.	Obs	Mean	Median	Std. Dev.
11	S.1 - 2025	90	-2.7	-1	4.5	90	-3.7	-2	5.1	134	-2.0	-1	2.6
11	S.1 - 2075	89	-9.2	-5	10.1	90	-11.3	-7.5	10.6	134	-8.4	-5	8.6
11	S.1 - 2130	83	-14.0	-8	12.8	84	-17.9	-15	13.3	126	-18.0	-10	17.9
11	S.1 - 2220	80	-21.9	-15	19.3	82	-26.8	-20	20.5	124	-27.0	-20	24.2
12	S.2 - 2075	66	-7.2	-5	7.0	71	-10.1	-6.7	10.0	104	-6.7	-3.75	7.3
12	S.3 - 2075	65	-10.6	-6	9.7	70	-12.7	-8	11.4	100	-8.7	-5.5	8.2
12	S.4 - 2075	64	-5.6	-3	5.5	71	-9.2	-5	10.0	101	-5.3	-3	5.8
13	S.A - 2075	63	6.3	2.5	8.3	60	5.6	3	5.9	110	3.8	2	4.1
13	S.A -2130	58	7.1	3	9.6	61	8.3	5	8.9	105	5.3	3	5.5
13	S.B - 2075	57	7.6	4	9.2	60	7.8	4.5	8.8	108	5.7	3	6.6
15	GDP	88	-2.6	-3	4.3	86	-2.1	-3	4.6	155	-2.1	-3	4.2
15	GHG	87	-2.3	-3	4.0	84	-1.7	-2	4.9	152	-2.4	-3	4.6

Results above reflect the trimming of outlier estimates below the 5th percentile or above the 95th percentile of total responses.

Table D2. Responses to Damage, Abatement, and Pandemic Questions by Self-Reported Expertise (Continued)

Question	Scenario	Climate Uncertainty Expertise				Scenario Modeling Expertise				Optimal Policy Modeling Expertise			
		Obs	Mean	Median	Std. Dev.	Obs	Mean	Median	Std. Dev.	Obs	Mean	Median	Std. Dev.
11	S.1 – 2025	63	-2.0	-1	2.5	64	-1.8	-1	2.5	90	-1.9	-1	2.1
11	S.1 – 2075	62	-9.1	-7	7.3	66	-8.3	-5	7.8	88	-7.4	-6	5.7
11	S.1 – 2130	57	-20.7	-15	16.5	61	-18.8	-12	17.9	81	-15.4	-14	10.9
11	S.1 – 2220	55	-34.9	-30	25.5	60	-32.0	-22.5	27.9	79	-26.4	-20	19.7
12	S.2 – 2075	55	-9.4	-5	11.4	56	-7.5	-5	8.5	66	-7.2	-5	6.7
12	S.3 – 2075	51	-12.2	-10	12.2	53	-10.4	-7	9.7	66	-10.0	-6	8.8
12	S.4 – 2075	52	-7.4	-4.5	8.3	54	-6.6	-3.5	8.0	65	-6.1	-4	5.4
13	S.A – 2075	50	4.4	3	5.1	56	5.1	3	6.2	69	3.8	2	4.5
13	S.A -2130	45	5.2	3	6.2	54	5.7	5	5.8	66	4.9	3.25	5.2
13	S.B – 2075	47	6.6	4	7.9	54	7.1	5	8.3	67	5.4	4	5.8
15	GDP	65	-2.4	-3	4.5	76	-1.6	-2	4.8	105	-3.3	-4	4.9
15	GHG	66	-2.9	-3.25	4.3	76	-1.9	-3	5.4	103	-3.4	-4	4.7

Results above reflect the trimming of outlier estimates below the 5th percentile or above the 95th percentile of total responses.

Table D2. Responses to Damage, Abatement, and Pandemic Questions by Self-Reported Expertise (Continued)

Question	Scenario	Climate Policy Expertise				Developing Country/Distribution Expertise			
		Obs	Mean	Median	Std. Dev.	Obs	Mean	Median	Std. Dev.
11	S.1 - 2025	89	-2.4	-1	3.8	76	-3.3	-2	5.0
11	S.1 - 2075	88	-8.2	-5	8.1	75	-9.7	-5	10.3
11	S.1 - 2130	81	-15.6	-10	13.6	70	-14.3	-9	12.5
11	S.1 - 2220	80	-24.6	-20	21.4	69	-19.7	-15	17.3
12	S.2 - 2075	72	-8.4	-4	9.7	61	-7.7	-5	8.2
12	S.3 - 2075	71	-10.8	-6	11.4	58	-10.7	-6	9.6
12	S.4 - 2075	74	-8.2	-4	10.6	58	-6.3	-3	7.1
13	S.A - 2075	76	3.9	2	4.4	54	4.2	2.75	4.5
13	S.A -2130	69	5.1	3	5.6	53	6.2	4	7.7
13	S.B - 2075	72	5.0	3	5.5	52	6.1	4	6.5
15	GDP	111	-1.7	-3	4.5	79	-2.4	-3	4.8
15	GHG	108	-2.3	-3.5	5.2	77	-1.9	-2	5.1

Results above reflect the trimming of outlier estimates below the 5th percentile or above the 95th percentile of total responses.

Table D3. Responses to Damage, Abatement, and Pandemic Questions, by Number of Qualifying Publications

Question	Scenario	Respondents with Multiple Qualifying Publications				Respondents with One Qualifying Publication			
		Obs	Mean	Median	Std. Dev.	Obs	Mean	Median	Std. Dev.
11	S.1 - 2025	95	-1.5	-1	2.2	187	-2.9	-2	3.8
11	S.1 - 2075	91	-7.1	-5	6.4	181	-9.1	-6	8.1
11	S.1 - 2130	86	-14.5	-9	13.0	171	-17.6	-14	14.5
11	S.1 - 2220	85	-20.9	-12	17.3	168	-27.1	-20	22.0
12	S.2 - 2075	62	-6.8	-3	8.1	148	-7.8	-5	7.2
12	S.3 - 2075	62	-10.3	-6	10.6	145	-10.1	-7	8.6
12	S.4 - 2075	61	-6.1	-4	6.7	145	-6.7	-5	6.3
13	S.A - 2075	70	3.3	2	3.6	133	4.8	3	4.8
13	S.A -2130	69	6.0	3	9.1	128	6.6	5	6.3
13	S.B - 2075	70	4.7	3	4.8	128	6.9	4	7.5
15	GDP	110	-2.8	-3	4.0	201	-2.9	-3.5	4.2
15	GHG	105	-2.8	-3	4.5	201	-3.2	-4	4.7

Results above reflect the trimming of outlier estimates below the 5th percentile or above the 95th percentile of total responses.

Table D4. Responses to Damage, Abatement, and Pandemic Questions by Category of Qualifying Journal Publication

Question	Scenario	Respondents from Economics Journals				Respondents from Environmental Economics Journals				Respondents from Development Economics Journals			
		Obs	Mean	Median	Std. Dev.	Obs	Mean	Median	Std. Dev.	Obs	Mean	Median	Std. Dev.
11	S.1 - 2025	56	-1.2	-1	1.2	206	-2.8	-1.5	4.0	19	-2.7	-2	2.8
11	S.1 - 2075	56	-5.3	-4	4.7	204	-10.2	-7	9.6	19	-8.5	-5	9.2
11	S.1 - 2130	51	-11.8	-7	11.0	192	-18.7	-15	16.0	18	-12.6	-10.5	10.6
11	S.1 - 2220	48	-19.0	-12	15.6	189	-28.1	-20	23.1	18	-17.0	-17	12.7
12	S.2 - 2075	39	-4.8	-4	3.9	158	-8.8	-5	8.7	16	-9.9	-4.25	16.3
12	S.3 - 2075	36	-7.0	-5	5.7	156	-11.5	-7	10.8	16	-10.7	-6	10.6
12	S.4 - 2075	36	-4.6	-4	3.0	156	-6.7	-4.5	6.6	16	-8.1	-2.6	12.1
13	S.A - 2075	38	2.8	2	2.7	155	4.8	3	5.1	12	3.6	2	3.6
13	S.A -2130	35	3.4	3	3.1	148	6.8	4.75	7.3	12	5.5	3	6.3
13	S.B - 2075	36	3.4	3	2.3	152	7.5	4.25	8.6	12	5.4	3.75	5.9
15	GDP	64	-2.2	-3	4.3	223	-3.1	-3	4.1	22	-3.0	-4	4.4
15	GHG	59	-0.9	-2	5.2	215	-3.6	-4	4.3	21	-3.4	-4	3.8

Results above reflect the trimming of outlier estimates below the 5th percentile or above the 95th percentile of total responses.

Respondents from Economics Journals - Had at least one qualifying publication in a top economics journal

Respondents from Environmental Economics Journals - Had at least one qualifying publication in a top environmental economics journal and NO qualifying publications in a top economics journal.

Respondents from Development Economics Journals - Had at least one qualifying publication in a top development economics journal and NO qualifying publications in a top economics or environmental economics journal.

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Endnotes

1 Parts of this discussion and the section that follows are adapted (with updates) from the Institute for Policy Integrity's publications on past surveys of economists. See Howard and Sylvan (2015; 2020) and Holladay et al. (2009).

2 For example, New York State's Department of Environmental Conservation cited Drupp et al. (2018) as primary evidence to justify its use of a 2% discount rate in the calculation of its central Value of Carbon. Similarly, the U.S. government's Interagency Working Group on the Social Cost of Greenhouse Gases (2021) cited Drupp et al. (2018) and Howard and Sylvan (2020) as evidence supporting their interim recommendation to allow agencies to apply discount rates below 2.5% when valuing climate impacts. Outside of the climate context, expert elicitation has been used by several agencies: the U.S. Environmental Protection Agency developed concentration-response functions for mortality from particulate matter exposure using expert elicitation (Howard, 2019); and the Department of Interior relied on the expert opinion of Dr. Stephen Brown of UNLV to develop a multitude of parameters for its MarketSim model when estimates were unavailable in the literature (BOEM, 2015).

3 In particular, the Condorcet Jury Theorem states that the probability of a correct answer by a majority of the group increases toward certainty as the size of the group increases, if each individual person is more likely than not to be correct (Surowiecki, 2004).

4 Specifically, Pindyck (2015) states that "the ad hoc equations that go into most IAMs are no more than reflections of the modeler's own 'expert' opinion…determining plausible outcomes and probabilities, and the emission reductions needed to avert these outcomes, would mean relying on 'expert' opinion. For an economist, this is not very satisfying…But remember that the inputs to IAMs (equations and parameter values) are already the result of 'expert' opinion; in this case the modeler is the 'expert'…In effect, we would use expert opinion to determine the inputs to a simple, transparent and easy-to-understand model."

5 *See* Resources for the Future. *The Social Cost of Carbon Initiative*. https://www.rff.org/topics/scc/social-cost-carbon-initiative/.

6 We use 1994 as the first year for inclusion as Tol (2009) notes that modern climate economics began to take shape in approximately that year. Given that a starting date of 1994 implies the inclusion of some publications 25 years or older, in future work we may analyze authors based on the timing of their publications.

7 For our 2015 survey, we included economics journals ranked in the top 25 according to Kalaitzidakis et al. (2003) or Kalaitzidakis et al. (2011), as well as the top six environmental economics journals according to Rousseau (2008) or Rousseau et al. (2009). For our 2021 survey, we update these 37 journals to include papers published from 2015 to 2020. Additionally, we expanded our environmental economics journal category to include the *Journal of the Association of Environmental and Resource Economists and Review of Environmental Economics and Policy* due to their rise in prominence since 2015. Finally, we included seven development economics journals based on Kalaitzidakis et al. (2011), the World Bank ranking, and Google Scholar.

8 We restricted our sample for this survey to economists, removing the authors of qualifying articles who did not have a Ph.D. in economics or work as an economist/economics professor. We conducted this screening to the best of our ability, though we were not able to find credentials for every respondent. In our 2015 survey, we chose to include all those who had authored a qualifying article in an economics journal, even if their credentials were in another discipline or they had not received a Ph.D.

9 The Holladay et al. (2009) survey used a smaller respondent pool, focusing only on the top 25 "standard" economics journals. That survey was sent to 289 experts, receiving 144 responses.

10 We expanded our selection criteria to include development journals in part based on concerns that our 2015 survey may have overly reflected the views of scholars in wealthy countries and, subsequently, climate impacts in North America and Europe.

11 Though the academic literature does not clearly define what constitutes an "acceptable" response rate (Anderson et al., 2011), our general response rate was roughly in line with the average rate for online surveys in recent periods. Our overall effective response rate (RR6) is slightly lower than the 37% average found across 31 studies summarized in Sheehan (2001). However, there is strong evidence that e-mail survey response rates have been declining over time (Sheehan, 2001; Fan & Yan, 2010). For example, Sheehan (2001)'s response rates over the 1998 and 1999 period average to 31%; these numbers are slightly lower than our response rates in this survey. Similarly, Manfreda et al. (2008) find that the average response rate for 45 web surveys was 11% (Fan & Yan, 2010). Our response rates are in line with or above the averages from these studies.

12 For example, the group that received the survey included authors who proposed an economic model that predicted a potentially positive effect on global agriculture from climate change, and others who subsequently criticized that model and approach.

13 We identified authors by whether they had published one or multiple articles that met our selection criteria, and whether they published in economics, environmental economics, or development economics journals. We sent these groups different links to identical surveys so that we could test for differences between groups.

14 Following Howard and Sylvan (2020), we regress the response to each question on two indicator variables: the first equal to one if the respondent replied between the first e-mail reminder and the second e-mail reminder, and the second equal to one if the respondent replied after the second e-mail reminder. Only two respondents submitted responses after the close date, so they were grouped with those who responded after the second e-mail reminder. The tests for whether the coefficients for each indicator variable are individually and jointly significant imply no response bias when we fail to reject the null hypothesis of equaling zero. We reject response bias in all cases for the standard significance rate of 5%.

15 Newell et al. (2018) questions the identification assumptions in Burke et al. (2015; 2018), finding that climate change has no statistical impact on economic growth. Letta and Tol (2019) analyze the impact of climate change on total factor productivity finding that climate change has a negative effect on the growth rate of poor countries only.

16 *See* Diffenbaugh and Burke (2019); Tol (2018).

17 Based on Climate Action Tracker (2021) data, emission cuts of 70% to 86% (relative to business-as-usual) are necessary by 2050 to meet a 2°C target, while cuts of 86% to 95% are necessary to reach 1.5°C. While Climate Action Tracker projections align closely with IPCC (2018, p. 12) in the short-run (i.e., 2030), IPCC predicts that net-zero emissions are necessary by 2050 and 2070 to reach the 1.5°C and 2°C targets, respectively. Climate Action Tracker projects net-zero deadlines of 2069 and post-2100 for these targets. Specifically, IPCC (2018, p. 15) argues with high confidence that renewables will need to supply 70–85% (interquartile) of electricity in 2050 to meet the 1.5°C target (with a full range of 59% to 97%).

18 As a point of reference, only three direct air capture facilities are operational globally beyond the small-scale demonstration scale as of March 2021 (Carbon180, 2021).

19 Hansel et al. (2020) states, "A key difference between DICE and the IPCC Special Report is the stance regarding the availability of carbon removal technologies leading to net-negative emissions. While the scenarios considered by the IPCC make use of negative-emissions technologies roughly by the year 2050, the DICE-2016R2 model assumes that this will only be feasible from 2160 onwards."

20 For instance, Climate Action Tracker (2021) shows that negative-emissions technologies must be deployed at a large scale by 2064 to 2088 to reach a 1.5°C limit and by 2089 to reach 2°C limit in the worst-case scenario. Similarly, the IPCC assumes negative-emissions technologies will be used by 2050.

21 This range appears to far exceed Burke et al. (2015)'s range as represented in their Figure 5a. However, the authors state that "At levels of Warming below 2°C, our estimates are at least 3 times higher than IAM estimates, typically 5-20 times higher, and sometimes up to 100X higher. At higher levels of warming, our estimates are again at least 2.4 times larger than the highest IAM estimate and typically are much larger." Their range of 5 to 20 times the DICE-2016R central estimate, as indicated by this statement, suggests a wide range of -1.7% to -6.8%.

22 Our untrimmed mean and median from the 2021 survey are -10.7% and -5%, which match quite closely the values of -10.2% and -5.5%, respectively, from our 2015 survey (Howard & Sylvan, 2020). If we use 99th percentile trimming on the 2021 data, we find damage estimates of -9.8% and -5%, which again matches quite closely our corresponding 2015 survey's estimate of -9.2% and -5%.

23 Calibrating DICE-2016R2's carbon price to replicate these temperature limits, we find that DICE-2016R2's abatement cost estimates are far below our survey results: 0.9% and 0.8% to reach 2.5°C in 2075 and 3.5°C in 2130, respectively, consistent with Scenario A; and 1.7% to reach 2°C by 2075. However, our median estimate of the 5th percentile response is roughly consistent with DICE-2016R: 1% of GDP for 2.5°C in 2075, 1% of GDP for 3.5°C in 2130, and 2% for 2°C by 2075. As total abatement cost estimates vary significantly by model (IPCC WGIII, 2014, p. 39), our cost estimates are consistent with the upper end of the IPCC range for corresponding abatement scenarios. One confounding issue is that our survey respondents were quite optimistic about mitigation technology. However, our cost estimates are more consistent with the unavailability of negative-emissions technologies.

24 When we trim at the 95th percentile, our trimming is not symmetric. The 2.75% estimate reflects the median of the untrimmed data.

25 For climate damages, the results are less clear, as experts with the most relevant expertise (publishing on climate damages, publishing on adaptation, and those identified based on multiple publications) are inconsistent in the direction by which they believe the full sample is potentially biased with respect to their damage forecasts. *See* Appendix D.

26 Similarly, the failure of the models to capture the slow pace of climate policy implementation to date, combined with potential technology limits (particularly resulting from insufficient R&D) could lead to a further downward bias in the IPCC's mitigation cost estimates. This partially explains why Weyant (2017) argues that a target of "550 ppm [this century] will likely cost somewhere between 0.1 percent and 10 percent of gross world product (GWP) per year" putting our survey estimates well within this wide potential range.

27 Future modeling is necessary to determine this assertion, as calibration of DICE-2016R2's climate model currently makes reaching 2°C impossible, contrary to scientific consensus (Howard & Sylvan, 2020).

28 Using this data, Howard and Sylvan (2020) found the probability of a 25% loss of GDP for a 3°C increase to be 9.2% (mean) and 5.0% (median). This is still slightly lower than our 2021 survey findings.

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