**EPA Responses to Peer Reviewer Comments on EPA's 2022 Technical Report, "External Review Draft: Report on the Social Cost of Greenhouse Gases: Estimates Incorporating Recent Scientific Advances".**

**PEER REVIEWER COMMENTS BY CHARGE QUESTIONS**

| **I. General Impressions** | | |
|---|---|---|
| **REVIEWER** | **REVIEWER COMMENT** | **EPA RESPONSE** |
| Cropper | *EPA's Report on the Social Cost of Greenhouse Gases: Estimates Incorporating Recent Scientific Advances* represents a huge advance in estimating the US Social Cost of Carbon (SCC). The estimates reported have successfully incorporated all of the short-term recommendations of the National Research Council (NRC) Committee on Valuing Climate Damages, and some of the longer-term recommendations. The report represents the state-of-the-art in executing the four steps of SCC calculation: (1) calculating probability distributions over future paths of population, GDP and emissions; (2) translating future emissions into future climate impacts; (3) estimating net damages associated with changes in climate; (4) discounting future damages to the present. The description in the report of these steps and how they were executed is excellent. | Thank you. |
| Cropper | While the current report admittedly does not cover all aspects of climate change (e.g., precipitation impacts and extreme weather events) and all categories of damages (e.g., the impacts of flooding) I believe that the information presented is accurate and that the conclusions reached are sound. | Thank you. |
| Fisher-Vanden | **(NOTE:** As requested by the USEPA at the second meeting, I have attempted to distinguish between comments that should be addressed in the current report **("SHORT-TERM")** and comments that should be considered in a future report **("LONG-TERM"))** | Thank you. |

| | | |
|---|---|---|
| Fisher-Vanden | The approach taken to generate SC-GHG estimates is well-designed and executed and the document is well-written and easy to follow, although missing key details (as I describe below in my detailed comments). The modeling framework holds together well, and many choices made are defensible and based on current science. | Thank you. |
| Fisher-Vanden | Some larger issues I see, which are elaborated further below under specific sections, are: • (**SHORT-TERM**): A significant amount is left out of the analysis that could move the SC-GHG estimates in either direction. Throughout the report, the explanation that an approach satisfies the National Academy report's recommendation is used to justify methodological choices but is not very satisfactory. The report should be more transparent about the tradeoffs and how shortcomings of their methodological choices would bias the SC-GHG estimates. In particular, the analysis leaves out feedbacks, interactions, and other important considerations like intra- and international trade that will bias the results. | Throughout the report, EPA has expanded and clarified the discussion that the report's SC-GHG estimates likely underestimate the marginal damages from GHG pollution. EPA has also expanded and clarified the discussion of modeling limitations, especially in Section 3.2 "Omitted Damaged and Other Modeling Limitations." These revisions specifically address feedbacks and interactions. As noted in the expanded discussion in Section 5, improved representation of interactions and feedbacks were among the National Academies' longer term recommendations. Intra- and international trade are discussed in several sections of the report, and Table 3.2.1 specifically highlights aspects of trade omitted from this analysis. Additional discussion in Section 3.3 describes how some trade, as represented in the DSCIM and GIVE agricultural damage specifications, can mitigate damages. |

| | | |
|---|---|---|
| Fisher-Vanden | • It is well-understood that far future damage estimates are very likely to be off and it is difficult to judge whether the right estimate would be higher or lower. It isn't all about growth uncertainty but ability to adapt and vulnerability in a richer world. The authors attempt to address this by having income influence the damage estimates, but this seems too simplistic since there will likely be constraints on populations' ability to adapt (e.g., island nations). The analysis also does not explicitly (but perhaps implicitly?) consider geoengineering options. Related, a world with climate change will be different and preferences will be very different as a result. (**SHORT-TERM**): It would be useful for the report to discuss what is explicitly and implicitly captured in this regard and how it would bias the estimates. (**LONG-TERM**): In a future report, it would be important to incorporate these omitted constraints into the estimates. | EPA has expanded discussion of adaptation and also the socioeconomic and emissions scenarios. Despite the limitations and uncertainties across modules, EPA has expanded and clarified the discussion that the report's SC-GHG estimates likely underestimate the marginal damages from GHG pollution. For example, EPA has revised Section 3.2 to explain how GIVE and DSCIM employ optimistic assumptions about coastal adaptation and likely underestimate these damages. Section 2.1 features an expanded discussion of the methodology for the RFF-SP socioeconomic and emissions scenarios, which take into account the likelihood of future emissions mitigation policies. WIth regard to explicit representation of eoengineering options, please see responses on Question 3e on longer term recommendations below for a discussion of the challenges involved in including solar radiation management (SRM) in the analysis. |
| Fisher-Vanden | • (**LONG-TERM**): Although I completely understand and appreciate the choice to go with a modular approach, it comes with trade-offs. The only models that can be swapped in are those that are structurally the same. This doesn't allow for innovation on the modeling side to capture feedbacks and processes better since they would encapsulate many steps in the causal chain. | Improved accounting of feedbacks and processes is an important area for future improvements, as highlighted within the National Academies longer term recommendations and discussed within the EPA report (see expanded discussion in Section 3.2 and Section 5). While the current modular approach, as implemented, appears as relatively distinct and independent modules, the framework allows researchers to advance any individual component while also providing the opportunity to add components that would establish relationships and feedbacks between them. We appreciate the comment as this will be important to keep in mind as the science develops and to convey the importance of advancing more dynamic dimensions of the overall modeling effort. |

| | | |
|---|---|---|
| Fisher-Vanden | • (**SHORT-TERM/LONG-TERM**): In the spirit of transparency, I would recommend some discussion in the report on the process for updating these estimates going forward; in particular, a discussion about how new science and approaches (outside of the current approach) will be incorporated into future estimates, and how other research communities can participate in the process going forward. I noticed that some of the same people who participated in the National Academy recommendations were also those who generated these new SC-GHG estimates. Although what the authors have done here is scientifically sound, a different set of people may have taken a different approach. From the few public comments that I have read, there is a distinct feeling that certain people and communities who have expertise to offer were shut out of the process which would be important to address. | As noted in the report, EPA will continue to review developments in the literature, including more robust methodologies for estimating the magnitude of the various direct and indirect damages from GHG emissions, and look for opportunities to further improve SC-GHG estimation going forward. This was also the process EPA followed for the current report. That is, EPA completed a careful review of the National Academies (2017) recommendations and the current state of the scientific literature. EPA then selected methodological updates based on the available published literature consistent with the National Academies near-term recommendations. Further, the EPA believes that offering opportunities for public comment and conducting a transparent, high-quality external peer review of the updated SC-GHG estimates is important to ensure that the methodological updates adopted in EPA's SC-GHG Report are consistent with economic theory and reflect the latest science. EPA considered the comments received through the two opportunities for public comment during the peer reviewer selection process and the comments received on the November 2022 Draft Report. EPA aslo had the benefit of the input recieved from the public, including researchers and other stakeholders, and other agencies through the Agency's participation in the Interagency Working Group's (IWG) work. EPA has added further dicsusion of the peer review and public comment process in the Executive Summary of the Report. EPA expects to continue to follow best practices for public comment and peer review processes in future updates. |
| Fisher-Vanden | • (**SHORT-TERM**): As elaborated below, a technical document that accompanies this report is needed so readers don't have to access, read, and knit together all of the cited documentation to fully understand what was done to generate these estimates. | Thank you for this suggestion. We have expanded the explanations of the the methodological updates throughout Section 2 to assist the reader. Also, per your suggestion below, we have added a statement at the outset of Section 2 to clarify that the discussion is intended to provide and overview of the methodological updates, and additional details of each underlying study are available in the sources cited throughout the report. |

| | | |
|---|---|---|
| Fisher-Vanden | • (**SHORT-TERM**): It might be useful to add a section that identifies important future research that is needed to improve the current estimates. This could provide a valuable research agenda for researchers in this field. | EPA agrees that there are many aspects of the SC-GHG estimation methodology that are important areas of future research. Throughout the report, EPA has expanded discussion of future research topics that could be further investigated and potentially incorporated in future updates of these SC-GHG estimates. In particular, Section 3.2 "Omitted Damages and Other Modeling Limitations" presents numerous topics that are candidates for further research. An expanded discussion in Section 5 reemphasizes the National Academies' longer term updating recommendations. As noted in the report, EPA will continue to review developments in the literature, including more robust methodologies for estimating the magnitude of the various direct and indirect damages from GHG emissions, and look for opportunities to further improve SC-GHG estimation going forward. |
| Forest | The update to the Social Cost of Greenhouse Gas Estimates is a significant step towards addressing the National Academies report in 2017 and continuing to improve the ability to assess the impact on the United States. | Thank you. |
| Forest | I am very happy to see the separate discussions on the four modular components provides sufficient material for the EPA to move forward and adopt the additional changes. | Thank you. |
| Forest | The new material and descriptions of updates in all modules include significant advances. The new materials have generally come from peer-reviewed research papers and the materials being provided by through both academic and research organizations addressing these critical issues. | Thank you. |
| Forest | I found the material to be very straight forward and easy to follow, despite the long footnotes, and recognize the differences between the academic research papers and the style of the EPA/government documents. | Thank you. |

| | | |
|---|---|---|
| Forest | The use of itemized lists helps present the key updates such that readers can scan the document and easily identify the key findings in each section. This should be done in each section if possible. The use of key tables and figures are adequate to convey the content related to the primary updates. | EPA has made several revisions and additions to the report tables to try to better clarify the methodological updates. These updates complement Table 5.1, which enumerates National Academies' near-term recommendations alongside the methodological updates employed in the report. Examples of other such summary tables include Tables 2.3.1 and 2.3.2, which describe the damage functions methodologies and underlying literature for the GIVE and DSCIM damage modules. The newly-added Table A.8.1. clarifies the treatment of uncertainty across modules. |
| Forest | As a committee member of the National Academies (2017) report, collectively, the new advances across all the subjects had significant updates. | Thank you. |
| Forest | The science and economics are continuing to mature, and the low-hanging fruit are few, while we're now picking from higher up in the trees. This continual upgrade and revisions process is an important component of this latest update to the Social Cost of Greenhouse Gas Estimates. The National Academies (2017) report provided questions to answer, and this report identifies where most of these have been answered. | Thank you. |
| Forest | To me, of the four components, the comprehensive update of the damage estimates is the newest part of the work and provides a major component that fits well with the other modules. | Thank you. |

| | | |
|---|---|---|
| Forest | The update to the damage module will need to be reviewed and revisited once the final version is completed. | EPA has submitted the draft report to extensive peer review and public comment, which has been broadly supportive of the methodology and process. While EPA has revised the report in response to this feedback, much of the feedback was focused on longer-term research opportunities and requests for additional clarifying discussion throughout the report. Therefore, EPA has not changed the core methodology between the draft and final versions of the report. EPA will continue to review developments in the literature, including new methodologies for estimating the magnitude of the various direct and indirect damages from GHG emissions, and look for opportunities to further improve SC-GHG estimation going forward. EPA would follow best practices for public comment and peer review for future methodological updates. |
| Kling | This is a much-needed improvement in estimating the social cost of carbon and greenhouse gas emissions. The Agency is to be applauded for taking leadership in developing this critically needed new set of estimates. | Thank you. |
| Kling | The document provides the basis for both an improved estimate to be used in rulemaking in the near term, as well as providing the core foundation for continuing refinements and improvements in the future. | Thank you. |
| Kling | While I have a range of questions and suggestions for improvement, it is important to recognize the significant step forward the agency has taken with this first set of estimates of the Social Cost of GHGs. | Thank you. |
| Kling | The overall structure of the report is clear and the development of the modular approach as recommended by NASEM is well articulated. By establishing a modular platform, the Agency is well positioned to both improve the current set of estimates and allow for updates over time as the scientific and economic basis for the estimates evolve and improve. | Thank you. |

| | | |
|---|---|---|
| Kling | Despite these strengths, there are shortcomings with the report in its current form. I begin with some overarching concerns and then address each of the charge question areas in more detail below.<br>1. My first reaction to the writing style and content was that it was not detailed enough to be adequate for detailed technical review. After the helpful Zoom with EPA staff, I better understand the intended audience. The current level of depth suits their intended purpose well. However, a great deal of the analysis to support the module development and the empirical estimates generated are not sufficiently documented for careful review. Perhaps it would be useful to make clear in the intro that the document is intended as a road map, and that by necessity many of the details and decisions are documented in supporting materials and the interested reader should look there. Another possibility is to provide technical appendices. | Thank you for this suggestion. We have added a statement at the outset of Section 2 to clarify that the discussion is intended to provide and overview of the methodological updates, and additional details of each underlying study are available in the sources cited throughout the report. |

| | | |
|---|---|---|
| Kling | 2. Definitions. The NASEM (2017) report was careful to define each term used throughout the report and to use them consistently. This report would be improved if it included a glossary of key terms. For example, the NASEM report defines the social cost of carbon as "…an economic metric intended to provide a comprehensive estimate of the net damages – the monetized value of the net impacts, both negative and positive – from the global climate change that results from a small (1 metric ton) increase in carbon dioxide emissions," (exec. summary p. 1). This report provides a similar, but not identical definition "the SC-GHG is the monetary value of the net harm to society from emitting a metric ton of that GHG to the atmosphere in a given year." Beyond the obvious extension to all GHGs (which is great), this report's definition does not clarify that the SC-GHG is metric intended to provide a comprehensive estimate. The fact that it is intended to do so but does not yet achieve that goal due to many omitted components, is important for transparency and for explaining updates in the future. In addition to providing a comprehensive estimate of impact damages, I suggest making clear in the definition that the metric include both future and current damages. Finally, the definition of the SC-CO2 as developed in this document differs from the definition of SCC in the NASEM report as this new social cost incorporates multiple GHG emissions, both through their effect on climate and through direct externalities (positive or negative) on ocean acidification, etc. I suggest highlighting these advances early in the document. | Thank you for these suggestions. EPA has revised the definition of the SC-GHG to capture these points about comprehensiveness and future damages. Throughout the report, EPA has expanded discussion about how the presented SC-GHG estimates likely underestimate the marginal damages from greenhouse gas pollution. EPA has also expanded the discussion in Section 1 on the gas-specific nature of the SC-GHG. EPA has not produced a glossary for this report, but EPA will continue to consider this suggestion in subsequent updates. |

| | | |
|---|---|---|
| Kling | 3. To be clear, the report does a good job in many places of describing that there are many important omissions from the current estimates of this metric, but this is an important enough of a point that it would be valuable to articulate clearly and early. I suggest that in the introduction, executive summary, and summary the EPA state more explicitly that current estimates of the metric do not meet the full bar of the intention, that however this is a major step to improve these estimates. I hope that doing so early will add to transparency so that when the next update is introduced with different numbers and more modules, the IWG or EPA can point to the current document as having laid out the foundation that such updates are expected and desirable, rather than appearing idiosyncratic or worse yet, politically motivated. | Throughout the report, EPA has expanded discussion about how the presented SC-GHG estimates likely underestimate the marginal damages from greenhouse gas pollution. And EPA has now highlighted this "partial accounting" in the very first paragraph of the Executive Summary. EPA has also expanded and clarified the discussion in Section 3.2 "Omitted Damages and Other Modeling Limitations" and in the summary discussion of the path forward in Section 5. |
| | Other useful definitions from the NASEM report include NASEM (2017) defined climate impacts as “the biophysical or social effects driven by climate change” and climate damages as the “monetized estimates of the social welfare effects” (p. 138 and elsewhere). Consistent use of terminology like this throughout would aid transparency. | EPA has reviewed and expanded the description of the SC-GHG in the Executive Summary for improved clarity. This revision includes some specific examples of climate impacts and clarification that the SC-GHG measures the value of those impacts. |

| | | |
|---|---|---|
| Kling | 4. In a number of places in the document the EPA reports that the estimates presented here are "conservative." In some case this conservative (meaning lower bound?) estimate is explained as coming from omissions of information (like monetization of some damage impacts), in other cases, it is explained as an intentional effort to be conservative (also meaning to provide a lower bound?). The first issue is unavoidable and just needs more emphasis. I suggest explicitly using the words "lower bound" as "conservative" can have multiple meanings (e.g., if one were a proponent of the precautionary principle, conservative would mean use the highest damage estimate possible). The second issue is problematic for use of these metrics in benefit-cost analysis or any other economic efficiency interpretation. In general, if we are focusing on a s ingle point in the SCC distribution for use in efficiency analysis, we should be trying to estimate the **mean willingness to pay** not percentile of the distribution that lies to the left. Inadequate attention to the economic welfare interpretations of the monetized damage components. | EPA has revised the report to remove the term "conservative" (except when appearing in a quotation) for improved clarity. EPA has also expanded and clarified the discussion that the report's SC-GHG estimates likely underestimate the marginal damages from GHG pollution. EPA agrees that SC-GHG estimation is not a bounding exercise. EPA's methodology reflects EPA's best understanding of the literature, so while some of EPA's modeling decisions and methodological limitations led to known underestimation of the SC-GHG, these were cases where EPA had insufficient evidence to support an alternative approach. |
| Kling | 5. The report describes many places where the advice of NASEM (2017) was followed. That report was excellent and following their advice is great, but there are things that were suggested in that report that were not undertaken. A reader could easily believe otherwise (see Table 5.1 which lists the NASEM recommendations that were implemented but omits those that were not). For example, page 9 indicates that in the short run the IWG should, among other things update the damages by presenting spatially disaggregated market and nonmarket damages by region and second in both monetary and natural units (incremental and total) …. little to none of this has been done. As I argue below the omission of natural unit impacts is particularly concerning given how much remains nonmonetized. This point does not undermine any of the value of these new numbers, the point is to be transparent about what these numbers represent and what they do not. | EPA has added clarification in the Executive Summary and around Table 5 that this report has focused on addressing the National Academies' near-term recommendations with many longer-term recommendations still outstanding areas for further research. EPA has also expanded the discussion of the longer term National Academies recommendations in Section 5, which includes the longer term recommendation to "disaggregate market and non-market climate damages by region and sector, with results that are presented in both monetary and natural units." The Report now also presents additional information on the physical impacts of climate change, including Figures 3.2.1 and 3.2.1.1, which show regional heterogeneity in projections of changes in temperature, sea level, and precipitation. |

| | | |
|---|---|---|
| | Equation 2.5.1 on page 62 provides something like this, but its variables are not defined (the use of $\Delta_t$ for "marginal damages" is confusing, is this defined in consumption of money?) and it does not discuss the aggregation component or the interpretation component. | EPA has clarified the notation and discussion around this equation. |
| Oppenheimer | The document **Report on the Social Cost of Greenhouse Gases: Estimates Incorporating Recent Scientific Advances** is, as far as this reader can discern, accurate in its representation of the current literature. The presentation is exceptionally clear and would be accessible to a knowledgeable non-expert working in the climate policy domain. The document's conclusions are sound *within the self-constrained scope of its analysis* . | Thank you. |
| Oppenheimer | However, the document does not go as far as it could in exploring the implications of ambiguities, sensitivities, and other characterizations of uncertainty. | EPA has expanded and clarified the discussion of uncertainties in each module throughout Section 2 and with the additions of Appendix A.8 and Table A.8.1. EPA has also discussed a variety of sensitivities and uncertainties in the review of the literature and in the presentation of the multiple modeling approaches in the report, including the three damage modules. |
| Oppenheimer | In the long history of the climate change problem, it is this very arena, almost by definition, that has continued to provide surprising results and outcomes that force policy makers to update their approaches. For example, while the report does a good job of accounting for a range of plausible outcomes for ice sheet loss, it treats coastal adaptation "based on an optimistic assumption that optimal, lowest cost adaptation opportunities will be realized globally under perfect foresight about SLR." | EPA has expanded and clarified the discussion of the coastal adaptaption, challenges in modeling these decisions, and limitations in the current approach, including in Section 3.2 "Omitted Damages and Other Modeling Limitations." EPA will continue to follow the literature on projecting coastal adaptation when estimating the SC-GHG. |

| | | |
|---|---|---|
| Oppenheimer | While the report does label this assumption as “optimistic”, it begs the question of why a pessimistic assumption wasn’t likewise deployed. In other cases, “many interactions and feedback effects are not yet represented, both in modeling physical earth system changes [e.g., feedback effects of tipping elements] and economic damages.” | As EPA describes in the report, EPA faced a variety of limitations, which contributed to underestimation. EPA has expanded this discussion of these limitations in Section 3.2. EPA's methodology reflects EPA's best understanding of the literature, so while some of EPA's modeling decisions led to known underestimation of the SC-GHG, these were cases where EPA had insufficient evidence to support an alternative approach. For example, EPA's methodology includes an optimistic representation of coastal adaptation. EPA's objective, conditional on the data and methods available, was to calculate SC-GHG estimates that reflect of the expected willingness to pay, which as other reviewers noted, is the appropriate metric for benefit cost analyses. |
| Oppenheimer | Even though only one view of coastal adaptation and therefore only one end of a large range of possibilities is deployed for coastal damages, this may be better than the report’s other shortcoming: presenting no estimate at all for other features of the physical or social systems. | EPA has expanded discussion of limitations in Section 3.2 "Omitted Damages and Other Modeling Limitations." For some categories of impacts, EPA was limited by the available published literature capable of being incorporated into the damages module to monetize these impacts. EPA has increased the discussion of physical impacts, for which monetized impacts are unestimated or underestimated. EPA will continue to review developments in the literature, including more robust methodologies for estimating the magnitude of the various direct and indirect damages from GHG emissions, and look for opportunities to further improve SC-GHG estimation going forward. |
| Oppenheimer | Simply put, the number of “Not Yet Incorporated” features in Table 3.2.1 is rather startling. Certainly, an approach more sophisticated than the 25% cost increment embedded in some of the modeling referred to but not deployed here could have been introduced, at least for some sectors/features of the system. | EPA has expanded and clarified the discussion that the report's SC-GHG estimates likely underestimate the marginal damages from GHG pollution. But EPA disagrees with applying ad hoc multipliers or placeholders for missing or underestimated impacts. EPA will continue to review developments in the literature, including more robust methodologies for estimating the magnitude of the various direct and indirect damages from GHG emissions, and look for opportunities to further improve SC-GHG estimation going forward. |

| | | |
|---|---|---|
| Oppenheimer | The rationale that the current approach allows the report to claim it uses “the most conservative damage function specification” will undoubtedly be challenged because some of the omitted features might, in fact, reduce damages, if (in my judgment) modestly. | EPA has revised the report to remove the term "conservative" (except when appearing in a quotation). EPA has also expanded and clarified the discussion that the report's SC-GHG estimates likely underestimate the marginal damages from GHG pollution. |
| Oppenheimer | Worse yet, “most conservative” is not very useful as a guide to policy if no quantification or qualitative expert judgment, even of low confidence, is attempted for such a large part of the scope of the problem. | EPA has revised the report to remove the term "conservative" (except when appearing in a quotation). EPA has also expanded and clarified the discussion that the report's SC-GHG estimates likely underestimate the marginal damages from GHG pollution. |
| Oppenheimer | Authors of this report may have been constrained by the limitation of consistency with the temperature-only estimates provided by the Climate Impact Lab, thus restricting the analysis to impacts that are easily represented as functions of temperature. | EPA agrees that the the representations of non-temperature channels are important areas of future research. EPA has expanded the discussion of model limitations in Section 3.2, including the addition of Section 3.2.1, "Further Discussion of Precipitation Impacts of Climate Change." EPA has also clarified that some of the underlying damage studies incorporate other climate variables, such as precipitation. Limitations of the climate module are just one of several reasons for the empty and partial circles in Table 3.2.1. For example, alternative treatments of precipitation and other non-temperature variables require damage functions from the economics literature to map the changes in these variables to market and non-market economic damages over time. |
| Oppenheimer | However, this approach could and should have been supplemented with additional modeling (e.g., semi-empirical, RCM’s) or estimation procedures (meta-analysis of existing literature, sensitivity testing) that would have permitted bounding of costs of other impacts. | EPA has clarified that some of the underlying damage studies incorporate regional climate impacts and other climate variables, such as precipitation. EPA's objective, conditional on the data and methods available, was to calculate SC-GHG estimates that reflect the expected willingness to pay, the appropriate metric for benefit cost analyses. |
| Schlenker | EPA’s “Report on the Social Cost of Greenhouse Gases: Estimates Incorporating Recent Scientific Advances” outlines a revised methodology to derive the social cost of greenhouse gases. | Thank you. |

| | | |
|---|---|---|
| Schlenker | I believe the report is well written: it provides a history of how the social cost of carbon was previously derived, a rational for its revision, specifically how EPA is following the guidelines given by the National Academies of Sciences, Engineering, and Medicine (NASEM), as well as planned further revisions. I very much support the modular framework NASEM recommended, as it makes the individual steps in how the Social Cost of Greenhouse Gases (SC-GHG) is derived clear and allows people to modify individual components when new data becomes available or to test the sensitivity of the results to various parameters. Moreover, the analysis went away from the highly aggregated Integrated Assessment Models (IAM) that had previously been used and that did not incorporate the latest empirical findings. | Thank you. |
| Schlenker | It should be noted that several [public] comments were very complimentary for the work EPA had conducted [Docket ID EPA-HQ-OAR-2021-0317-2433, Docket ID EPA-HQ-OAR-2021-0317-2410]. I concur – EPA is advancing our state of knowledge. There are specific suggestions for improvements I will discuss in more detail below, but I believe the proposed rule is an important step forward. | Thank you. |
| Schlenker | There are some [public] comments [Docket ID EPA-HQ-OAR-2021-0317-2339 and EPA-HQ-OAR-2021-0317-2359] whether the derived estimates are defensible. I do not share those concerns. While EPA acknowledges that there are uncertainties, simply not using any value because the analysis is uncertain does not avoid the problem but instead chooses a value of zero. Given the presented evidence, EPA's revised values are clearly more defensible than a value of zero. A lot of evidence is given in the cited studies that changing weather patterns have an effect on societies. | Thank you. |

| | | |
|---|---|---|
| Wagner | The *Technical Support Document: Social Cost of Greenhouse Gas Estimates* represents a real step change in the formal calculation of the U.S. Social Cost of Carbon ($SC\text{-}CO_2$), not least because of its explicit calculation of the Social Cost of Methane ($SC\text{-}CH_4$) and Nitrous Oxide ($SC\text{-}N_2O$). It is generally well-written, technically sound, responsive to a host of comments and inputs (e.g. National Academy of Sciences 2017; Carleton and Greenstone 2021; Wagner et al. 2021) since the prior updates under the Obama administration (U.S. Government Interagency Working Group on Social Cost of Carbon 2015), and generally represents well the emerging consensus in the literature (e.g. Moore et al. 2023). | Thank you. |
| Wagner | The ~$200 'headline' number (for a 2% discount rate) for each ton of $CO_2$ emitted today is well within the emerging scientific consensus of a significant body of work that shows climate change is indeed much more costly than the prior 'interim' ~$50 number would suggest (e.g. Rennert et al. 2022; Moore et al. 2023; Bauer, Proistosescu, and Wagner 2023).[1] [1] Amazingly, even Barrage and Nordhaus's (2023) recent analysis agrees with this broad assessment. They do argue for an "optimal" carbon price of ~$50/t CO2. However, as they show in Figure 8, a discount rate of 2% would indeed come close to a $200 SCC. | Thank you. |
| Wagner | The 2% discount rate, too, is appropriately chosen to replace what the U.S. Government Interagency Working Group's (2015) effort called the "central" 3% rate, with significant work pointing to using the lower 2% rate instead (e.g. Drupp et al. 2018; Council of Economic Advisors 2017; Greenstone and Stock 2021; Wagner et al. 2021). In fact, the proposed update to Circular A-4 argues convincingly for an even lower discount rate of 1.7% to be used in the short term (U.S. Office of Management and Budget (OMB) 2023). | Thank you. |

| | | |
|---|---|---|
| Wagner | My one major recommendation is to improve the representation of climatic and climate-economic risks and uncertainties in the report, perhaps especially in the Executive Summary and the main Table ES.1 (see more below) but also throughout the report. The resulting SCC presented here can only be described as a 'partial' estimate, with a potentially long upper tail. That fact needs to be clear and consistently presented throughout the report. | EPA has expanded and clarified the discussion that the report's SC-GHG estimates likely underestimate the marginal damages from GHG pollution. And EPA has now highlighted the "partial" nature of the estimates in the very first paragraph of the Executive Summary. EPA has also expanded and clarified the discussion in Section 3.2 "Omitted Damages and Other Modeling Limitations." EPA has also added Appendix A.8 and Table A.8.1. clarifying the treatment of uncertainty across modules. |

**II. Response to Charge Questions**

**Charge Question 1.**

**Charge Question 1.a.** ***Does the modular approach taken in this draft report offer an improved opportunity to draw on expertise from the wide range of scientific disciplines relevant to SC-GHG estimation relative to the estimation approach underlying the IWG methodology to date (which relies on the default bundled structure of the DICE, PAGE, and FUND integrated assessment models)? Why or why not?***

| REVIEWER | REVIEWER COMMENT | EPA RESPONSE |
|---|---|---|
| Cropper | The use of a modular approach is a significant improvement over the bundling of DICE2013, PAGE and FUND. While each of these integrated assessment models (IAMs) has played an important role in enriching our understanding of the nature of climate change and policies to control it, the versions used to construct the interim SCC did not reflect the state of the art in climate science or in the modeling of climate damages. | Thank you. |
| Cropper | The advantage of the modular approach is that each of the four steps of SCC estimation can be executed by experts in the relevant area. | Thank you. |

| | | |
|---|---|---|
| Fisher-Vanden | (**LONG-TERM**): Although making the modeling framework modular can, in principle, allow for the ability to "plug and play" any alternative socioeconomic, climate, or damage model based on new science, the reality is that the only models that can be swapped in are like-minded models that take in the same inputs and generate the same outputs. It doesn't allow for new science on the integration of modeling components that can capture key feedbacks, dynamics, and interactions across submodels. The integrated assessment modeling community and the multisector dynamic community have a lot to offer in terms of new science in this area. | Improved accounting of feedbacks and interactions is an important area for future improvements, as highlighted within the National Academies longer term recommendations and discussed within the EPA report (see expanded discussion in Section 3.2 and Section 5). While the current modular approach, as implemented, appears as relatively distinct and independent modules, the framework allows researchers to advance any individual component while also providing the opportunity to add components that would establish relationships and feedbacks between them. We appreciate the comment as this will be important to keep in mind as the science develops and to convey the importance of advancing more dynamic dimensions of the overall modeling effort. |
| Fisher-Vanden | It should be noted that to capture feedbacks and interactions, it is not enough to just iterate across the four modules (socioeconomics, climate, damages, discounting) since this will not capture integrated impacts—the fact that impacts in one sector will affect impacts in another sector—e.g., sectors competing for the same scarce water. | Thank you, we agree that further incorporation of feedbacks, both across modules and damage functions (e.g., land-energy-water nexus), is an important are for future research. EPA will monitor developments in the literature and will further integrate these types of complex relationships into our modeling of the SC-GHGs as feasiable and appropriate. |
| Fisher-Vanden | This and the NASEM report both highlight the shortcomings of the previous IWG modeling approach as motivation for the approach that was taken in these new SC-GHG estimates. I don't disagree with the points made in these reports. However, there are other integrated modeling approaches that could have been used and weren't. There are obvious trade-offs between approaches, and it would be important to explain these trade-offs. From my read of it, the authors have given more weight to the importance of modularity (to allow for easy updates on the individual components) and improving the representation of uncertainty. In doing this, however, they are giving less weight to capturing feedbacks and interactions and providing sectoral and regional detail to understand distributional effects. | The point about tradeoffs is important and we thank the reviewer for highlighting this in the current report. As you note, and we agree, the modeling advancements made in this report offer a significant imporvement from the previous methods and represent a step in the right direction towards transparency, reproducibility, and open-source modeling such that the research community can continue to advance individual components both on their own and jointly. We have expanded discussion in the report (e.g., in Section 3.2) that the current approach does not fully capture feedbacks and interactions, and believe that the modular approach will provide a solid foundation to begin building in the feedback and interaction components that you mention here. We are continuing to monitor advancements made in this arena and anticipate incorporating these into future modeling efforts. |

| | | |
|---|---|---|
| Fisher-Vanden | (**SHORT-TERM**): In this report, it would be important to discuss how these choices and omissions bias the SC-GHG estimates. | Thank you. We have significantly expanded discussion in the Report, specifically Section 3.2, about the importance of omitted impacts and associated damages, including many feedbacks and interaction effects. |
| Forest | Yes, the modular approach works well, with the caveat that as finer scale information will eventually be added into more than one module and this will add another layer of complexity. | Thank you. |
| Forest | In the long run, new tools will be required to improve the sampling strategies across all modules to estimate the final distributions of the SC-GHG. | Thank you, we agree and will continue to monitor advancements in this area. |
| Kling | As noted above, the move to a modular approach is highly valuable and sets the stage for continuing improvements. | Thank you. |
| Kling | A suggestion for Figure 2.1 is to add a box coming from the damages module to represent unmonetized damages. Perhaps it would be “as yet unmonetized damages”? or something of that sort. Again, the goal is transparency and recognition of this omission. | Thank you for this suggestion as we agree it is important to recognize and document the ommited or unmonetized impacts of greenhouse gas emissions. In figure 2.1 we have included an arrow and box from the damages model to explicitly represent this omission labeled "Non-monetized Impacts". |
| Oppenheimer | The modular approach is certainly a major improvement over the previous approach because it increases transparency, avoids or makes more transparent many of the implicit and explicit expert judgments that the modeling underlying the previous approach obscured, and makes far easier the inclusion in the report of results from empirical modeling. The latter has in many ways revolutionized the study of many climate impacts as represented by a large and rapidly increasing literature. To not be able to include these results in a consistent manner would have undermined the credibility of this report. | Thank you. |

| | | |
|---|---|---|
| Schlenker | The derivation of the SC-GHG has always required the four steps (modules) identified in Figure 2.1, however, earlier studies have often used simplifying assumptions on various parameters, e.g., picking an exogenous GDP or population growth rate, or implicit performed the three steps without breaking them apart. The modular approach has three major advantages: first, it clarifies the underlying assumptions and uncertainties of each step by dedicating a separate section it. Second, it allows for easy updating and revisions as new data become available – only the corresponding module will have to be adjusted. Finally, the sensitivity of the results to various modules is easily derived, e.g., several comments were with regard to the appropriate discount rate. | Thank you, we agree. |
| Wagner | It does, and it does so well. The modular framework directly responds to calls from the U.S. National Academy of Sciences (2017) for just such a modular framework. The implementation builds on an impressive modeling effort spearheaded by Resources for the Future's Social Cost of Carbon Initiative, culminating in the Greenhouse Gas Impact Value Estimator (GIVE) model (Rennert et al. 2022) and the 'Mimi' modeling platform created by David Anthoff, Richard Plevin, Cora Kingdon, and Lisa Rennels: mimiframework.org. | Thank you. |

| **Charge Question 1.b.** ***Was the modular approach described clearly in the draft report? Do you have any recommendations for improving the presentation in the draft report?*** | | |
|---|---|---|
| **REVIEWER** | **REVIEWER COMMENT** | **EPA RESPONSE** |
| Cropper | I think it is well described. | Thank you. |

| | | |
|---|---|---|
| Fisher-Vanden | The report provides a very nice description and overview, but I found myself having to read a number of papers provided in citations or on websites to truly understand what was done and how the different pieces connected. For instance, how the RFF-SP socioeconomic projections were constructed and then fed into the damage models such as DSCIM was not explained well. From reading the DSCIM user manual, I now realize that the DSCIM estimates were based on SSPs and RCPs and in order to connect to the RFF-SPs, the authors were required to construct a weighted average of SSP projections to replicate a particular RFF-SP projection. Thus, it isn't the case that the RFF-SPs are direct inputs to the DSCIM estimates. This was not clear in the report and is an important point since this approach could create consistency issues (as I discuss below in the damages module section). I wouldn't have known this if I had not consulted other sources of information. (Note: It is unclear to me whether enough time was provided for the review panel to read and comprehend all of the necessary supporting documentation before commenting on the scientific soundness of some of these estimates). | Thank you for this suggestion. We have expanded discussion of the development of the RFF-SPs in Section 2.1 and expanded the footnote in Section 2.3 that discusses the emulator approach to help clarify the process and integration of socioeconomics into DSCIM. We have also added a statement at the outset of Section 2 to clarify that the discussion in the report is intended to provide an overview road map of the methodological updates, and that additional details of each underlying study are available in the sources cited throughout the report. |
| Fisher-Vanden | (**SHORT-TERM**): Therefore, this report is excellent for providing an overview, but not appropriate for trying to understand and comment on what is going on under the hood. A much more detailed technical document, similar to the DSCIM user manual, for instance, should accompany this report. | Thank you for this suggestion. We have added a statement at the outset of Section 2 to clarify that the discussion is intended to provide an overview road map of the methodological updates, and that additional details of each underlying study are available in the sources cited throughout the report. |
| Forest | Yes, the modular approach is clear for me. I have no specific recommendations at this time. | Thank you. |
| Oppenheimer | Yes, very clearly, and I have no specific recommendations with regard to the presentation. As indicated in my response to Question 1, I do have specific and general criticisms of the substantive approach, particularly regarding the treatment of uncertainty. | Thank you. |
| Kling | See above. | Thank you. |
| Schlenker | The modular approach is well described. | Thank you. |

| | | |
|---|---|---|
| Wagner | Yes, and no. I also appreciate that the complete replication code is available via Github: github.com/USEPA/scghg | Thank you. |

**Charge Question 1.c.** ***Are there alternative, superior approaches that EPA should consider using to achieve its goals for this update? Please describe the advantages of these approaches.***

| REVIEWER | REVIEWER COMMENT | EPA RESPONSE |
|---|---|---|
| Cropper | None. | Thank you. |
| Fisher-Vanden | (**LONG-TERM**): Similar to how this report used alternative damage function models, EPA could also offer SC-GHG estimates based on fully integrated modeling. | Thank you, we hope to build on the current framework and incorporate these suggestions in future updates. |
| Fisher-Vanden | (**SHORT-TERM**): Even though the authors leave this as a 'long-term goal' in SC-GHG estimation, at a minimum, the authors should attempt to measure and discuss how leaving out the integration and feedbacks would bias the SC-GHG estimates since these current estimates will likely be used for many years. | Thank you for this suggestion. We have offered an expanded discussion in section 3.2 to document the ommision of these effects and cite studies that investigate their likely impacts on the SC-GHG estimation process. |
| Fisher-Vanden | (**SHORT-TERM**): It would also be useful for the report to explain how new science will be incorporated into future SC-GHG estimates. What will the process be for this? Will it rely on updates from the teams already in place? | Thank you. Please see our response to this comment under the General Impressions section above. |
| Forest | To keep the modular paradigm/structure, I am advocating for more creative opportunities to incorporate climate/weather extremes into all modules when running an instance of the full model. | Thank you, we similarly encourage the research commnity to continue to advance the science in this area and anticipate incorporating these additional impacts into future updates. We have offered an expanded discussion of this and similar impacts in Section 3.2 of the Report. |
| Forest | Each module has some connections to the climate data that drives emissions, the current observed climate pathways (given the uncertainty in projections based on historical records), and the impacts estimates. | Thank you. |

| | | |
|---|---|---|
| Forest | I am not clear yet, on how the discounting might be connected to climate, but one relevant idea is that people's preferences are psychologically connected to higher anxiety about the "current" climate trajectory. In turn, this would imply a stronger sense of urgency that would increase the value of the long-term future. | Thank you for this comment. We understand this to be related to risk-aversion, which we provide an expanded discussion in the Report, specifically sections 2 and A3. However, the idea of climate risk salience is not one that we have found significant discussion on in the literature. We will keep this concept in mind as we continue to monitor the literature on discounting and temporal components of preferences. |
| Forest | With a view towards sensitivity testing of the SC-GHG modules, I advocate to use stratified or direct sampling methods that allow accounting for the modules as well as the internal parameters within the modules. | Thank you, we agree this would be a great next step to further enhance the representations of uncertainty both within and across model components. As the research community continues to advance the modules and expand into new, alternative, modules, we will look for opportunities to incorporate this type of uncertainty in future updates. |
| Forest | Variants of Latin Hyper-Cube Sampling strategies (or similar tools) or methods of deep uncertainty quantification (e.g., Oddo et al. 2017, doi:10.1111/risa.12888) should be considered as model complexity increases. | Thank you for this suggestion. As additional components become available and incorporated into published models, we will consider this approach in future updates. |
| Kling | No. | Thank you. |

| | | |
|---|---|---|
| Oppenheimer | As noted above, the treatment of uncertainty is incomplete and could be improved. In particular, where physical science or adaptation science is incomplete, a one-ended (fuzzy) bounding exercise, as used for adaptation to coastal impacts, will not do. | EPA's objective, conditional on the data and methods available, was to calculate SC-GHG estimates that reflect the expected willingness to pay, which as other reviewers noted, is the appropriate metric for benefit cost analyses. As EPA describes in the report, EPA faced a variety of limitations, which contributed to underestimation. EPA's methodology reflects EPA's best understanding of the literature, so while some of EPA's modeling decisions led to known underestimation of the SC-GHG, these were cases where EPA had insufficient evidence to support an alternative approach. For example, EPA's methodology includes an optimistic representation of coastal adaptation.<br><br>EPA agrees that treatment of uncertainty in SC-GHG estimation is a valuable area for further research. EPA has expanded and clarified the discussion of uncertainty throughout the report, including a new Appendix A.8 and Table A.8.1 summarizing EPA's methodology for the treatment of uncertainty. |
| Oppenheimer | There is really no excuse for not using available information to estimate some version of a low-probably “upper bound,” especially when high impact phenomena are at issue (like damage from intense precipitation events). This is old ground that has been covered and contested over and over and I find it surprising that this report retreated to what the authors probably considered to be safe ground, the so-called “conservative damage function specification.” | Thank you for this. In generating the report, our objective, conditional on the data and methods available, was to calculate an estimate of the SC-GHG that reflected the expected willingness to pay, which is the appropriate metric for use in benefit cost analyses, as noted by other reviewer comments. As described in the report, EPA faced a variety of limitations that, taken in total, likely cause the SC-GHG to be underestimated. This is not the same as a bounding analysis, which would not provide the necessary inputs for benefit cost analyses that include changes in GHG emissions. As noted in other responses, EPA has revised the language in the report to generally avoid the phrase "conservative" to reduce the risk of misinterpretation. |

| | | |
|---|---|---|
| Oppenheimer | In fact, this report is inconsistent in using the range determined by deploying both FACT and BRICK for sea level rise while not using a similar approach for other features, which instead were simply elided. | In Section 2.2 of the report, EPA summarizes the factors leading to the differences in the BRICK and FACTS SLR projections in the out years of the modeling horizon. The Agency does not consider them to be a bounding exercise. These are two models were developed by independent research teams and published in the peer reviewed literature, thus, providing different lines of evidence on the SLR component. As noted in the report, in the absence of a probabilistic assessment of the likelihood of the processes reflected in each model, the EPA retains use of both approaches. |
| Oppenheimer | Had this lacuna been thought about in advance, a bounding exercise for features other than sea level rise but analogous to the treatment in IPCC Sixth Assessment Report, WGI, Chapter 9.6.3.2 could have been developed in a timely fashion. At this time, it may or may not be too late to revise the approach to uncertainty, but this ought to be a top priority for the next cycle of SCC estimation. | In generating the report, our objective, conditional on the data and methods available, was to calculate an estimate of the SC-GHG that reflected the expected willingness to pay, which is the appropriate metric for use in benefit cost analyses, as noted by other reviewer comments. As described in the report, EPA faced a variety of limitations that, taken in total, likely cause the SC-GHG to be underestimated. For example, EPA's methodology includes an optimistic representation of coastal adaptation. This is not the same as a bounding analysis, which would not provide the necessary inputs for benefit cost analyses that include changes in GHG emissions.<br><br>EPA agrees that treatment of uncertainty in SC-GHG estimation is a valuable area for further research. EPA has expanded and clarified the discussion of uncertainty throughout the report, including a new Appendix A.8 and Table A.8.1 summarizing EPA's methodology for the treatment of uncertainty. |
| Oppenheimer | An adequate representation of the right-hand tail is a critical feature for policy makers and aside from the bounds on outcomes implied by using both FACT and BRICK, this report fails to estimate tail risk, e.g., consequences of tipping points and other high-impact, low likelihood phenomena. | EPA notes that the large tails mentioned by the reviewer do, in fact, inform the SC-GHG estimates to the degree that they are able to be incorporated into the modeling based on available data and methods. We will continue to follow the literature and incorporate additional impacts of climate change, include their distribution, into the SC-GHG modeling as feasible and appropriate. As previously noted, EPA does not view the use of both FACT and BRICK as a bounding exercise. |

| | | |
|---|---|---|
| Schlenker | NASEM had short-term and long-term recommendations. I believe EPA has followed the recommendations it was given for short-term revisions. There are of course additional steps that can be done, as the report acknowledges, but EPA has done a remarkable step forward. | Thank you. |
| Wagner | There are not, and I'm saying that as the co-author of such "alternative" approaches. Daniel, Litterman, and Wagner (2018; 2019) and Bauer, Proistosescu, and Wagner (2023) present such an "alternative" approach of treating $CO_2$ in the atmosphere as a "risky asset" with negative payoff. That approach results in an "optimal" $CO_2$ price as the *output* of a benefit-cost analysis. It is no replacement for the calculation of climate damages used in the SC-$CO_2$, serving as an *input* into regulatory benefit-cost analyses. | Thank you, we agree and appreciate the disctintion you make between this exercise and the "alternative" line of research you have helped to advance. |
| Wagner | The same goes even more so for any efforts aimed at scrapping benefit-cost analyses altogether (Stern and Stiglitz 2021). It is true that other countries and jurisdictions rely less on benefit-cost analyses in setting domestic climate policy, and instead have passed laws that mandate (net) decarbonization by a date certain. Such approaches are crucial in regulatory environments where such net-zero laws are enshrined in law, and where regulatory analysis focuses on minimizing costs to achieve certain targets. That is not the case in the U.S. under most circumstances, once again pointing to the importance of calculating the SC-$CO_2$, SC-$CH_4$, and SC-$N_2O$ as a crucial input into benefit-cost analyses (Aldy et al. 2021; Wagner 2021). | Thank you for this comment. We agree that SC-GHG estimates are an important input into benefit-cost analyses. |

| **Charge Question 1.d.** ***Do you have longer term recommendations regarding approaches the EPA should consider for future updates?*** | | |
|---|---|---|
| **REVIEWER** | **REVIEWER COMMENT** | **EPA RESPONSE** |

| | | |
|---|---|---|
| Cropper | In the longer term, as the NRC recommended, there need to be feedbacks among modules. If along a particular socioeconomic path there is a high probability of a negative climate outcome, and significant damages, this will reflect GDP along the path. | Thank you, we agree. We have expanded the discussion in Section 3.2 about many opportunities for future improvements, including accounting for interactions and feedbacks across modules. |
| Fisher-Vanden | (**LONG-TERM**): Explore the generation of alternative estimates based on new fully integrated modeling efforts that are being done outside of the IWG efforts. | Thank you, we agree and will continue to monitor all developments in the published academic literature. In fact, if at any time there are advancements related to this comment and the estimation of SC-GHGs not yet cited in this report, EPA would welcome the notification. |
| Forest | The only significant alternative would be to do a full Monte Carlo Sampling strategy with multiple millions of simulations. This would allow running an n=1000 or larger stratified sampling approach (or if computing is available, a full random sampling with n=10^9) that could incorporate individual realistic futures to consider from high resolution Earth system models. This would lead to creating a 10+ year project to consider how to address the tails of the distribution. | Per National Academies (2017) recommendations, EPA has taken the approach of implementing reduced complexity climate models that are feasibly paired with probabilistic socioeconomic futures and accounting for uncertainties throughout the system using a Monte Carlo sampling approach. Long-term recommendations and goals include improving our understanding of the distribution of damages which would require finer resolution climate projections, and more fuller characterization of the tails of climate impacts. |
| Kling | See above. | Thank you. |
| Oppenheimer | See my answer to (c). | Thank you. |

| | | |
|---|---|---|
| Schlenker | There is one potential downside to the modular approach: breaking the analysis into four subgroups might make feedback loops (shown in Figure 2.1) more challenging to implement as each module is developed in isolation and builds on a previous module. EPA acknowledges in Figure 2.3.1 that currently feedback loops are not included. The large uncertainty on future emissions paths is in part due to these feedback loops. The current approach is very much linear going from module 1 to module 4, but I would encourage EPA to incorporate feedback loops going forward, e.g., how is GDP growth impacted by climate change itself? | Thank you for this suggestion, we have kept this in mind throughout development of the report and will continue to do so moving forward. In response, the Report offers an expanded dsicussion of need to better capture interactions and feedbacks and specifically with respect to the feedback of damages on the socioeconomic module in particular in Section 3.2 . As ntoed in the Report, the National Academies pointed to this as longer term need: see Rec 3-3 and Concl 3-1 , and surrounding discussion - e.g., "...Developing an SC-CO2 estimation framework with a more tightly integrated socioeconomic module will take time—likely more than the 2-3 years that this report defines as the near term. Thus, some version of, or alternative to, the near-term strategy presented here will need to be used for the next revision of the SC-CO2, and perhaps for one or more of the subsequent revisions." |
| Schlenker | Will warming induce additional demand for cooling (ACs) that itself causes more emissions and amplify warming? | Thank you for highlighting the potential for feedbacks between climate impacts and demand for energy systems. We have expanded the discussion in Section 3.2 to identify this response, and provided additional citations and need for future (long-term) updates in accordance with the National Academies' recommendations. |
| Wagner | There are indeed longer-term improvements the EPA could take, beginning with continuing to update damage functions to reflect the latest science—i.e. moving further damages from “unquantified quantifiables” into the quantified column (Proistosescu and Wagner 2020). (Table 3.1.4 shows some of the disaggregation. It also raises further question as to whether it is indeed appropriate to average across different damage modules, or whether some are better thought as being additive.) | Thank you for this comment. EPA will continue to work towards incorporating more of the unquantified quantifiables as discussed in section 3.1 and 3.2. |

| | | |
|---|---|---|
| Wagner | Then there are the many climate risks that either have not or cannot be quantified. Here, EPA needs to be clear whenever such an omission has occurred. The current EPA approach does a good job accounting for risks. However, more can and should be done, beginning with quantifying major climatic tipping points. The report cites Dietz et al. (2021); it does not incorporate the resulting numbers. (See charge question 4 below.) | EPA agrees that the climate module omits some potentially large-scale Earth system feedback effects (e.g., from tipping elements or 'tipping points') and that recent studies have started to make progress on incorporating more tipping points in the estimation of SC-GHG. In particular, Dietz et al. (2021) have advanced the quantification of tipping elements to explicitly account for several important temperature feedbacks within the climate system. The EPA has expanded the discussion of Dietz et al. (2021) and their results in Section 3.2 of the Report to acknowledge significant advancements made in this area. The EPA will continue to follow progress in this line of research and look for opportunities to better reflect tipping elements and other Earth system feedback effects and to account for non-climate mediated GHG effects in future updates of the SC-GHG estimates. Throughout the report, EPA has expanded discussion about how the presented SC-GHG estimates likely underestimate the marginal damages from greenhouse gas pollution. EPA has especially expanded discussion in Section 3.2 "Omitted Damages and Other Modeling Limitations" including remarks and references on tipping elements |
| Wagner | Further long-term improvements should look toward better representing climate damages affecting productivity and economic growth rates (e.g. Moore and Diaz 2015), explicitly factoring in "equity weights" (e.g. Anthoff and Emmerling 2018), and considering the importance of how further structural changes in risks and uncertainties affect the distribution of the SC-$CO_2$ (Moore et al. 2023). | Thank you for this comment and the accompanying citations. We have expanded the discussion of the economic growth effects literature in Section 2.3 and discuss the literature pertaining to equity weighting in Appendix A.7. We will continue to follow the literature on both these issues going forward. |

**Charge Question 2.**

**Charge Questio 2.a.** ***Does the socioeconomic and emissions module in this draft report offer an improved approach for reflecting uncertainty and account for future policies and dependencies between variables than the approach used in the IWG methodology to date (which relies on four business-as-usual and one 550 ppm stabilization scenario from the Stanford Energy Modeling Forum exercise, EMF-22)? Why or why not?***

| REVIEWER | REVIEWER COMMENT | EPA RESPONSE |
|---|---|---|
| Cropper | The RFF-SPs are a huge improvement over the five equally likely scenarios from the Energy Modeling Forum that constituted the SPs in previous estimates of the SCC. The RFF-SPs are based on econometric analysis (for GDP growth) combined with expert elicitation, using experts in each field. In most cases, the probability distributions for each SP span the values produced by the IPCC Shared Socioeconomic Pathways. This is a useful point of comparison, although the SSPs are not probabilistic. | Thank you. |
| Fisher-Vanden | The reasoning given for generating new scenarios using the methodology of the RFFSPs is related to the need to better represent the far future and to generate probabilistic long-run projections of population and economic growth, which was missing with the SSP/RCP scenarios. To address these needs, the RFF-SPs apply the Muller, Stock, and Watson (2022) approach which is based on convergence in economic growth theory to generate a set of probabilistic GDP projections. Therefore, my understanding is that future economic growth is driven by assumptions made about the speed of convergence of individual economies and their influence on the convergence of other economies with similar characteristics. The RFF-SPs then use expert elicitation (from a panel of macro growth economists) to extend the projections to 2300. | Thank you for your comments. Your understanding and description of the economic growth projections is correct. EPA has added additional details on the economic growth projections form Muller, Stock, and Watson to the discussion of this module in Section 2.1. |

| | | |
|---|---|---|
| Fisher-Vanden | (**LONG-TERM**): Although this approach does address some of the important shortcomings of the IWG approach as identified in the NASEM report, it creates others that suggests a hybrid approach (e.g., one that combines growth projections with structural modeling) may be warranted: | Thank you for this recommendation. The National Academies similarly recommended that in the longer term it would be beneficial to develop a new socieoconomic module, based on a detailed-structure model, that meets the criteria of scientific basis, uncertainty characterization, and transparency, and various other characteristics (See Recommendation 3-3 in National Academies (2017)). The National Academies also outlined future research needs to contribute to the design and implementation of such a new module. The EPA will continue to follow advances in the published literature and look for opportunities to incorporate new data, information and scientific research on hybrid or alternative approaches in future updates. |
| Fisher-Vanden | (**LONG-TERM**): How do these RFF-SP projections ensure plausibility without some connection to structural models? That is, are the large structural changes that would have to occur in many lesser developed countries to reach convergence feasible? To assess this, you would need to know the structure and characteristics of the current economy and what structural changes would need to occur. In many instances, I presume, this may not be feasible based on fixed factors, technology, and other country-specific characteristics and endowments. In the construction of the SSP/RCP scenarios, structural economy-wide models helped identify and shape the set of scenarios by pointing out where certain pairings would not be possible—e.g. certain RCPs were not achievable with certain SSPs without an infeasible set of technologies. We could be seeing a similar problem here with the use of these RFF-SPs. | Ensuring plausibility of the socioeconomic and emissions projections is important for an exercise that makes projections far into the future. The economic growth and population projections made use of statistical methods to estimate these historical relationships over time. Muller, Stock and Watson 2022 estimate "rates for some countries that are so slow that they might not converge (or diverge) in century-long samples." These findings are incorporated into the RFF-SPs. The statistical projections in the RFFs are supplemented (per NASEM recommendations) with expert elicitation and review. For population, Raftery and Sevcikova (2023) combine the statistical approach with expert review and elicitation. For economic growth, the RFF-SPs are increasingly weighted with expert's opinions. Implicit in this is that the experts agreed that these projections are feasible. |

| | | |
|---|---|---|
| Fisher-Vanden | (**SHORT-TERM**): The report should discuss how the SC-GHG estimates would be different if trade was captured. | Thank you for the comment. EPA agrees that capturing global trade is important in estimating the SC-GHG. In places where the scientific literature provided climate change damage functions that included estimates of welfare damages with trade, we have incorporated these studies into the estimates. For example, the damges in the GIVE agricultural sector (Moore et al. 2017) are the total welfare changes after allowing for trade adjustments (Global Trade Analysis Project) from shocks to agricultural production from climate change. The impact of trade on climate damages is an important area for future research. |
| Fisher-Vanden | (**LONG-TERM**): Importantly, the RFF-SP approach is not set up well for incorporating feedbacks from the damage modules and interactions across impacts. DSCIM, for instance, generates fine-scale dose-response functions by sector which could easily be incorporated into structural economy-wide models with spatial and sectoral detail. Not only would it allow for feedbacks, it would also allow for the explicit representation of integrated impacts, rather than modeling impacts separately for each sector. It isn't clear how this could be done with the RFF-SP model. As argued in the DSCIM description, it is important to estimate impacts at the fine scale and then aggregate up. Thus, it would also be important to capture feedbacks and interactions at the fine-scale and aggregate up. | As discussed in responses above, EPA agrees that incorporating feedbacks and interactions is an important area for future research. EPA has expanded discussion of this issue in Section 3.2 and Section 5. |
| Fisher-Vanden | (**SHORT-TERM**): The report should include some discussion of how these feedbacks and interactions could be captured with the current approach. | Thank you for your comment. In reponse, we have expanded discussion in Section 3.2 on potential interactions and feedback effects within and across modules including some findings in the literature on feedbacks. |
| Fisher-Vanden | (**LONG-TERM**): Should the SC-GHG estimates capture distributional impacts somehow? If so, this doesn't seem possible with the current socioeconomic approach. | We agree that additional work and research is is needed to improve presentation of the distributional effects of climate change. The National Academies' report pointed to the importance of presenting spatially disaggregated results that could, in turn, enable methods that would better identify vulnerable populations and those most at |

| | | |
|---|---|---|
| Fisher-Vanden | (**SHORT-TERM**): The report should discuss whether this will be possible with the current approach and if so, how. | risk. Discussion of these dimensions and presentation of evidence from GIVE and DSCIM, and an expanded discussion of available evidence from domestic modeling efforts such as FrEDI, can be found in Section 3.3 of the report. |
| Fisher-Vanden | The RFF-SPs capture one type of uncertainty, from what I can tell. (I had to read Rennert et al, 2021 to understand this since the EPA Supplemental document does not provide details). They are capturing uncertainty by using expert elicitation where "experts provided their 1st, 5th, 50th, 95th, and 99th quantiles for the variables of interest: levels of OECD GDP per capita for 2050, 2100, 2200, and 2300" (Rennert et al, 2021) to "modify econometric projections of GDP per capita based on the MSW (2019) methodology and generate density functions of internally consistent projections of economic growth at the country level." Thus, the uncertainty captured is uncertainty related to speed of convergence (how far a country is from the frontier), I believe. | In response to your comment we have added additional descriptions in section 2.1 of the methods used to estimate the economic growth projections in the RFF-SPs. This includes sources of uncertainty. We have also added a table in the appendix that summarizes the treatment of uncertainty within the estimates of the SC-GHG. MSW (2019) includes uncertainty in the common parameters that determine the OECD growth rate in addition to country- and factor-specific parameters. Over time this uncertainty in the OECD growth rate relies increasing on expert elecilation. |
| Fisher-Vanden | (**LONG-TERM**): The current approach does not capture uncertainty related specifically to technological change, population growth, changes to the energy system, etc, or structural uncertainty related to how factors/sectors interact. Rather it is implicit in an expert's opinion on growth in GDP per capita in OECD countries. Again, this was an approach that was chosen by the authors that addresses some shortcoming from previous approaches but creates others. (How come the expert elicitation panel did not include experts involved in the SSP scenarios? These people have a lot to offer to this process). | We agree that technological change and changes to the energy systems are important considerations and that future research is warranted to better undersatnding how they impact economic and population growth. Uncertainty in population growth has been captured in the population projections developed by Raftery and Ševčiková's (2023) and incorprated into Rennert et al. (2022a). The RFF-SPs drew on experts from their respective disciplines for population, economic growth and emissions. Some of these experts (e.g., Keywan Riahi) were involved in the SSP scenarios. For a full list of the participating experts see the appenidx to Rennert et al. 2022a. Section 2.1 includes an expanded discussion of the development of the RFF-SPs and a new Appendix (A.8) summarizes the treatment of uncertainty across all modules. |

| | | |
|---|---|---|
| Fisher-Vanden | (**SHORT-TERM**): The report should be more forthcoming on the types of uncertainty that are being captured and the types of uncertainty that are not, with a discussion of the magnitude and direction of the uncertainties that are left out. | Thank you for your comment. In response, we have expanded our discussion of the types and source of uncertainy in the socioeconomic module. We have also added Table A.8.1: Treatment of Uncertainty in section A.8 of the Appendix. This table outlines the key modeld uncertinaties and the sources of the uncertinaties. |
| Fisher-Vanden | (**LONG-TERM**): Therefore, an alternative approach may be to combine the growth modeling approach of MSW (used in the RFF-SPs) with the structural modeling, say, done by the IPCC economy-wide models (NOT the aggregate IWG models) in order to ensure that these economic growth projections are plausible and, to be clear to consumers of these estimates what these growth projections imply for the structure of individual countries in order to generate such growth projections. (This was a strength of the SSPs). This will be important for the damage estimates especially since some of these damage functions were estimated based on SSP/RCPs. It is also important for capturing interactions and feedbacks since economy-wide models are well-equipped to incorporate damage feedbacks. | Thank you for the suggestion for future research that could provide projections of structural economic details consistent with the RFF-SPs that may be relevant for improving damage functions and there incorporation into the modeling. As discussed in the responses above, EPA will continue to evaluate the literature and the use of structural modeling for socioeconomic projections. EPA will also continue to evaluate the literature on incorporating cross-sectoral feebacks into the estimation of the SC-GHG. |
| Forest | I would offer the discussion from Sarofim et al. (2021, https://doi.org/10.1038/s41558-020-00973-9) that advocates for a hierarchy of modeling paradigms which fits the needs of the research question. Depending on the outcomes of the climate model projections, the users may want to account more carefully for non-linear outcomes for specific projections or impacts. Ultimately, this requires using models that include such non-linear equations. If the high-impact tails of a distribution are critical to the specific costs entering into the SC-GHGs, additional research will be needed to assess the uncertainties in the climate response and climate impacts. | We agree that accurately and carefully capturing non-linear outcomes is important for modeling outcomes of climate change. Throughout the models used in this report, non-linear relationships are present. The approach to discounting and risk aversion accounts for these tails of the distribution in estimating the SC-GHG. Assessing additional uncertinaties, non-linear outcomes, tipping points and feedbacks in the climate response and climate impacts is an important area for future research. While we applied FaIR1.6 in the current modeling, we will continue to evaluate the fesability and merits of alternative modeling platforms, including more complex climate that may be able capture additional system dynamics. |

| | | |
|---|---|---|
| Forest | The typical example from the climate science arena would be to ask: How close are we to any tipping points within the Earth system? If yes, then the non-linearities have a critical role to play to assess the level of impacts. The natural emissions of carbon dioxide, methane, and nitrous oxide still have a role to play as feedbacks driven by the anthropogenic forcings. | We agree that natural sources of GHG emissions and feedbacks are important in estimating actually estimating GHG emissions. We have expanded discussion of feedbacks across modules, including from climate to emissions, that are not yet incorporated into the modeling. Incorporarting feedbacks such as this is an important area for future research. |
| Kling | The work developed by RFF and used to produce the socioeconomic and emissions projection is a significant improvement and to follow the recommendations of NASEM (2017) well. | Thank you. |
| Oppenheimer | I'll pass on responding here as others involved in this review have greater expertise on this particular subject. | Thank you. |
| Schlenker | The report makes the underlying assumptions clear. There is a lot of uncertainty about future development, e.g., the confidence band on population forecasts by 2030 is very large. EPA does its best to incorporate this uncertainty in its analysis by following the statistical interpolation paired with expert solicitation that NCSEM recommended. | Thank you. |
| Wagner | Yes. It is the most comprehensive effort to date to update the socioeconomic pathways and represents an impressive undertaking, reflecting some of the latest insights around probabilistic growth projections (e.g. Christensen, Gillingham, and Nordhaus 2018). | Thank you. |

**Charge Question 2.b.** ***Are there additional or alternative existing sources of probabilistic socioeconomic projections that EPA should consider for this update? Please describe the advantages of these approaches.***

| REVIEWER | REVIEWER COMMENT | EPA RESPONSE |
|---|---|---|
| Cropper | None. | Thank you. |

| | | |
|---|---|---|
| Fisher-Vanden | (**SHORT-TERM/LONG-TERM**): For comparison, why not use the SSP/RCPs scenarios as was used by the DSCIM team to generate their damage estimates instead of the RFF-SPs to see what difference it would make in the SC-GHG estimates? | Thank you for the suggestion. While it is feasiable to create an SC-GHG estimte for each SSP/RCP, these SC-GHG estimates would not be directly comparable to the SC-GHGs using the RFF-SPs. There is significant uncertainty over the long run trajectory of population, economic growth, and emissions. Being able to capture that uncertainty in the SC-GHG estimates is an important facet of the modeling (see sections 2.1, 2.4 and 2.5). Deterministic scenarios, such as the SSP/RCPs, are unable to fully capture these important uncertanties. Therefore, a comparison between the report's SC-GHG estimates and alternatives generate with the SSP/RCPs would be challenging as it reflects both different assumptions about the trajectory of socioeconomics and emissions, but also an omission of key uncertainties. |
| Forest | This is not my area of expertise. | Thank you. |
| Kling | None that I am aware of. | Thank you. |
| Oppenheimer | See response to part (a). | Thank you. |
| Schlenker | None in the short-term. I would encourage them to take feedback loops seriously for the long-term revisions (GDP growth is itself a function of climate change). | Thank you. |
| Wagner | n/a | Thank you. |

**Charge Question 2.c. D*o you have recommendations for improving the clarity and accessibility of the updated socioeconomic and emissions module? Do you have recommendations for increasing transparency and strengthening the characterization of uncertainty for this module in this update?***

| REVIEWER | REVIEWER COMMENT | EPA RESPONSE |
|---|---|---|
| Cropper | None. | Thank you. |

| | | |
|---|---|---|
| Fisher-Vanden | (**SHORT-TERM**): As mentioned prior, this is another instance of having to read a number of other papers in order to fully understand what was being done. Please supply a technical document to accompany the report. | Thank you for this suggestion. We have expanded the description of the development of the RFF-SPs in Section 2.1 of the report. We have added a statement at the outset of Section 2 to clarify that the discussion is intended to provide an overview road map of the methodological updates, and that additional details of each underlying study are available in the sources cited throughout the report. |
| Forest | For the emissions model, specifically, we know that the emissions and sinks of methane are strongly dependent on climate variables such as temperature and precipitation within the tropics and extratropics. | We appreciate your comment on how climate can impact methane. These climate feedback effects are an important area for future research. We have highlighted them more explicitly in Table 3.2.1 and the accompanying text in section 3.2 on ommitted feedbacks. |
| Forest | For methane, the destruction rate of methane is a key issue and should be included in the models. | The destruction rate of methane is a key component of the climate module. We have expanded the discussion in Appendix A.1 to note that FaIR 1.6.2 has a constant methane lifetime of 9.3 years, which is shorter than the IPCC AR6 best estimate of a methane perturbation lifetime of 11.8 years, but was chosen by the model creator in order to make the model consistent with historical concentrations and natural emission sources. Future versions of FaIR include a dynamic methane lifetime, as noted in the report ("An alternative version of the model, FaIR 2.0, was recently published (Leach et al. 2021) that offers some advantages with respect to simplicity and the inclusion of a flexible, state-dependent methane lifetime"). We will continue to evaluate the incorporation of updated versions FaIR, along with other climate modeles, into estimation of the SC-GHG. |

| | | |
|---|---|---|
| Forest | While the heat-trapping gases will take multiple decades to impact temperature, the concentrations of nitrous oxide and methane can have immediate impact on air quality and thus, have direct impacts on human health and on local ecosystems when they are emitted. To better understand these impacts, we need to incorporate the secondary effects of the GHGs that contribute to the damage estimates, which could help clarify how these effects add to the Social Costs or to identify what processes could be missing. | Section 3.2 highlights that non-climate mediated effects of nitrious oxides and methane have not yet been incorpated into the SC-GHG. Tropospheric ozone formation (from CH4) and stratospheric ozone destruction (from N2O) are listed as 2 examples non-climate mediated effects of GHGs that have yet to be included (Table 3.2.1), and we have expanded the discussion of the O3 health benefits of CH4 reduction to include new results in the published literature on this effect. EPA intends to evalate these effects for incorporation into the SC-GHG estimation in future updates. |
| Forest | While not explicitly having specific suggestions on the socioeconomic module, we know that climate change can have direct and indirect effects on the socioeconomic activities. **From a communication perspective, we should develop storylines to explain both direct and indirect interactions of the socio-economic and emissions model with the other modules.** Within the context of SC-GHG, we should use such storylines to help the public and the private sector improve communications and clarify many of the subtler issues as research continues to improve these tools. While we have a clearer understanding of how climate change is driven by emissions, we must also create clearer messages on how feedbacks from climate change are similarly driving changes in both socio-economic factors and emissions. | Thank you for your comment. The SC-GHG estimates are intended to reflect the mean willingness to pay for marginal changes in GHG emissions, conditional on the available data and methodologies, most often in benefit cost analysis. We agree that incorporating feedbacks between the modules, for example from the climate and damages to the socioeconomic module, could improve the SC-GHG estimates and will continue to evaluate the literature on approaches for modeling additional feedbacks. As mentioned in responses above, EPA has expanded discussion of feedbacks in Section 3.2 and elsewhere in the report. |
| Kling | This is a place where more details would be useful, especially more details about how the future climate scenarios were informed and altered by expert judgment. | We have expanded the discussion in Section 2.1 about the development of the emissions projections and the other components of the RFF-SPs. |
| Kling | An important part of these projections is the advice from NASEM to take account of future emission policies and the consequences. Again, this is to be applauded, but documentation of how this was done, how big of an effect this component had should be discussed and documented. | Resources For the Future (RFF) choose the "Evolving Policies" case for the RFF-SPs because it "corresponds to the USG approach to benefit cost analysis, which evaluates US regulations as incremental against a more expansive backdrop of other policies and conditions and is responsive to NASEM recommendations for including future background policy in the uncertain distributions of socioeconomic projections." The publically available RFF-SPs |

| | | |
|---|---|---|
| Kling | Visually demonstrating how much of an effect on the emissions stream the judgements on policy responses and adaptations would improve the transparency of the report. If possible, it would also be valuable to document/explain how much difference incorporating these policies induced changes made in the computation of the social cost estimates. | socioeconomic projections." The publically available RFF-SP3 don't include emissions projections from the "Current Laws and Regulations" case. Therefore, we are unable to visually demonstrate the differece between the "Current Laws and Regulations" and "Evolving Polcies" cases and document how these polcies impact the SC-GHGs. |
| Oppenheimer | See response to part (a). | Thank you. |
| Schlenker | The one comment I have on clarity is to better explain that the uncertainty bands include policy options. When people see the wide confidence bands by 2300, an intuitive response might be to discredit the model as unreliable given the large range of possible outcomes. | EPA has expanded the discussion of uncertainty in the socioeconomics and emissions module in Section 2.1 of the the report. This includes an expanded discussion on policy uncertainty and its impact on emissions estimates. Given the very-long term nature of the projections it is reasonable that uncertainty would be wide in 2300. |
| Schlenker | However, a big fraction of the “uncertainty” is due to policy choices, which aren’t modeling uncertainty – see next point. Treating each RFF-SP as equally likely might make it look as these are random possible outcomes of the future – but again, they are in large part choices. | Policy choices are import in the projection of emissions and are an important source of uncertainty. For example, the experts stated that uncertainty in emissions was dependent on the likelihood that countries meet their pledges under the Paris Agreement or that countries enhanced thier pledges in high economic growth states of the world. Incorporation of endogenous policy choices in the modeling framework would require a model that included feedbacks between the climate and damages module and an empirical understanding of how countries are expected to respond to climate outcomes, technological progress, emissions reductions in other countries and other determinants of policy choices. Even with such a model there would still be policy uncertainty given uncertainty about climate response to emissions, damages, economic growth and technological progress. |

| | | |
|---|---|---|
| Wagner | Same general comment here as elsewhere: It is key to do represent the nature of risks and uncertainty in a consistent fashion. One good way to doing so might be a consistent portrayal of probability density functions across different scenarios akin to Figure 2 in Rennert et al. (2022), Figure 2 in Dietz et al. (2021), and elsewhere. | We agree that representing the risk and uncertainty in the report is important for understanding the approach to estimating the SC-GHG. In our time-series graphs we adopted a consistent format to represent the distributions over time rather than to show the full probability density function for one point in time (e.g., 2100 or 2200). To present the distribution of the discounted marginal damages (see Figure 3.1.1) we choose to use a box plot (similar to Figure 2 in Rennert et al., 2022). Like the time-series graphs this figure shows the percentiles of the distribution. This figure also shows the right-skew of the distribution. |

**Charge Question 2.d.** ***Do you have longer-term recommendations for improvements to this module in future updates?***

| REVIEWER | REVIEWER COMMENT | EPA RESPONSE |
|---|---|---|
| Cropper | As noted above, there should, ideally be feedbacks from the damages module to the socioeconomic pathways. This is something for future research. | Thank you. We agree this is an important area for future research and have highlighted it more explicitly in the discussion in Section 3.2. |
| Fisher-Vanden | See comments under a. | See response under a |
| Forest | My long-term suggestions are most relevant for natural emissions being driven by the future climate changes that would add additional feedbacks on both climate impacts and on climate change itself. The ability to assess these feedbacks will be critical and then, we must feed the natural emissions into both the climate module and the impacts module as well would be useful. | Thank you. We agree this is an important area for future research and have highlighted it more explicitly in the discussion in Section 3.2. |
| Kling | See above. | See response above |
| Oppenheimer | See response to part (a). | See response under a |

| | | |
|---|---|---|
| Schlenker | The report states “RFF-SPs explicitly account for the likelihood of future climate policies,” so part of the divergence in the observed emission pathways is hence due to public policy choices. I would separate the range of future emissions that is (i) due to modeling uncertainty, e.g., on population growth, from (ii) emissions changes that are due to climate policies. That makes it clearer what fraction we don’t know (modeling uncertainty) versus what are simple choices. | Resuorces For the Future (RFF) choose the "Evolving Policies" case for the RFF-SPs because it "corresponds to the USG approach to benefit cost analysis, which evaluates US regulations as incremental against a more expansive backdrop of other policies and conditions and is responsive to NASEM recommendations for including future background policy in the uncertain distributions of socioeconomic projections." The publically available RFF-SPs don't include emissions projections from the "Current Laws and Regulations" case. Therefore, we are unable to disaggregate the differece between the "Current Laws and Regulations" and "Evolving Polcies" cases. |
| Wagner | A key longer-term improvement is an explicit treatment of adaptation to current and projected future climate damages. Doing so is difficult for a number of reasons, not least in understanding which way the sign goes. E.g. does adaptation in form of human migration count as a cost of unmitigated climate change, or does it lower costs? Even where the sign is clear, quantification is anything but simple. Yet it needs to be part of a comprehensive effort to account for the full costs of unmitigated climate change. | We agree that adaptation is important for estimating the damages from climate change. We have applied damage functions that either explicitly include adaptation or implictly include adpatation and the costs of adaptation in the damage functions. Regarding migration due to climate change, we agree that these impacts have not yet incorporarted in the SC-GHG estimates. We have listed climate displacement and migration as an impact that has not yet been incorporated (Table 3.2.1). This is an important area for future research. Note that our country-level population projections do include international migration to account for the flow of people acrosss countries over time. This migration is exogenous to climate change impacts in the damages module. Feedbacks from the damage module to account for climate induced migration is also an important area for future research. |

| | | |
|---|---|---|
| Wagner | A second such topic concerns internalizing the rapidly declining costs of carbon mitigation technologies (Gillingham and Stock 2018). These costs do not affect the EPA's SC-$CO_2$ as much as calculations of the "optimal" SC-$CO_2$, but they do still enter via socio-economic pathways. Consistency here is key, including e.g. with forecasts by the U.S. Energy Information Administration and other efforts (Wagner et al. 2021). Moreover, these projections are rapidly changing, not least due to major U.S. government investments in clean energy via the Inflation Reduction Act, the bipartisan infrastructure law, and the CHIPS and Science Act leading to learning-by-doing on a massive scale (e.g. Arkolakis and Walsh 2023; Wagner and Friedmann 2023). | We agree that the evolution of the costs of GHG mitigation and adaptation relevant technologies impact future emissions. In the "Evolving Policy" case experts were asked to incorporate "expected changes in technology, fuel use, and other conditions" into their emissions projections. The evolution of costs and technology would have been implicit in those estimates. We also agree that these projections would change overtime as more information becomes available. The "Evolving Policy" case utilized in this report implicitly includes the experts "expected evolution of future policy," though we recognize that those expectations may evolve over time as new information becomes available. |

**Charge Question 3.**

**Charge Question 3.a.** ***Does the climate module in this draft report offer an improved representation of how GHG and other forcing agent emissions translate into climatic variables that are needed by the damage module relative to the estimation approach underlying the IWG methodology to date (which relies on the default climate process in the DICE, PAGE, and FUND integrated assessment models, except for a common probability distribution for the climate sensitivity parameter)? Why or why not?***

| REVIEWER | REVIEWER COMMENT | EPA RESPONSE |
|---|---|---|
| Cropper | The FAiR model improves significantly upon the climate portions of DICE2013, FUND and PAGE. These IAMs do not reflect the latest climate science (e.g., Joos et al. 2013) which suggests that the maximum impact of a pulse of CO2 on mean global temperature will be felt within 20 years. (See also Figure A.5.7 in the Appendix.) The FAiR model was developed by members of the NRC committee in response to their criticisms of the climate portions of DICE, FUND and PAGE. | Thank you. |

| | | |
|---|---|---|
| Fisher-Vanden | (**LONG-TERM**): It seems important for the climate module to capture precipitation and not just temperature, which is a shortcoming of the current approach. My understanding, though, is that this was done because the damage functions are only based on temperature and not precipitation which is a shortcoming of these damage functions. | EPA agrees that the representation of precipitation is an important area of future research. Please see Section 3.2.1 "Further Discussion of Precipitation Impacts of Climate Change" for an expanded discussion. EPA has also clarified that some of the underlying damage studies incorporate other climate variables, such as precipitation. |
| Forest | Yes, this update provides an improved representation of the climate response to the net radiative forcing based on the accumulation of GHGs in the atmosphere and ocean. | Thank you. |
| Forest | The testing of the Reduced-complexity Climate (RC) models has been tested against IPCC-class Earth System Models. Developers of all three models (FAIR1.6.2, MAGICC7, and HECTOR2.5) are are participating in the IPCC RCMIP (Nicholls, Z. R. J., et al., 2020, https://doi.org/10.5194/gmd-13-5175-2020). | Thank you for this comment. We have expanded the discussion in Section 2.2 to provide this additional information about the models. |
| Forest | The goals of the RCMIP project are to be able to assess the perturbation between the reference scenario and a perturbed scenario to determine the additional global warming associated with the perturbed forcing. This perturbation is fed into the climate impacts module to estimate the climate impact damages. Based on the RCMIP results, these three models have the necessary components to estimate the global mean temperature that can be used in the RC module. | |
| Kling | This is outside my area of expertise. | Thank you. |

| | | |
|---|---|---|
| Oppenheimer | While the climate module approach improves upon the previous framework, it falls short in producing only changes in temperature as the primary output (the motivation for which I note in General Impressions). This may be the primary reason that Table 3.2.1 has so many open circles. | EPA agrees that the the representations of non-temperature channels are important areas of future research. EPA has expanded the discussion of model limitations in Section 3.2, including the addition of Section 3.2.1, "Further Discussion of Precipitation Impacts of Climate Change." EPA has also clarified that some of the underlying damage studies incorporate other climate variables, such as precipitation. Limitations of the climate module are just one of several reasons for the empty and partial circles in Table 3.2.1. For example, alternative treatments of precipitation and other non-temperature variables require damage functions from the economics literature to map the changes in these variables to market and non-market economic damages over time. |
| Oppenheimer | Much as I recommend above that the treatment of uncertainty across many features of this analysis should be broadened, I likewise recommend that some additional features of the climate system, especially precipitation, be included in SCC uncertainty range. | EPA agrees that the the representations of uncertainty and non-temperature climate variables are important areas of future research. EPA has expanded and the clarified the discussion of uncertainty throughout the report, including the addition of Appendix A.8, "Treatment of Uncertainty." EPA has also expanded the discussion of model limitations in Section 3.2, including the addition of Section 3.2.1, "Further Discussion of Precipitation Impacts of Climate Change." EPA has also clarified that some of the underlying damage studies incorporate other climate variables, such as precipitation. Limitations of the climate module are just one of several reasons for limitations in the treatment of uncertainty. For example, alternative treatments of precipitation and other non-temperature variables require damage functions from the economics literature to map the changes in these variables to market and non-market economic damages over time. |

| | | |
|---|---|---|
| Oppenheimer | While parameterization of global mean precipitation change as a function of temperature is often done, regional precipitation changes, which are what count for impacts, are not so easily estimated in this manner. Still, it might have been feasible to estimate an uncertainty range for regional precipitation changes. The strict adherence to FaIR's output temperatures as the sole independent variable driving impacts seems to have inhibited creativity on this score. While it may be too late now to correct this problem, it surely should be atop the agenda for the next round of SCC estimation. | EPA agrees that improved representation of precipitation impacts is an important areas of future research. EPA has expanded the discussion of model limitations in Section 3.2, including the addition of Section 3.2.1, "Further Discussion of Precipitation Impacts of Climate Change." EPA has also clarified that some of the underlying damage studies incorporate other climate variables, such as precipitation. However, limitations of the climate module are just one of several reasons for limitations described in Section 3.2. For example, alternative treatments of precipitation and other non-temperature variables require damage functions from the economics literature to map the changes in these variables to market and non-market economic damages over time. EPA has added Figure 3.2.1.1 "Changes in Local Mean Surface Precipitation in 2100," which further highlights the evidence on changes in local precipitation. |
| Schlenker | This is outside my area of expertise and I defer to my colleagues on the committee that are climate modelers. | Thank you. |
| Wagner | Yes, it does. Much work has gone into assessing climate uncertainty, oft focused on climate sensitivity uncertainty (Sherwood et al. 2020). The EPA report reflects the latest consensus assessment by the IPCC in AR6. | Thank you. |

**Charge Question 3.b.** ***Are there additional or alternative existing climate models that can be used to reflect the latest scientific consensus on the relationships between GHG emissions, atmospheric GHG concentrations, and surface temperature change, as well as their uncertainty, and can project their profiles over time, that the EPA should consider for this update? Please describe the advantages of these approaches.***

| REVIEWER | REVIEWER COMMENT | EPA RESPONSE |
|---|---|---|
| Cropper | None. | Thank you. |
| Fisher-Vanden | I defer to others on the review panel who are better equipped to comment on this. | Thank you. |

| | | |
|---|---|---|
| Forest | Higher order complexity models are available and should be considered to benchmark the RC models. Despite the computational costs Not withstanding can be prohibitive, we should be testing “state of the science” models now that improve our level of understanding for regional climate changes. | EPA has added discussion of Reduced Complexity Model Intercomparison Project (RCMIP) (Nicholls et al. 2020) to Section 2.2. EPA has also clarified that in addition to the global temperature paths produced by the reduced complexity modeling, some of the underlying damage studies incorporate information from the global climate models and other climate variables, such as precipitation. |
| Kling | Again, outside of my expertise. | Thank you. |
| Oppenheimer | The following might be feasible: a limited number of simulations with a few ESMs (or several realizations of one ESM) that have shown some skill with regional precipitation could be run in order to develop upper and lower limits on regional precipitation change. | Thank you for this suggestion. EPA has expanded the discussion of precipitation in Section 3.2.1, "Further Discussion of Precipitation Impacts of Climate Change." EPA has also clarified that some of the underlying damage studies incorporate various spatial resolutions and other climate variables, such as precipitation. However, limitations of the climate module are just one of several reasons for limitations described in Section 3.2. For example, alternative treatments of precipitation and other non-temperature variables require damage functions from the economics literature to map the changes in these variables to market and non-market economic damages over time. EPA has added Figure 3.2.1.1 "Changes in Local Mean Surface Precipitation in 2100," which further highlights the evidence on changes in local precipitation. The described methods underlying this figure present a potential pathway for further research on this topic. As new damage functions that are suitable for inclusion in the modeling platform and utilize precipitation changes as a direct input we will consider this suggestion for implementation |
| Schlenker | This is outside my area of expertise and I defer to my colleagues on the committee that are climate modelers. | Thank you. |
| Wagner | Sherwood et al. (2020) is indirectly cited via IPCC AR6. Given the importance of that prior assessment, I would suggest citing it here directly as well. | We have added a direct citation to Sherwood et al. (2020). |

**Charge Question 3.c.** ***Are there other models/methods for projecting sea level impacts resulting from temperature change than those used in the draft report that the EPA should consider for this update? Please describe the advantages of these approaches.***

| REVIEWER | REVIEWER COMMENT | EPA RESPONSE |
|---|---|---|
| Cropper | None. | Thank you. |
| Fisher-Vanden | I defer to others on the review panel who are better equipped to comment on this. | Thank you. |
| Forest | I am only familiar with the two sea-level models in this report at this time. | Thank you. |
| Kling | Not that I am aware of. | Thank you. |
| Oppenheimer | Given current ice sheet modeling limitations, the key consideration with regard to the physical science aspects is whether the approach used in this report provides uncertainty bounds that are consistent with AR6. Since this is the case, I have no additional recommendations on the approach to modeling physical sea level rise. | Thank you. |
| Oppenheimer | However, assuming your request's use of "impacts" in this question includes the ameliorating (or worsening) effects of adaption (maladaptation), see my comments under General Impressions on the inference of damages from the estimated range of rise. The assumption of optimal adaptation is absurd on its face given all evidence to the contrary for the US in particular. See a summary of my presentation to PCAST, October 18, 2021 at https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&ved=2ahUKEwjripOu68z9AhUgFVkFHQzDD3wQFnoECAgQAQ&url=https%3A%2F%2Fwww.whitehouse.gov%2Fwp-content%2Fuploads%2F2021%2F12%2FMinutes_PCAST_Oct-18-19-2021_FINAL.pdf&usg=AOvVaw2V072hEMrr5EgbzvFxjekk Notably, Federal policy toward adaptation has improved since then but the institutional obstacles noted largely remain unaddressed. | EPA agrees that SLR damages and the representation of adaptation generally are important topics for further research. EPA has expanded the discussion of the adaptation assumptions, including further discussion of CIAM in Section 2.3 and further discussion of the limitations in Section 3.2. EPA has also added reference to this PCAST presentation as well as Lorie et al. (2020).<br><br>Please see previous response. |

| | | |
|---|---|---|
| Schlenker | This is outside my area of expertise and I defer to my colleagues on the committee that are climate modelers. | Thank you. |
| Wagner | n/a [I defer to other peer reviewers' expertise here.] | Thank you. |

**Charge Question 3.d.** ***Do you have recommendations for strengthening the presentation of this module, e.g., with respect to increasing transparency or characterization of uncertainty in the draft report? Do you have recommendations for how to enhance the discussion of earth system changes and resulting impacts that are not yet reflected in the climate module (either in Section 2.2 or 3.2)?***

| REVIEWER | REVIEWER COMMENT | EPA RESPONSE |
|---|---|---|
| Cropper | None. | Thank you. |
| Fisher-Vanden | I defer to others on the review panel who are better equipped to comment on this. | Thank you. |
| Forest | Based on the RCMIP work (Nicholls et al. 2020), I would consider figures to develop storylines of the trade-off between ocean carbon and heat uptake and the surface warming due to the GHGs. Additionally, we need to better describe uncertainties of the trade-offs between surface warming and net radiative forcing. These may be technical issues, but users might understand that if the ocean is not warming quickly, then the land/ocean surface must be warming faster. | EPA has added discussion of Reduced Complexity Model Intercomparison Project (RCMIP) (Nicholls et al. 2020) to Section 2.2. EPA has also expanded the discussion of ocean heat uptake and climate sensitivity (including a more detailed footnote) in Section 2.2. |
| Kling | It would be helpful to a nonexpert (like me) to understand the baseline on which to consider the 1 GtC pulse of carbon dioxide. Is that a .001% pulse or more like a 5% pulse? | We have added an explanation of pulse sizes in a footnote following Figure 2.2.2 in Section 2.2. |
| Kling | Figure 3.2 contains a list of the set of climate impacts that are not currently captured in the climate module. It would be useful to discuss the consequences of those omissions for the computation of the social cost of GHG estimates. Given that these climate impacts are not represented in this work, what does that imply for the damage estimates that cannot be included in the SC GHG estimates (such as the impacts of ocean acidification as explained on page 35). | In the report, EPA has expanded discussion regarding the limtations of the SC-GHG estimates and that taken in there totality, these limitations suggest that the marginal damages of GHG emissions are likely underestimated. For example, EPA has expanded the discussion in Section 3.2 "Omitted Damages and Other Modeling Limitations" including tipping elements and Section 3.2.2 "Further Discussion of Ocean Acidification and Other Non-Climate Mediated Impacts of GHG Emissions." |
| Oppenheimer | See my previous comments. | Thank you. See above for response to your previous comments. |

| | | |
|---|---|---|
| Schlenker | The report states how "Reduced-complexity climate models […] are computational emulators of the climate system." Predicted climate change is highly non-uniform, with higher latitudes seeing more warming. The emulator captures this, but the report exclusively focuses on the mean temperature increase. | EPA has expanded and clarified discussion to explain how some of the underlying damage studies incorporate various spatial resolutions and other climate variables, such as precipitation. In particular, see updates in Section 2.2 "Climate Module," Section 2.3 "Damage Module," and Section 3.2 "Omitted Damages and Other Modeling Limitations." Also, Figures 3.2.1 and 3.2.1.1 emphasize regional differences in projected temperature, sea level, and precipitation changes. EPA agrees that the regional heterogeneity of climate impacts is an important area of further research. |
| Schlenker | I would highlight more that these mean increases translate into non-uniform warming around the globe, with the US seeing above-average warming. This non-linear warming is then used in the next section on damages. | Thank you. Please see response above. |
| Wagner | Here as elsewhere, one note on representing risks and uncertainties: Tables 2.2.1 and 2.2.2 present the long right-tailed distribution for both equilibrium and transient climate sensitivity distribution. For consistency sake, it would be good to present the calibrations of the tables graphically in a way that is consistent across modules—akin to Figure 2 in Rennert et al. (2022), Figure 2 in Dietz et al. (2021), and elsewhere. Doing so would also highlight the right-skewed nature of the climate sensitivity distributions more so than a table can. | Thank you for this suggestion. EPA has expanded the discussion of climate sensitivity and FaIR parameters in Section 2.2 "Climate Module." However, EPA has not incorporated the suggested figures. EPA considers Tables 2.2.1 and 2.2.2 sufficient for describing the climate parameter distributions for the purposes of this report, but EPA acknowledges that exploring additional methods for consistent graphic representations of uncertainty across modules could be a useful area for future research on effectively communicating uncertainty. |
| Wagner | This module also makes clear how the resulting SC-$CO_2$ can only be described as a 'partial' estimate, given e.g. that precipitation impacts are (largely) excluded from the analysis. The report, in part, uses the term "conservative" when it means "lower bound" and/or "partial." Calling the resulting SC-$CO_2$ a "partial" estimate might also be important from a process perspective, establishing the fact that the calculations will inevitably be updated going forward. | We have added discussion in both the Executive Summary and thoughout the report to emphasize the partial, still incomplete coverage of the categories of climate impacts and associated damages that are represented in the modeling. |

| **Charge Question 3.e.** ***Do you have longer-term recommendations for improvements to this module in future updates?*** | | |
|---|---|---|
| **REVIEWER** | **REVIEWER COMMENT** | **EPA RESPONSE** |

| | | |
|---|---|---|
| Cropper | None. | Thank you. |
| Fisher-Vanden | (**LONG-TERM**): This module must include precipitation and the damage functions must be able to take this important climate variable into account. | Thank you for this suggestion. EPA agrees that improved representation of precipitation impacts is an important areas of future research. EPA has expanded the discussion of model limitations in Section 3.2, including the addition of Section 3.2.1, "Further Discussion of Precipitation Impacts of Climate Change." EPA has also clarified that some of the underlying damage studies incorporate other climate variables, such as precipitation. However, limitations of the climate module are just one of several reasons for limitations described in Section 3.2. For example, alternative treatments of precipitation and other non-temperature variables require damage functions from the economics literature to map the changes in these variables to market and non-market economic damages over time. |
| Forest | The ability to sample the transient climate response and the sea level changes are the key elements in the current RC models until moving to more comprehensive models. I am concerned that "solar radiation reduction" could be a realistic scenario that might not be modeled well with the current modeling systems. | Thank you for the suggestion of exploring the inclusion of solar radiation management (SRM) within the SC-GHG framework. As noted in the report, the RFF-SPs represent the most suitable and current proababilistic scenarios for estimating the SC-GHG. While these scenarios do include the potential for future mitigiation policy, they do not include the potential for SRM, to the best of our knowledge. EPA will continue to follow the scientific literature on incorporating the likelihood of future policy interventions, including SRM, into probabilisitic scenarios appropriate for estimating the SC-GHG. |
| Kling | Continuing to focus on both physical and monetized impacts should continue to be prioritized in future updates. | Thank you. EPA agrees that a focus on both physical and monteized impacts is important for furture updates. |
| Oppenheimer | A start has been made by several research groups around the world on realistic modeling of coastal adaptation. EPA ought to do better in the future than merely asserting "lower bound" to justify using a ridiculously optimistic assumption for coastal adaptation. Let's try to get a plausible upper bound, too. | EPA agrees that SLR damages and the representation of adaptation generally are important topics for further research. EPA has expanded the discussion of the adaptation assumptions, including further discussion of CIAM in Section 2.3 and further discussion of the limitations in Section 3.2. EPA has also added additional references on the topic of coastal adaptation. |
| Schlenker | This outside my area of expertise and I defer to my colleagues on the committee that are climate modelers. | Thank you. |
| Wagner | n/a [I defer to other peer reviewers' expertise here.] | Thank you. |

**Charge Question 4.**

**Charge Question 4.a.** ***Does the damages module in this draft report offer a more robust representation of the current body of scientific evidence on climate damages than the damage functions embedded in the three integrated assessment models used in the IWG methodology to date (which relies on the default damage functions in the DICE, PAGE, and FUND integrated assessment models)? Why or why not?***

| REVIEWER | REVIEWER COMMENT | EPA RESPONSE |
|---|---|---|
| Cropper | The current damage modules represent a significant improvement over the damage functions in DICE, FUND and PAGE for two reasons: they are based on more recent studies than the studies underlying DICE 2013, FUND and PAGE, and the three damage modules represent independent sources of information. The damage function in DICE 2013, FUND and PAGE used in the previous SCC were not independent sources of information. | Thank you. |
| Cropper | The DSCIM estimates are based on extensive, original empirical work, at a fine spatial scale. The GIVE model relies on other well-regarded published studies. Howard and Sterner is a meta-analysis of both top-down and bottom-up damage studies. The use of all three sources of damages strengthens the results. | Thank you. |
| Fisher-Vanden | The damages module in this report is an improvement over the IWG methodology in that it captures updated science (and numerous new studies) on measuring and monetizing impacts including regional and sectoral disaggregation and coverage, and greater use of empirical evidence. However, these approaches have some drawbacks: | Thank you. |

| | | |
|---|---|---|
| Fisher-Vanden | (**LONG-TERM**): Sectoral damages do not feedback to the socioeconomic module, which will affect economic growth and thus emissions and ultimately damages. As argued in this section of the report, it is important to estimate impacts at the fine scale and then aggregate up. Thus, it would also be important to capture feedbacks and interactions at the fine-scale and aggregate up. | As discussed in the responses above, EPA agrees that feedbacks and interactions are an important area of further research. EPA has expanded discussion of this issue (including feedbacks from damages to the socioeconomic module) in the Report and will continue to review developments in the literature and look for opportunities to further improve SC-GHG estimation going forward. |
| Fisher-Vanden | (**SHORT-TERM**): The report should discuss how leaving out these feedbacks would bias the SC-GHG estimates. | Throughout the report, EPA has expanded and clarified the discussion that the report's SC-GHG estimates likely underestimate the marginal damages from GHG pollution. EPA has also expanded and clarified the discussion of modeling limitations, especially in Section 3.2 "Omitted Damaged and Other Modeling Limitations." These revisions specifically address feedbacks and interactions and discussion of literature suggesting that inclusion of feedback effects is expected to increase estimates of climate damages. EPA agrees that estimating the monetized impacts of specific feedback channels is an important area of further research. |
| Fisher-Vanden | (**LONG-TERM**): All of the damage function approaches considered in both the IWG and this report estimate sectoral and regional damages separately and do not consider integrated impacts (the fact that impacts in one sector or region could influence impacts in another sector or region), indirect sectoral impacts, or trade implications which could alleviate or exacerbate these estimates. | EPA has expanded and clarified the discussion of modeling limitations, especially in Section 3.2 "Omitted Damaged and Other Modeling Limitations." These revisions specifically address feedbacks and interactions. Intra- and international trade are discussed in several sections of the report, and Table 3.2.1 specifically highlights aspects of trade omitted from this analysis. Additional discussion in Section 3.3 describes how some trade, as represented in the DSCIM and GIVE agricultural damage specifications, can mitigate damages. EPA agrees that feedbacks and interactions are an important area of further research. EPA will continue to review developments in the literature and look for opportunities to further improve SC-GHG estimation going forward. |

| | | |
|---|---|---|
| Fisher-Vanden | (**SHORT-TERM**): This report should include a discussion of how modeling sectoral impacts separately would bias the SC-GHG estimates. | EPA has expanded and clarified the discussion of modeling limitations, especially in Section 3.2 "Omitted Damaged and Other Modeling Limitations." These revisions specifically address the omission of interactions across damage categories. One example is water market impacts. Although the cross-category interactions are not estimated, EPA has expanded discussion about how the presented SC-GHG estimates likely underestimate the marginal damages from greenhouse gas pollution. EPA has also noted the progress of large cross-disciplinary multisector dynamic modeling efforts. EPA will continue to review these developments in the literature and look for opportunities to further improve SC-GHG estimation going forward. |
| Fisher-Vanden | Damage functions are functions of temperature and not other climate variables such as precipitation and extremes which are key to impacts. (**LONG-TERM**): Future estimates should address this issue. | EPA agrees that the the representations of non-temperature channels are important areas of future research. EPA has expanded the discussion of model limitations in Section 3.2, including the addition of Section 3.2.1, "Further Discussion of Precipitation Impacts of Climate Change." EPA has also clarified that some of the underlying damage studies incorporate regional climate impacts and other climate variables, such as precipitation. Limitations of the climate module are just one of several reasons for the empty and partial circles in Table 3.2.1. For example, alternative treatments of precipitation and other non-temperature variables require damage functions from the economics literature to map the changes in these variables to market and non-market economic damages over time. |

| | | |
|---|---|---|
| Fisher-Vanden | (**SHORT-TERM**): This report should discuss how this omission would bias the SCGHG estimates. | EPA agrees that the the representations of non-temperature channels are important areas of future research. EPA has expanded the discussion of model limitations in Section 3.2, including the addition of Section 3.2.1, "Further Discussion of Precipitation Impacts of Climate Change." EPA has also clarified that some of the underlying damage studies incorporate regional climate impacts and other climate variables, such as precipitation. Limitations of the climate module are just one of several reasons for the empty and partial circles in Table 3.2.1. For example, alternative treatments of precipitation and other non-temperature variables require damage functions from the economics literature to map the changes in these variables to market and non-market economic damages over time. |
| Fisher-Vanden | Also potentially problematic is the lack of a direct connection between the RFF-SPs and damage functions. For instance, the DSCIM estimates were based on SSPs and RCPs and in order to connect to the RFF-SPs, the authors were required to construct a weighted average of SSP projections that most closely resemble each RFF-SP projection. Thus, it isn't the case that the RFF-SPs are direct inputs to the DSCIM estimates. I believe this could bias the damages results if there are nonlinearities in the inputs to the damage function since you are taking weighted averages of multiple SSPs that individually could be much different from each other. | We have expanded discussion of the development of the RFF-SPs in Section 2.1 and expanded the footnote in Section 2.3 that discusses the emulator approach to help clarify the process and integration of socioeconomics into DSCIM. |

| | | |
|---|---|---|
| Fisher-Vanden | (**LONG-TERM**): The socioeconomic or damage module should be revised so there is a direct connection. This highlights the potential issues that can arise with the modular approach—there needs to be consistency on the outputs and inputs between two connected modules. | Thank you for this suggestion. Opportunities for integrating feedbacks between modules and bringing further consistency across underlying assumptions about the economy are important areas for future research and EPA will continue to evaluate the literature for new methods that address these issues. For this report, EPA has expanded and clarified the discussion of modeling limitations, especially in Section 3.2 "Omitted Damaged and Other Modeling Limitations." These revisions specifically address feedbacks and interactions between damages and socioeconomics. The National Academies (2017) identified explicitly accounting for feedbacks between the damages and climate modules to the socioeconomic module as an important longer-term goal in the SC-GHG estimation process. |
| Fisher-Vanden | (**SHORT-TERM**): The report should assess and discuss the implications of the weighted average scenarios approach taken for the damage estimates. | EPA has expanded discussion of the development of the RFF-SPs in Section 2.1 and expanded the footnote in Section 2.3 that discusses the emulator approach to help clarify the process and integration of socioeconomics into DSCIM. EPA acknowledges that alternative implementations of DSCIM could be an area of further research. |
| Fisher-Vanden | (**LONG-TERM**): Another reviewer on the panel made the excellent point that it is important to recognize and capture the fact that damages will affect utility through different channels. This point underscores the importance of structural modeling that can capture these different channels. | Thank you for this comment. The potential for interactions between different climate change impacts within the utility function and how that impacts aggregate willingness to pay for GHG reductions is an important area for future research. EPA recognizes that the current approach utilizing separate willingness to pay estimates across underlying damage categories may not fully incorporate these potential interactions. EPA will continue to review developments in the literature with respect to utility function representation and structural modeling in monetizing climate impacts. |

| | | |
|---|---|---|
| Fisher-Vanden | (**SHORT-TERM**): Therefore, this report is excellent for providing an overview, but not appropriate for trying to understand and comment on what is going on under the hood. A much more detailed technical document, similar to the DSCIM user manual, for instance, should accompany this report. | Thank you for this suggestion. We have added a statement at the outset of Section 2 to clarify that the discussion is intended to provide an overview road map of the methodological updates, and that additional details of each underlying study are available in the sources cited throughout the report. |
| Forest | Yes, this update provides a better general estimate of the damages than a few functional representations in the original models. While these are more comprehensive, they are most likely to be underestimating damages if smaller sectors are left out. | Thank you. |
| Kling | I suggest EPA considering dropping the use of the term “sector” to describe components of damage and instead use their alternative term “impact category.” The term, “sector” in economics typically refers to an industry (agriculture, manufacturing, etc.) which is not what is being referenced fhere. Further, the broad terms of health, agriculture, suggest that the EPA has monetized and considered all impacts in that category, but in most/all cases, many impacts are currently omitted. For example, DSCIM incorporates only mortality under the “health sector.” The agricultural sector, etc. are also only partial. | EPA agrees with this suggestion. EPA has replaced the term "sector" with "category" in many instances throughout the report. EPA has added clarification about the remaining uses of the term sector, including additions to a footnote in Section 2.3. |
| Kling | Footnote 76 documents the source of the value of risk reduction (VSL) as being the dated 1990 estimate, updated for income growth. Numerous authors have called for these numbers to be updated for years. Their continued use may be understandably pragmatic for now but updating these numbers using improved methodology and data is long past due. I urge EPA to prioritize that effort. | Thank you for this suggestion. As with other aspects of SC-GHG estimation, EPA will continue to review developments in the literature on valuation of mortality risk and look for opportunities to further improve this risk-valuation and SC-GHG estimation going forward. |

| | | |
|---|---|---|
| Kling | It is unclear how summing 5 separate damage estimates relates to the underlying welfare theory. Specifically, each of the 5 damage estimates constructs a separate welfare measure that come from different revealed preference methods. In the case of mortality valuation, the use of a value of risk reduction construct to multiply by the expected change in mortality is theoretically consistent with the ex-ante welfare values that are appropriate. I am less clear how the energy component--- the change in energy expenditures --- is related to the *ex-ante* wtp to avoid uncomfortable temperatures. Since estimates of increased energy use to heat and run air conditioning is approach, it seems that the theoretical basis should come from the use of the revealed preference methods of defensive expenditure. In that case the literature on how to use defensive expenditures to estimate the bounds on theoretically correct wtp is necessary to make this linkage. Bartik developed a key result (also covered nicely in coverage in applied welfare economics textbooks (Bockstael and McConnell, Phaneuf and Requate, Freeman et al.)) that make clear these expenditures can only be viewed as lower bounds. | Throughout the report, EPA has expanded and clarified the discussion that the report's SC-GHG estimates likely underestimate the marginal damages from GHG pollution. In particular, EPA has added a reference to Bartik (1988) in Section 2.3 "Damage Module." EPA discusses how damage estimates based on defensive expenditures may understate the full welfare impact of a climate change. EPA will continue to review the literature on damage estimation and look for opportunities to further improve the representation of the theoretically correct welfare measure. |
| Kling | Given that the estimates in this report indicate a negative estimate for energy costs, and that number is nothing but a lower bound, that's a point that is important to make. I think similar questions can be asked about the other issues. This question is probably best thought of as a long run component of a research agenda rather than something necessary to address now. | Please see response above. |
| Oppenheimer | Yes, see my comments in response to General Impressions and Question II.1.a. The inclusion of empirical modeling as an equal contributor to this assessment provides an important improvement. Of course, more work needs to be done to understand the ways the processes and empirical damage functions differ from the current method versus the earlier approach, especially with regard to their respective abilities to capture the effect of adaptation, if they do at all. | Please see responses above in the "General Impressions" section. EPA has expanded and clarified the discussion of the methodological updates, including the discussion of the representation of adaptation. In particular, EPA has expanded the discussion of adaptaption in Section 3.2 "Omitted Damages and Other Modeling Limitations." |

| | | |
|---|---|---|
| Oppenheimer | Furthermore, the out-of-sample question needs to be explored in great detail for particular impacts in order to assess the limitations of projection based on inference from empirical studies (see for example, the Wagner submission, Fig. 3A and related comments). This should be a project for future research. | EPA will continue to review developments in the literature on damage function estimation and projection, including the representation of out-of-sample impacts, and look for opportunities to further improve SC-GHG estimation going forward. EPA has also expanded the discussion in Section 3.2 "Omitted Damages and Other Modeling Limitations." |
| Schlenker | The NASEM highlighted that the previous IAMs did not incorporate the latest scientific findings. The current analysis is a big step forward. I congratulate the EPA for its efforts to include three separate well-described approaches. These include both micro-level statistical studies as well as aggregate damage functions and a meta-analysis. I realize that meta-studies are common in the literature, but I am personally a bit hesitant to employ them as they place equal weight on each study when I believe some are more defensible than others. | Thank you, we agree that the different lines of evidence presented and evaluated in the Report is a significant advancement in the estimation of the SC-GHGs. Given the still relatively narrow sectoral scope of the recently developed DSCIM and GIVE models, EPA includes the third meta-analysis based damage function to reflect a synthesis of the state of knowledge in other published climate damages literature. Studies that employ meta-analytic techniques offer a tractable and straightforward way to combine the results of multiple studies into a single damage function that represents the body of evidence on climate damages that pre-date CIL and RFF's research initiatives. Regardling the meta-analysis considered in the report, the published paper carefully evaluates each of the underlying studies for quality and uniqueness, in addition to establishing consistency in their outcomes. EPA has expanded on the discussion of available studies and the use of meta-analyses in estimating climate impacts in Section 2.3.3. |
| Schlenker | As discussed below, the sectoral damages vary vastly by approach and it would be interesting to dive further into where the differences stem from going forward and go with the number that is most defensible and describe the others as sensitivity checks. | EPA has expanded on the discussion in the report about the differences in outcomes in each sector across different damage modules presented in the report. Specifically, EPA has expanded on Section 3.1, and also added Appendix 8 (Treatment of Uncertainty) that sheds additional light on the underlying differences and outcomes. |
| Wagner | In short, it is a clear step forward from the prior Interagency Working Group (2015) effort. If Rennert et al. (2022) is any guide here, it may also be the single most important update affecting the final number with the sole exception of assumed discount rates. | Thank you. |

| | | |
|---|---|---|
| Wagner | At the same time, it may also be the module in need of most work. In particular, a closer look at the decomposition of the three damage modules (see e.g. Table 3.1.4) makes it unclear whether it is more appropriate to average across the three functions or perhaps even, in part, add them. DSCIM focuses on five sectors or impact categories, GIVE on four, leaving out labor productivity. The sole overlap in sources across the two is Diaz (2016) for sea-level rise damages. It would take quite a bit more work of diving into the specific sources to understand whether it is truly appropriate to average across them, or whether even adding (some of) the now separate damage modules might be more appropriate. | The Report describes each approach and state of the damage function literature (e.g., Section 2.3) and provides an explanation for how these different lines of evidence were incorporated into the damage module (see e.g., Section 4.1). In Section 4.1, EPA also notes that given the relatively modest variation in the SC-GHG estimates across the three damage modules in Tables 3.1.1-3.1.3, the values presented in Table 4.1.1 are similar to what would be obtained under alternative approaches for drawing on the multiple lines of evidence represented by the three damage modules. EPA further notes that development of more formal integration approaches to account for structural uncertainty across damage functions is an opportunity for improvement in future updates. One approach to integrating different lines of evidence would be at the stage of model estimation (e.g., structural uncertainty across damage modules). However, currently DSCIM is a stand-alone model with a spatial resolution of over 25k impact regions and requires complex estimation and large capacity computing power. Therefore, this type of integration with the other damage modules is not currently feasible as each independent model was created by independent research teams and include a single characterization of each impact category that was identified by the research teams as the best available for inclusion in each of the models. |
| Wagner | Similarly, the damage function based on the Howard and Sterner (2017) meta-analysis is just that: a by now well-established analysis of several prior published results. It, too, is a clear step forward from the prior Interagency Working Group (2015) effort, tet some of these prior studies, by now, are rather outdated themselves and would deserve a second look. For example, mortality seems to barely figure into the calculation, once again raising the question of whether averaging across damage modules is the appropriate step, rather than adding some damage function components to those from DSCIM and GIVE. | EPA has expanded the discussion in the Final Report to recognize the updated Howard and Sterner (2022) working paper and other emerging meta-regression studies incorporating more recent global damage estimates. See previous response regarding how EPA combined the different lines of evidence within the damages module. EPA will continue to follow the published literature in this area. |

**Charge Question 4.b.** ***Does the draft report's use of multiple damage functions reflect the breadth of the current scientific literature on damages for this update? If not, what changes do you recommend? Do you think that there is a better approach for this update?***

| REVIEWER | REVIEWER COMMENT | EPA RESPONSE |
|---|---|---|
| Cropper | I have no further changes to suggest. | Thank you. |
| Fisher-Vanden | There are a number of integrated modeling studies that examine fine-scale impacts as part of the integrated assessment and multisector dynamics modeling communities, although this work is focused on providing fine scale analysis rather than aggregate damage functions. Please see, for instance: https://climatemodeling.science.energy.gov/program-area/multisector-dynamics | Thank you for pointing us to these ongoing cross-disciplinary multisector dynamic modeling efforts. We have included discussion of them in the Section 3.2. |
| Forest | At this time, the damage function module is in a state of flux as more damages are identified and not yet in the literature. So, it's a moving target and will most likely always be an underestimate. | Throughout the report, EPA has expanded and clarified the discussion that the report's SC-GHG estimates likely underestimate the marginal damages from GHG pollution. EPA has expanded the discussion of omitted damage categories in Section 3.2 "Omitted Damaged and Other Modeling Limitations." EPA will continue to review the literature on damage estimation and look for opportunities to further improve the SC-GHG estimation going forward. |
| Kling | See above. | See response above. |
| Oppenheimer | I believe that comparing results from these three research frameworks provides as credible an assessment as is now possible within the limitations of the modeling approaches deployed within each framework. | Thank you. |
| Oppenheimer | I worry much more about what was left out (see Table 3.2.1) as a source of error than I worry about the way the modeling of the included impacts was aggregated and the aggregations presented and compared. However, my concerns about the treatment of uncertainty and adaptation noted above remain. | Please see responses on uncertainty and adaptation above. EPA has expanded and clarified the discussion that the report's SC-GHG estimates likely underestimate the marginal damages from GHG pollution. EPA has also expanded the discussion of adaptation (particularly in Section 3.2) and uncertainty (with the addition of Appendix A.8 and Table A.8.1). |

| | | |
|---|---|---|
| Schlenker | I think the EPA has made a big step forward by switching to the modular approach and including three different damage approaches. The one exception is [a public] comment [Docket ID EPA-HQ-OAR-2021-0317-2183], who talk about possible tipping points and encourage EPA to highlight them further. While I wouldn't ask EPA to include them in their baseline numbers, it would be informative to include them in a sensitivity check to showcase how much they might change the results. One of the largest concerns for me about the current approach is that the approach might not correctly capture that we are setting irreversible self-enforcing feedback loops into motion and hence underestimate future damages. | EPA has expanded and clarified the discussion of modeling limitations, especially in Section 3.2 "Omitted Damaged and Other Modeling Limitations." These revisions specifically address tipping points and feedbacks including expanded discussion of Dietz et al (2021). EPA agrees that tipping points and feedbacks are very important areas of further research. EPA will continue to review these developments in the literature and look for opportunities to further improve SC-GHG estimation going forward. |
| Schlenker | As was discussed in our meeting, it would be great to stress that additional sectoral impacts will be added in the future. They might also result in benefits for some sector (e.g., recreation). | One advantage of the modular framework recommended by the National Academies and adopted in the updated SC-GHG estimation is that future research on new or alternative damage functions can be incorporated into the damage module in a relatively straightforward way as they become available. The EPA will continue to review developments in the literature, including more robust methodologies for estimating the magnitude of the various categories of climate impacts and explore ways to better inform the public of the full range of net damages from GHG emissions. Recreation impacts are listed in Table 3.2.1 as one of the categories of climate impacts that is not yet represented in the models underlying the damage module. |
| Wagner | One possible extension (or cross-check) here might be to look at the statistical damage functions presented by the IPCC (2022), in particular the Figure Cross-Working Group Box ECONOMIC.1, panels (a)-(c), p. 16-114. | Section 3.3 now includes some discussion of total-economy empirical studies that econometrically estimate the relationship between GDP and a climate variable. |

| | | |
|---|---|---|
| Wagner | Another is to explicitly account for climatic tipping points, as in Dietz et al. (2021). Doing so alone would, according to our analysis, increase the SC-$CO_2$ by between ~27-43%, with a potentially long right tail: | See response to similar comment in 1d. EPA agrees that representation of tipping points is an important area of further research. EPA will continue to review developments in the literature on tipping points and associated monetized damages as EPA looks for opportunities to further improve SC-GHG estimation going forward. EPA has expanded the discussion of tipping points in Section 3.2 "Omitted Damages and Other Modeling Limitations." This includes additional discussion of Dietz et al. (2021). |
| Wagner | That tail, in turn, leads to roughly a 1 in 10 chance of these eight modeled climatic tipping points more than doubling the SC-$CO_2$.<br><br>We do so here in Figure 3 of Bauer, Proistosescu, and Wagner (2023):<br><br>One striking observation: statistical "end-of-century" estimate might reverse the shape of the damage function from concave to convex. All this makes it important to highlight the large differences and resulting uncertainties across different assumed damage modules. | See response above.<br><br>See response below.<br><br>See response below.<br>EPA agrees that damage function estimation and projection are important areas of further research, including the representation of out-of-sample impacts. EPA will continue to review developments in the literature on damage function estimation and projection and look for opportunities to further improve SC-GHG estimation going forward. EPA has also expanded the discussion of tipping points in Section 3.2 "Omitted Damages and Other Modeling Limitations." This includes additional discussion of Dietz et al. (2021). |

**Charge Question 4.c.** ***For the damage categories that are represented, are there additional studies or valuation methodologies that the EPA should consider in modeling these categories in this update? Please describe the advantages of these studies relative to the methods used in the draft report.***

| REVIEWER | REVIEWER COMMENT | EPA RESPONSE |
|---|---|---|
| Cropper | None. | Thank you. |
| Fisher-Vanden | See comment in b. | See response in b. |
| Forest | N/A | Thank you. |
| Kling | See above. | See responses above. |

| | | |
|---|---|---|
| Oppenheimer | I am not as expert on current valuation methods as others reviewing this report so I will refrain from commenting on this one. | Thank you. |
| Schlenker | The biggest sectoral impact is health (Table 3.1.4), which crucially depends on the value of a statistical life (VSL). There is an inherent tension between the current report and how EPA traditionally uses VSL. It is my understanding that EPA uses the same VSL for all ages (it once discussed using different values by age but then reverted back giving ethical considerations), even though there are revelated preference studies showing that it varies by age. Carleton et al. (2022) does use age-years lost, implying a different VSL per age group (older people have fewer life years left). Moreover, Carleton et al. (2022) uses an income-elasticity of one, which implies that if a person dies in a country that has one tenth of US income, it is valued at one tenth the US value. Scaling VSL by income has a theoretical and empirical underpinning: people who are faced with tradeoffs that can lower their mortality risk reveal a lower willingness to pay when their income is lower. | EPA notes in the report, "While the main specification of DSCIM employs an age-adjusted valuation approach for monetizing net health damages (inclusive of adaptation costs), in the results presented in this report, the projected changes in premature mortality are monetized using country-level population-average measures of the willingness-to-pay for mortality risk reductions." In other words, in this report EPA applies does not adjust the WTP by age similar to EPA's application of the VSL in other context, such that there is no inconsistency between this report and current EPA practice in VSL. EPA provides additional discussion of VSL and age-adjustment in Appendix A.7. |
| Schlenker | However, as comment 2464 points out, this is very different from the setting of greenhouse gas emissions where most of the emissions are caused by high-income developed countries, while most damages are felt in low-income countries (Figure 9 in Carleton et al). There is evidence that people care about the distributional aspects, e.g., Cai, Cameron, and Gerdes (2010) https://doi.org/10.1007/s10640-010-9348-7 | EPA provides extensive discussion of VSL in Appendix A.7. EPA will continue to review developments in the literature on valuation of mortality risk and look for opportunities to further improve this risk-valuation and SC-GHG estimation going forward. While EPA will continue to assess the broader literature on BCA, social welfare, and equity as it seeks to apply the best available science in its analyses, this report develops SC-GHG estimates that are considered to be consistent with the Kaldor-Hicks criterion that guides all the other elements of the EPA's BCAs. In addition to conducting Kaldor-Hicks based BCA, EPA has and will continue to analyze the distribution impacts of climate change and the impact on communities with environmental justice concerns in its rulemakings, as feasibale and appropriate. |

| | | |
|---|---|---|
| | I respectfully disagree with the comments made by Professor Kling. Again, there is a big difference whether people themselves make choices / tradeoffs between increased mortality risks and or whether it is imposed by others. There can be a big difference between willingness to pay and willingness to accept, see Hanemann (1991): https://www.jstor.org/stable/2006525. In his proposition 2, he shows that if there is zero substitutivity, the former could be finite while the latte is infinite. So the VSL for action caused by others might be much higher. I am not aware of VSL studies in developing countries that look at harm (mortality risk) that is not endogenous to the country but caused by authors. | Please see response above. |
| Schlenker | There is also an ethical perspective. The same studies, e.g., Viscusi and Masterman https://doi.org/10.1017/bca.2017.12, that argue for an income elasticity of 1 for international setting, say it should be 0.5-0.7 for domestic stetting. Yet, EPA does not differentiate VSLs by income within the US (New York has more than twice the average income than Mississippi, and we don't value deaths in Mississippi less than New York). | Please see response above. |
| Schlenker | Let me illustrate the flip-side of this argument: the report outlined why using global impacts is appropriate, partly because we expect other countries to join in using similar regulation. It might be hard for the equivalent of EPA in India to argue to its citizens that a death in the US is 32 (current ratio of GDP per capita) as bad as a death in India. | Please see response above. EPA agrees that investigating countries' own estimates of their populations' VSLs would be an interesting area of further research. |
| Schlenker | What would be sensitivity of the SC-GHG to using different income-elasticities for the global VSL – I believe this should be discussed, at least in an appendix. | EPA provides this discussion in Appendix A.7. For example, EPA notes that Carleton et al. (2022) included an empirical exploration in sensitivity analyses of how climate-related mortality damages change under a variety of valuations. They found net damages from climate change mortality risk changes of $15-$65 per ton CO2 when using a WTP-based VSL (similar to the approach used in this report) and damages of $46-$144 per ton CO2 when using a global average VSL, where the range is across the socioeconomic-emissions scenario modeled. |

| | | |
|---|---|---|
| Wagner | See (b) above around the use of 'statistical' damage functions and especially also the tipping points component. | See responses above. |

**Charge Question 4.d.** ***Are there additional categories of damages that should be considered for inclusion in the individual sectoral damage functions in this update? Please describe the peer reviewed literature that could be used to inform the modeling of these damage categories.***

| REVIEWER | REVIEWER COMMENT | EPA RESPONSE |
|---|---|---|
| Cropper | None. | Thank you |
| Fisher-Vanden | (**LONG-TERM**): Indirect impacts and integrated impacts are very important and not considered in this report. | We agree that there are still many missing categories of impacts and associated damages. See Section 3.2 for an expanded discussion of these important areas for research for future updates. |
| Forest | N/A | Thank you |
| Kling | See above. | Thank you |
| Oppenheimer | See my foregoing comments on precipitation and sea level rise adaptation. | See responses above to those comments. |
| Schlenker | EPA has based their analysis on three highly respected analyses (published in Nature and the Quarterly Journal of Economics) and incorporated the sectors used in those studies. I don't think it is realistic for EPA to add additional sectors that were not covered in the original studies. However, it might be good to note already now that future revisions will include additional sectors, however, I do believe that mortality will likely continue to be the most significant part (there is a reason studies focus on this sector first). | EPA has expanded and clarified discussion of the modular approach and plans for future updates. EPA notes that one advantage of the modular approach is that future research on new or alternative damage functions can be incorporated in a relatively straightforward way. DSCIM and GIVE developers have work underway on other impact categories that may be ready for consideration in future updates (e.g., morbidity and biodiversity). EPA will continue to review developments in the literature and look for opportunities to further improve SC-GHG estimation going forward. |
| Wagner | Arguably the largest omission concerns climatic tipping points a al Dietz et al. (2021).[2] [2Full disclosure: I am among the "et al"s.] | See response to similar comment in 1d above. |

**Charge Question 4.e.** ***Do you have recommendations for strengthening the presentation of this module, e.g., with respect to increasing transparency of the damage function calibrations or characterization of uncertainty in the draft report?***

| REVIEWER | REVIEWER COMMENT | EPA RESPONSE |
|---|---|---|
| Cropper | None. | Thank you |
| Fisher-Vanden | (**SHORT-TERM**): As mentioned above, this report is excellent for providing an overview, but not appropriate for trying to understand and comment on what is going on under the hood. A much more detailed technical document, similar to the DSCIM user manual, for instance, is needed. | Thank you for this suggestion. We have added a statement at the outset of Section 2 to clarify that the discussion is intended to provide an overview road map of the methodological updates, and that additional details of each underlying study are available in the sources cited throughout the report. |
| Forest | Not at this time. | Thank you |
| Kling | See above. | See responses above. |
| Oppenheimer | No. | Thank you |
| Schlenker | Since they are based on published studies, interested readers can revert to those studies. A few recommendations I have are:<br>1) Further outline the differences between studies for various sectors in Table 3.1.4. | We have expanded discussion in Section 3.1 of how DCSIM differs from GIVE, added more discussion of agricultural damages in Section 3.2, and a new appendix that summarizes the treatment of uncertainty within each module, including the various climate impact categories included in GIVE and DSCIM. |
| | 2) Figure 2.3.2 plots the damage function. a) Please plot them all using the same y-scale so they are comparable.<br>b) The one for the GIVE model seems to be consistently higher damages for various temperatures - I realize this is for damages in 2100 (one point in time)<br>+1C: GIVE 1%, DSCIM: 0%<br>+2C: GIVE 2.5%, DSCIM: 0%<br>+3C: GIVE 4%, DSCIM: 1%<br>+4C: GIVE 5%, DSCIM: 2%<br>+5C: GIVE 7.5%, DSCIM: 4%<br>+6C: GIVE 10%, DSCIM: 6.5% | We have revised Figure 2.3.2 so that all panels use the same y-axis scale. |

| | | |
|---|---|---|
| | Yet, the social cost of carbon is higher for DCSIM than GIVE. What is the intuition for this? Is it in the time profile (i.e., Figure 2.3.2 gives damages in 2100, where GIVE is higher, but DSCIM has higher damages by say mid-century?). But then, DSCIM gives lower SC-GHG for methane, which has a faster impact on warming and I would have expected the S-CH4 methane to be even bigger under DSCIM model). Could you give some intuition how they compare over time. | We have expanded discussion in Section 3.1 of how DCSIM differs from GIVE. To summarzie, what is important for the estimate of the SC-GHG is not the height of the damage function but the slope of the damage function (e.g., marginal damages). The relative slope between the damage functions varies across global mean surface temperatures. DSCIM is relatively flat at lower global mean surface temperatures and relatively steep at high hlobal mean surface temperatures. |
| Wagner | Instead of averaging across damage functions, a key improvement seems to be distinguishing between parametric uncertainty within any one damage function on the one hand, and structural uncertainty across different damage functions. In Bauer, Proistosescu, and Wagner (2023), for example, we explicitly account for both types of uncertainties. We make no judgment call over which damage function is more appropriate, nor do we average across them. We instead "assign a hyper-parameter in our simulated climate damages that randomly chooses a damage function," allowing us "to remain agnostic with respect to which damage function we choose." I would counsel a similar approach here. | Thank you for this comment. EPA notes that the development of more formal integration approaches to account for structural uncertainty across damage functions is an opportunity for improvement in future updates. Given the computational framework currently used to estiamte the DSCIM damage function it is not currently feasible to integrate it with GIVE and the Meta-analysis using the suggested approach. EPA will continue to monitor developments in this space and opportunities for more formal treatments of structural uncertainty in future updates, like the approach discussed in Bauer et al. 2023. |
| Wagner | Meanwhile, at the very least, this module points once again to the appropriateness of calling the resulting SC-$CO_2$ a "partial" estimate, given that any of the individual damage functions used only account for some of the known climate impacts. | Throughout the report, EPA has expanded and clarified the discussion that the report's SC-GHG estimates likely underestimate the marginal damages from GHG pollution. EPA has expanded the discussion of omitted damage categories in Section 3.2 "Omitted Damaged and Other Modeling Limitations." |

| **Charge Question 4.f.** ***Do you have longer-term recommendations for improvements to this module in future updates?*** | | |
|---|---|---|
| **REVIEWER** | **REVIEWER COMMENT** | **EPA RESPONSE** |

| | | |
|---|---|---|
| Cropper | When the climate module is able to produce estimates of precipitation and extreme weather events, damages associated with flooding will need to be included. As the report itself notes, there are many categories of damages, including tipping points (see Table 3.2.1). | EPA has expanded and clarified discussion to explain how some of the underlying damage studies incorporate various spatial resolutions and other climate variables, such as precipitation. In particular, see updates in Section 2.2 "Climate Module," Section 2.3 "Damage Module," and Section 3.2 "Omitted Damages and Other Modeling Limitations." Also, Figures 3.2.1 and 3.2.1.1 emphasize regional differences in projected temperature, sea level, and precipitation changes. EPA has expanded discusssion of tipping points as well. Limitations of the climate module are just one of several reasons for the empty and partial circles in Table 3.2.1. For example, alternative treatments of precipitation and other non-temperature variables require damage functions from the economics literature to map the changes in these variables to market and non-market economic damages over time. EPA will continue to review the literature on climate modeling and damage estimation and look for opportunities to further improve the SC-GHG estimation going forward. |
| Fisher-Vanden | See comments above. | See responses above. |
| Forest | The major advances must include more comprehensive impacts that will eventually need to be derived from higher complexity earth system models. | EPA has expanded and clarified discussion to explain how some of the underlying damage studies incorporate various spatial resolutions and other climate variables, such as precipitation. In particular, see updates in Section 2.2 "Climate Module," Section 2.3 "Damage Module," and Section 3.2 "Omitted Damages and Other Modeling Limitations." EPA will continue to review the literature on climate modeling and damage estimation and look for opportunities to further improve the SC-GHG estimation going forward. Limitations of the climate module are just one of several reasons for the empty and partial circles in Table 3.2.1. For example, alternative treatments of precipitation and other non-temperature variables require damage functions from the economics literature to map the changes in these variables to market and non-market economic damages over time. |

| | | |
|---|---|---|
| Kling | The last few paragraphs of section 3.2 suggest seemingly straightforward ways to include additional damage values into the SCC estimates, why not do them? | We appreicate your suggestion on the inclusion of additional damage values. For this report EPA relied on three existing peer reviewed damage functions. The damage categories included are therefore limited to those categories which had been integrated into the models. Section 3.2 provides numerous examples of peer reviewed literature that estimate the impact of climate change on additional categories of damages. Integration of additonal damage categories into GIVE and DSCIM is ongoing (see section 2.3 for examples). We will continue to evaluate the literature and additional damage categories as they are integrated into models for estimating the SC-GHGs. |
| Oppenheimer | See above – the presentation is fine; the issue is the missing content. | Thank you for your comment, we have responded to your comment about missing content above. |
| Schlenker | EPA already outlined how they want to include other sectors, including non-market impacts. One important point to keep in mind when adding sectors and constructing confidence bands is that errors across sectoral impacts are likely highly correlated and not independent. | Thank you for the comment. As noted in other responses, future research into the feedbacks and connections between damage categories will be important for further improvements in the SC-GHG estiamtes. EPA will continue to follow the literature on this topic and incorporate additional feedbacks and connections between damage categories as appropriate and feasible. |

| | | |
|---|---|---|
| Schlenker | I believe there are especially two areas that warrant further study in the future that could significantly alter the overall results. First, one of the biggest unknowns is adaptation and whether it can significant lower the predicted cost. The Carleton et al 2022 paper estimates adaptation based on revealed preferences of who has adapted so far in warmer climates, but are they representative? Full disclosure: it uses the same approach to adaptation that I have used before for crops - so the same criticism to applies to my studies. Specifically, areas that are currently warmer have lower crop yields (and lower GDP), so the benefits from innovation are currently lower than what they would be if currently moderate climates (with higher yields or GDP) become warmer. The incentives for innovation might hence be higher in the future as what is picked up in the current data. Moreover, the analysis omits that we might have new technologies available in the future that weren't available in the past. Taken together, we might underestimate adaptation possibilities and hence overestimate damages. | We agree that accounting for adaptation, and the costs of adaptation, is important in SC-GHG estimation. In tables 2.3.1 and 2.3.2 we included a column that outlines how adaptation is accounted for in each impact category in the DSCIM and GIVE based damage functions. As you point out Carleton et al. 2022 estimates income-based adaptation. That is, how people respond to relaxation of the budget constraint (e.g., puchase air conditioner). Other forms of adaptation such as technologcal progress are also important in understanding the adaptation. As noted in an expanded dsicussion of this issue in Section 3.2 of the report, the modeling of future adaptation and its costs are an important area of future research. For example, even the empirically based estimation of revealed adaptation for other damages in DSCIM must rely on what has been observed in the historical record. It remains challenging to project how the costs of adaptation will increase at higher levels of warming and potential increases in the intensity of extreme events, and how quickly technological advances could help to work in the other direction to reduce the costs of adaptation investments or provide new adaptation alternatives. |

| | | |
|---|---|---|
| Schlenker | The second point relates to migration. In my opinion, one of the most disruptive effects of climate change might be the need to relocate – locally from flood-prone areas or even long-distance as regions become uninhabitable. | Although the damage functions applied in this report offer an improved accounting of adaptation and its costs, the modeled estimates employ optimistic assumptions about adaptation decisions (such as relocation) in the estimation of coastal damages in GIVE and DSCIM. For example, the representation of adaptation and its costs in both models are based on the CIAM model. CIAM does include local redevelopment and relocation cost for sea-level rise. However, it is a deterministic optimization model that assumes decision makers have perfect foresight about SLR conditions throughout the model time horizon and always choose the lowest-cost adaptation strategy and level of investment for each of the thousands of coastal segments (Diaz 2016). We have expanded the discussion of this issue in Section 3.2 of the Report and we will conitnue to evalute the literature on displacement and migration more generally as we continue to look for opportunities to improve SC-GHG estimation going forward. |
| Wagner | Updating the damage function is among the most challenging tasks. The most important: arrive at a clear process to continuously update the damage function module with the latest scientific estimates (see section 1d above). | One advantage of the modular framework recommended by the National Academies and adopted in the updated SC-GHG estimation is that future research on new or alternative damage functions can be incorporated into the damage module in a relatively straightforward way as they become available. The EPA will continue to review developments in the literature, including more robust methodologies for estimating the magnitude of the various damages from climate impacts and explore ways to better inform the public of the full range of GHG impacts. |

**Charge Question 5.**

**Charge Question 5.a.** ***Does the discounting module in this draft report adopt an approach that allows the discount rate to better reflect recent quantitative evidence on the consumption rate of interest and capture the long-term relationship between discount rates and economic growth relative to the discounting approach used in the IWG methodology to date (which relies on three constant, exponential discount rates)? Why or why not?***

| REVIEWER | REVIEWER COMMENT | EPA RESPONSE |
|---|---|---|

| | | |
|---|---|---|
| Cropper | When discounting climate damages, it is important to allow for the correlation between damages and the rate of growth in the economy—i.e., to allow for systemic risk (see, e.g., Gollier, AEA Papers and Proceedings 2014). Using constant exponential discounting does not allow for this. The consequences of ignoring the correlation between economic growth and damages have been illustrated in the RFF Brookings Paper https://www.brookings.edu/wp-content/uploads/2021/09/15985-BPEA-BPEA-FA21_WEB_Rennert-et-al.pdf<br>When there is considerable uncertainty in damages, failure to allow for this correlation can (incorrectly) increase the SCC by a factor of 10. | Thank you. We have added a footnote highlighting this point in Section 2.4.2. |
| Fisher-Vanden | The Ramsey formulation adopted in this section is an improvement over past discounting approaches, in my opinion since it allows for dynamic discount rates and long-term intertemporal trade-offs which is key to the climate change issue. | Thank you. |

| | | |
|---|---|---|
| Fisher-Vanden | What is interesting, though, is that the discount rates generated from this approach are not that far off from discount rates used in the IWG, although in this approach, discount rates fall slightly over time and uncertainty ranges include significantly higher and lower discount rates. | Thank you for this observation. While the rates in Table 2.4.2 (a near-Term Target Certainty-Equivalent Rate of 1.5%, 2%, and 2.5%) may seem close to the rate previously used by the IWG (a contstant discount rate of 2.5%, 3% and 5%) they represent different approaches. The 3% rates previously used by the IWG was OMB's estimate of the the consumption rate of interest in Circular A-4 (2003). The 2.5% and 5% previously used by the IWG were risk-adjusted certainty equivalent rates based on assumptions about the climate-related damages and market returns. These three values were applied by the IWG as constant exponential discount rates. The 1.5%, 2%, and 2.5% rates used in this report represent estimates of the current consumption rate of interest. In other words, these are updates to the 3% used by the IWG, and are used as the starting point for calibrating the $\eta$ and $\rho$ Ramsey parameters. Uncertainty in future economic growth, as modeld in the RFF-SPs, is what leads to the declining discount rate (as seen in Figure 2.4.1). We added some text before Figure 2.4.1, making this distinction clear. |
| Forest | Not at this time. | Thank you. |
| Kling | This area is better addressed by other reviewers. | Thank you. |
| Oppenheimer | Better for others to handle this one. | Thank you. |
| Schlenker | The update module provides a theoretical underpinning for why the chosen interest rates are used that are in line with the recommendation of NASEM. While some comments (e.g., 2253) have argued that an interest of zero is appropriate, I do not find this convincing. | Thank you. |

| | | |
|---|---|---|
| Schlenker | The Ramsey formula is a composite of a pure time preference (which one might argue should be set to zero) and a second term that incorporates that future generation are better off (wealthier) than the current generation. Taking money from the (poorer) present and consuming it in the (wealthier) future, when the value of having an extra dollar is lower, leads to a welfare decline. Within this framework, the only reason that we discount with the second term is because the future is better off. If climate change were so catastrophic that the future is worse off than the present, the interest rate would actually be negative. This might be worth highlighting. | You are correct that negative growth would lead to a negative second term, and we note that climate change damages are a greater burden to society in future states of the world with relatively lower economic growth. We have expanded on this point in a footnote in Section 2.4. |
| Wagner | Discounting has the single largest impact on the SC-$CO_2$. The discounting module applied in the EPA report appropriately represents the biggest advance from the prior SC-$CO_2$ efforts. It is based on Newell, Pizer, and Prest (2022), which drives a relatively simple yet well-founded "discounting rule" for the SC-$CO_2$. | Thank you. |
| Wagner | The arguments for using a 2% 'central' estimate and values of 1.5% and 2.5% around it, in turn, are well-founded in economic theory and in recent advances in empirical understanding (e.g. Drupp et al. 2018; Council of Economic Advisors 2017; Greenstone and Stock 2021; Wagner et al. 2021). In fact, as I mention above, the proposed update to Circular A-4 argues convincingly for an even lower discount rate of 1.7% to be used in the short term (U.S. Office of Management and Budget (OMB) 2023). This might well argue for an even lower 'central' estimate than the current 2%. | Thank you for the comment. As described in the report, the average real rate based on the 10-year Treasury securities is sensitive to the time period analyzed and the inflation measure used. For example, across a range of reasonable assumptions and methods Table 2.4.1 presents a range of 1.55% - 2.8% for the historic real rate or return on 10-year Treasury securities. EPA also examined additional lines of evidence to inform the range of discount rates used in the report. For example, the 30-year Treasury security is less susceptible to short-run monetary policy interest rate fluctuations and is, on average, 50 to 70 basis points higher than the 10-year security. Additional lines of evidence considered include other government projections of interest rates and recent surveys of techincal experts. When looking across these lines of evidence, EPA has determined a central estimate of 2 percent and a range of 1.5 to 2.5 is appropriate for the certainty-equivalent near-term rate. We note that the final update to OMB's Circular A-4 recommends a consumption interest rate of 2.0%. |

**Charge Question 5.b.** ***Are there discounting approaches other than Ramsey discounting that the EPA should consider for this update? Please describe the advantages of these approaches.***

| REVIEWER | REVIEWER COMMENT | EPA RESPONSE |
|---|---|---|
| Cropper | I would not consider alternative approaches. | Thank you. |
| Fisher-Vanden | I defer to others on the review panel who are better equipped to comment on this. | Thank you. |
| Forest | Not at this time. | Thank you. |
| Kling | This area is better addressed by other reviewers. | Thank you. |
| Oppenheimer | Same as (a). | Thank you. |
| Schlenker | I believe the Ramsey formula is appropriate. | Thank you. |
| Wagner | No. Ramsey discounting is the appropriate methodology here. As I mentioned in (1c) above, and as alluded to in the document, there are alternative approaches to Ramsey discounting, in particular use of Epstein-Zin utility functions (Epstein and Zin 1989; 1991; Weil 1990). | Thank you. |
| Wagner | This literature is worthy of further exploration, though despite important contributions to date (Lemoine and Rudik 2017), and my own participation in this literature (Daniel, Litterman, and Wagner 2018; 2019; Bauer, Proistosescu, and Wagner 2023), I do not believe that work on Epstein-Zin-style utility functions are ripe to supplant standard Ramsey discounting approaches in calculating the formal U.S. SC-$CO_2$. | Thank you for this comment. We agree this is an important area for continued research. We included Daniel, Letterman, and Wagner (2019) as a reference and explictly mentioned the Epstein-Zin specification in the draft report. We look forward to the published version of your other paper. |

**Charge Question 5.c.** ***Are there other descriptive approaches for calibrating the Ramsey parameters that the EPA should consider for this update? Please describe the advantages of these approaches relative to the methods used in the draft report.***

| REVIEWER | REVIEWER COMMENT | EPA RESPONSE |
|---|---|---|

| | | |
|---|---|---|
| Cropper | The advantage of the current calibration of Ramsey discounting is that it links the initial discount rate to market rates of interest. The US government has always adhered to a positive, rather than a normative, approach to discounting. This helps to preserve this approach, while allowing for the correlation described in Comment a. | Thank you. |
| Fisher-Vanden | I defer to others on the review panel who are better equipped to comment on this. | Thank you. |
| Forest | Not at this time. | Thank you. |
| Kling | This area is better addressed by other reviewers. | Thank you. |
| Oppenheimer | Same as (a). | Thank you. |
| Schlenker | No comment. | Thank you. |
| Wagner | n/a | Thank you. |

**Charge Question 5.d.** ***Is the discounting module described clearly in the draft report? Do you have recommendations for strengthening the presentation of this module, e.g., with respect to increasing transparency or characterization of uncertainty in the draft report?***

| REVIEWER | REVIEWER COMMENT | EPA RESPONSE |
|---|---|---|
| Cropper | None. | Thank you. |
| Fisher-Vanden | Unlike some of the other sections of the report, I felt like this section did a better job providing the details needed to understand what was being done, although I did end up reading some of the cited articles to get a fuller understanding of the approach and calibration. | Thank you. |
| Forest | Not at this time. | Thank you. |
| Kling | This area is better addressed by other reviewers. | Thank you. |
| Oppenheimer | Same as (a). | Thank you. |
| Schlenker | See part a. Maybe describe why the interest rate is positive in more detail and under what conditions it would be negative. | See reponse under 5.a |

| | | |
|---|---|---|
| Wagner | Yes, and no. This module might be the most challenging to get right, and the EPA report does a great job of explaining the intricacies in plain language. The discounting module is clearly written, and deserves wide circulation on its own as a standard entry into this literature. | Thank you. |

| **Charge Question 5.e.** ***Do you have longer term recommendations for improvements to this module in future updates?*** | | |
|---|---|---|
| **REVEIWER** | **REVIEWER COMMENT** | **EPA RESPONSE** |
| Cropper | None. | Thank you. |
| Fisher-Vanden | I defer to others on the review panel who are better equipped to comment on this. | Thank you. |
| Forest | Not at this time. | Thank you. |
| Kling | This area is better addressed by other reviewers. | Thank you. |
| Oppenheimer | Same as (a). | Thank you. |
| Schlenker | No comment. | Thank you. |
| Wagner | The key bit for longer-term updates, here as elsewhere, is around setting up the appropriate process to help identify conditions under which the discount rates used here might be updated. One such example is our improved understanding of the appropriate "climate beta" (Dietz, Gollier, and Kessler 2018; Lemoine 2021), which may well merit updates to the discounting module in the future. | Thank you for this comment. We agree that an improved understanding of the climate beta is important for future updates. We have cited Dietz, Gollier, and Kessler 2018 and Lemoine 2021, and we are aware that this topic is of keen interest to researchers (e.g., Gollier 2021). The climate beta is not a choice variable in the model runs, but, instead, comes from the modeling framework and assumptions. We have added a discussion of the climate beta in a new appendix, and we will look to incorporate future literature on the climate beta in future updates. |

| **Charge Question 6.** |
|---|

| **Charge Question 6.a.i.** ***Does the methodology in the draft report more explicitly reflect existing evidence on individuals' preferences over risks in the valuation of climate damages than the IWG methodology to date (which maintained an assumption of risk neutrality throughout the analysis and indirectly incorporated risk aversion through exogenous adjustments to the discount rate and through consideration of a fourth value reflecting the 95th percentile of the SC-GHG results under a 3% discount rate)? Why or why not?*** | | |
|---|---|---|
| **REVIEWER** | **REVIEWER COMMENT** | **EPA RESPONSE** |

| | | |
|---|---|---|
| Cropper | The current approach more adequately captures risk preferences than the previous ad hoc adjustment of constant exponential discount rates and the focus on the 95$^{th}$ percentile of the SCC. The discussion of risk aversion in the current draft is excellent. | Thank you. |
| Fisher-Vanden | I believe the methodological approach to account for risk aversion is consistent with the discounting approach and an improvement over past studies. | Thank you. |
| Forest | No comment. | Thank you. |
| Kling | Yes, this is a much-improved approach. | Thank you. |
| Oppenheimer | Better for others to handle this. | Thank you. |
| Schlenker | Comment [Docket ID EPA-HQ-OAR-2021-0317-2183] had some useful suggestions on going from a positive to normative justification for the chosen interest rate – this would be worth considering when providing justification, as well discussion on the climate beta. The comment is a better summary than what I can provide. | We agree that public comment 2183 on this report provides useful comments on discounting frameworks and the climate beta. As pointed out in that comment, the U.S. Federal government has a long tradition of using a positive discounting framework. EPA has chosen to maintain this approach to retain consistency with the discounting approach taken in the rest of its benefit-cost analysis and because it provides a strong data-driven estimate of the discount rate. With regard to the estimation of $\eta$ and $\rho$, EPA recognizes the positive approach taken implies a risk premium that is below the observed market premium and that there is currently no consensus on alternative specifications that can also solve the 'equity premium puzzle.' With regard to the climate beta, this is not a policy choice parameter. The correlation between climate damages and economic growth, which defines the climate beta, arises from the damage function for each damage category, which is also a data-driven positive exercise. The commenters are correct that the implied climate beta in the models used is close to one. For transparency and clarity in the assumptions used for this estimate, EPA has added a section on the implied climate beta for the three models in Appendix A.4. |

| | | |
|---|---|---|
| Wagner | The treatment of risk aversion poses the largest challenge to the standard Ramsey discounting framework and all but calls for using Epstein-Zin-style preferences. I do not, however, believe that literature is ripe for incorporating here (see 5b above). | See reponse under 5.b |

**Charge Question 6.a.ii.** ***Are there other parameterizations/approaches that have been applied in the empirical literature that the EPA should consider for incorporating risk aversion in this update? Please describe the advantages of these approaches relative to the methods used in the draft report.***

| REVIEWER | REVIEWER COMMENT | EPA RESPONSE |
|---|---|---|
| Cropper | None. | Thank you. |
| Fisher-Vanden | I defer to others on the review panel who are better equipped to comment on this. | Thank you. |
| Forest | No comment. | Thank you. |
| Kling | No. | Thank you. |
| Oppenheimer | Better for others to handle this. | Thank you. |
| Schlenker | No comment. | Thank you. |
| Wagner | One important addition is adding at least one scenario/model run that explicitly factors in "equity weights" (e.g. Anthoff and Emmerling 2018). This is especially appropriate given the theoretical problems with using the EPA report's Purchasing Power Parity (PPP) adjustment of the estimate of a Value of a Statistical Life (VSL) and claims around the application of the Kaldor-Hicks criterion (see 6bi below). | See response under 6.b.i. |

**Charge Question 6.a.iii.** ***Do you have recommendations for strengthening the presentation of this modeling decision in the draft report, e.g., with respect to increasing transparency of the parameterization and implementation with the damage functions used in this update?***

| REVIEWER | REVIEWER COMMENT | EPA RESPONSE |
|---|---|---|
| Cropper | As noted above, the discussion of the current parameterization of $\eta$ is very clear and I agree with the current choices. | Thank you. |

| | | |
|---|---|---|
| Fisher-Vanden | This section, in contrast with other sections, was better at being transparent and forthcoming with the biases to the SC-GHG estimates resulting from their choice of parameter values (e.g., bottom of pages 64 and 65). This type of transparency is needed throughout the report. | Thank you. |
| Forest | Not at this time. | Thank you. |
| Kling | My primary suggestion for this section is to provide more information and tables comparing the results. Table 3.1.1 – 3.1.3 report the SC-GHGs by sector by damage module, but not be "sector". To better compare and understand differences and similarity in the 3 damage modules, it would be very useful to see these disaggregated by sector and by region of the world. Table 3.1.4 does provide a comparison across sectors by only for a single year, not it's time path over time and not by geography region. | EPA has expanded on the discussion in the report about the differences in outcomes in each sector across different damage modules presented in the report. Specifically, EPA has expanded on Section 3.1, and also added Appendix 8 (Treatment of Uncertainty) that sheds additional light on the underlying differences and outcomes. In addition, we note that Table 3.1.4 indicates the relative contribution of each sector within each model and gives some indication of the comparison across models. The within-model contribution is relatively consistent across emission years modeled, and the across-model comparison can be obtained from Table 3.1.1. Some factors limit the ability to present disaggregated results across some dimensions. For example, the three models each have a different geographic scale. The meta-analysis is a global model and cannot be disaggregated by region. DSCIM aggregates nearly 25,000 impact regions produced in a high-performance computing environment to a global scale, so the regional data is not directly available to EPA. Only GIVE produces results at a country level that can be directly accessed. |
| Kling | The welfare gain predicted for the DSCIM energy estimates reported in Table 3.1.4 needs explanation. My suspicion is that this reflects the lower bound nature of an expenditure change relative to the underlying welfare measure being sought to estimate (see Bartik bounds and related work). | Thank you for this comment. The details of the DSCIM energy estimate are in Rode et al (2021). EPA agrees that potential energy savings are a lower bound of the compensating variation for this sector. A reference to Bartik (1988) has been added. |

| | | |
|---|---|---|
| Kling | I encourage EPA to provide physical effects of whatever damage categories they can that are note monetized even if monetization is a ways off. This is consistent with best practices as articulated in EPAs Guidance for Economic Analysis and was recommended by the NASEM report. I also feel that it would add transparency. | We appreciate this suggestion. You are correct that providing the physical effects of the damage categories is consistent with recommendations under EPA's Guidelines for Economic Analyses, and is among the National Academies' longer term recommendations. The focus of updating the SCGHG estimates to date has been on modeling the damage categories that can be monetized. However, we have made efforts to provide projections of physical effects based on the RFF-SPs+FaIR outputs where possible. We provided a figure of global ocean pH and heat (Figure 3.2.2) in the draft report and have added a map and discussion of projections of annual precipitation change (Section 3.2.1). EPA will continue to look for opportunities to include additional projections of physical effects whose associated damages can not yet be monetized in future updates. |
| Oppenheimer | Better for others to handle this. | Thank you. |
| Schlenker | No comment. | Thank you. |
| Wagner | [n/a] | Thank you. |

| **Charge Question 6.a.iv.** ***Do you have longer run recommendations for improved ways to account for risk aversion in future updates?*** | | |
|---|---|---|
| **REVIEWER** | **REVIEWER COMMENT** | **EPA RESPONSE** |
| Cropper | None. | Thank you. |
| Fisher-Vanden | I defer to others on the review panel who are better equipped to comment on this. | Thank you. |
| Forest | The psychological and behavioral sciences will need to be considered to address long-term risks. The mainstream discussions of observed climate changes based on the historical climate records does not fully account for the radiative forcing due to the emissions in the last few decades. | |

| | | |
|---|---|---|
| Forest | The current younger generations will be experiencing the climate change from the accumulated forcing from the past 30-40 years. The assessments of risk aversion should be stratified by age and use tools such as the assessment "Global Warming's Six Americas" from the Yale Program on Climate Change Communication. Other global projects to assess risk aversion through surveys need to be considered on this topic. | Thank you for these suggestions. EPA agrees that these are important considerations and areas needing further study. |
| Kling | No. | Thank you. |
| Oppenheimer | Better for others to handle this. | Thank you. |
| Schlenker | No comment. | Thank you. |
| Wagner | Include Epstein-Zin preferences, potentially as a scenario/model run, much like factoring in equity weights (see 5b above.) Doing so will allow for an explicit exploration of higher—and perhaps more appropriate—risk-aversion parameters than are currently used. | Thank you for this suggestion. EPA will continue to follow the literature on on recursive utility specifications (such as Epstein-Zin preferences) and other alternative formulations. We agree this is an important area for continued research. |

**Charge Question 6.b.i.** ***Given the spatial resolution available in the modeling performed for this update, do you have recommendations for ways to provide a more robust characterization of the distributional impacts of climate change in the draft report?***

| REVIEWER | REVIEWER COMMENT | EPA RESPONSE |
|---|---|---|
| Cropper | The DSCIM authors have made the spatial distribution of climate damages (e.g., for mortality, energy consumption) clear in their published work. I think it is fine to refer to the reader of the TSD to these papers. | Thank you. |
| Fisher-Vanden | The DSCIM damage estimates are done at a very fine spatial scale and would allow for distribution impacts to be captured if integrated into the right socioeconomic model. As I recommend above in section 2a., this provides further support for taking a hybrid approach with the socioeconomic projections since the structural economy-wide models are becoming finer scale (even down to the country level) to allow for these types of distributional effects to be captured. | See response under 2a. |

| | | |
|---|---|---|
| Fisher-Vanden | (**LONG-TERM**): it will be important in future SC-GHG estimates to capture feedbacks, interactions, and intra- and international trade to truly capture the distributional impacts of climate change. There are plenty of studies that have shown the importance of this. | Thank you for this recommendation. EPA agrees that it is important to account for these factors. We have provided an expanded discussion of the importance of feedbacks and interactions in section 3.2 of the final report, and EPA will look for opportunities to incorporate these effects in future updates. |
| Forest | Improvements will need to use existing weather and climate models and identify how resolution is currently limiting the evaluation of extreme events. Emulators of weather extremes are new and valuable tools that are more available in the insurance industry (aka catastrophe models). Precipitation and wind extremes are not resolved at scales that are not in any current regional or global models. The development of these tools in the environmental modelling research area are only now becoming available. | This is useful information. EPA agrees that accurately capturing the impact of extreme events is important but limited by the resolution of current models. We have provided an expanded discussion of omitted categories in section 3.2, including a new subsection discussing precipitation impacts and a map of projected precipitation changes, to the final report. EPA will continue to evaluate advanced models and emulators of precipitation, wind, and other weather extremes and will look for opportunities to incorporate them in future updates. |
| Forest | An additional component is how to extract information for damage functions that are not explicitly modeled. The non-linear models will need multiple inputs (e.g., wind, humidity, air quality, temperature, etc.) that are currently being developed for individual cities. A comprehensive assessment probability functions are not capable to capture the concurrent extremes that would require more than one from the long list of inputs. | |
| Kling | Presenting physical impacts by region as well as monetized impacts might help provide a more thorough understanding of the distributional effects. | See response under 6.a.iii. |

| | | |
|---|---|---|
| Oppenheimer | Given the high spatial resolution of the impact models, it seems a pity that ways could not be found to estimate distributional impacts beyond the mostly descriptive statements in the report. The next generation of SCC assessments should make it a priority to determine which constraints are limiting and develop estimation procedures to overcome these limitations. | Thank you for this comment. For the final report, we have expanded the discussion and presentation of the distribution of impacts from our models to the extent our modeling framework permits. We have also provided a discussion of other modeling efforts that may be used to understand the distribution of climate impacts. In particular, a greater understanding can come from the Framework for Evaluating Damages and Impacts (FrEDI ) and the Fifth National Climate Assessment, both described in the final report. Ultimately, the primary purpose of this report is to document and explain the methodological updates in the SC-GHG estimation. Additional reports and other models may be needed to explore the distribution of consequences fully. However, EPA does recognize that understanding the heterogeneity in the distribution of climate change damages across the globe and within the U.S. is extremely important and will continue to look for opportunities to improve and expand the presentation of distributional effects in future updates. |
| Oppenheimer | Once again, taking an approach that emphasizes plausible upper and lower bounds on distributional consequences could provide useful information for policy makers even before end-to-end high-resolution modeling is available, even if not totally consistent with the aspiration for the sort of quantitative distributions derived in this report. | Thank you for this comment. EPA agrees that understanding the distribution of climate change impacts is important. We have expanded the discussion and presentation of the distribution of impacts from our models to the extent our modeling framework permits. We have also provided a discussion of other modeling efforts that may be used to understand the distributional impacts. Ultimately, the primary purpose of this report is to document and explain the methodological updates in the SC-GHG estimation, which are designed to evaluate the expected value of the SC-GHG as is needed in benefit-cost analysis. Additional reports and other models may be needed to explore the distribution consequences fully. |

| | | |
|---|---|---|
| Schlenker | Several of the critical comments highlighted the cost imposed on local natural gas producers. It is standard practice for studies using the Kaldor-Hicks criterion to weight losses against gains, without actually making transfer payments. However, as Arrow et al (1996) (https://doi.org/10.1126/science.272.5259.221) point out, “Although benefit-cost analysis should focus primarily on the overall relation between benefits and costs, a good analysis will also identify important distributional consequences.” While the overall benefits clearly swamp the cost, does EPA have ideas or recommendations on how the most negatively impacted communities can be helped. | Thank you for this question. The primary purpose of this report is to document and explain the methodological updates in the SC-GHG estimation. General guidance for evaluating the distributional consequences of regulations may be found in EPA's Guidelines for Preparing Economic Analyses. General guidance on addressing the distributional consequences of regulations is outside the scope of this report. |
| Wagner<br><br>Wagner | One key assumption behind the distributional impacts of climate change is the EPA report’s PPP-adjustment of the estimate of a Value of a Statistical Life (VSL). While this application seems appropriate at first glance, it is theoretically and practically inconsistent with a strict interpretation of the Kaldor-Hicks criterion (Bressler and Heal 2022)..<br>Furthermore, doing so departs from OMB’s previous guidance “for treating equally persons of different income levels at a given time, for the purposes of valuation” (National Academy of Sciences 2017, 183). A full reconciliation of theory and practice would be difficult. I would, thus, counsel to treat the PPP-adjusted estimates as one possible scenario and also present a scenario that explicitly includes equity weights, while removing the erroneous “Kaldor-Hicks” justification for using PPP-adjusted VSL estimates.[3]<br>_____ | Thank you for this suggestion. Including a scenario that explicitly includes equity weights in the VSL used to value the modeled mortality risk changes would require the explicit choice of a social welfare function, which would take the analysis beyond the intended purpose of developing SC-GHG estiamtes for use in a standard benefit-cost analysis. As discussed in Appendix A.7, the standard approach in the literature is to use either the market exchange rate or PPP to adjust the GDP value, but it involves a tradeoff between full consistency with the potential compensation test of the Kaldor-Hicks criterion and improved representation of the preferences in the country under consideration. Using the PPP takes into account the different price levels and different baskets of goods consumed across countries, and it more accurately describes relative standards of living across countries. This is completely consistent with the Kaldor-Hicks criterion of comparing the magnitudes of gains and losses using individual's preference, even though there may be some cases where the potential compenstation |

| | | |
|---|---|---|
| | [3]It is important to note here that the newly released draft Circular A-4 explicitly permits equity weights in regulatory analysis (U.S. Office of Management and Budget (OMB) 2023) | test is not met if market exchage rates are used. Using PPP-adjusted estimates is a standard approach in the literature (Hammitt and Robinson 2011, Nordhaus 2017, 2018a, Robinson, et al. 2019a) and is the same approach used in the damage function estimates in GIVE and DSCIM. EPA view this as the best practice for benefit transfer of VSL estimates, but we recognize that this is an approximation. |

**Charge Question 6.b.ii.** ***Do you have recommendations for strengthening the presentation and discussion in the draft report regarding what constitutes damages to U.S. populations in the case of a global pollutant that could have international implications that impact the United States? Is the reporting of damages occurring within U.S. borders based on current modeling capabilities in GIVE and DSCIM described transparently in the draft report? If not, do you have recommendations for how this presentation and discussion could be strengthened?***

| REVIEWER | REVIEWER COMMENT | EPA RESPONSE |
|---|---|---|
| Cropper | In section 1.2, the report does note the NRC arguments for looking at global damages, even if one is interested only in impacts on the US. | Thank you. |
| Fisher-Vanden | (**SHORT-TERM**): Again, reading other documentation was essential to being able to understand this. The report does not provide enough detail. | We appreciate your suggestion for additional detail in this section. We have expanded discussion of the complexities involved in determining what constitutes damages to U.S. population in the case of a global pollutant in Section 1.3, and expanded discussion of available evidence, including from U.S.-specific data and research such as FrEDI, in Section 3.3 of the report. |
| Forest | While it is not my expertise, I support improvements in the estimation approaches that would address how to provide global SC-GHG estimates that could influence economic damages through global mechanisms like supply chains or pandemics. | We agree with your desire to improve estimates of how global mechanisms can include international and regional economic damages. EPA will continue to follow the research on global mechanisms, such as climate-induced supply chain disruptions. |

| | | |
|---|---|---|
| Kling | The explanation provided for using global damages vis-à-vis the effect of not doing so for US citizens is well stated. From the perspective of a worldwide social planner, there is of course another important reason for urging a global number. If each country were to design policy to equate marginal damages with marginal abatement costs using only the damages their pollution inflicts on their own citizens, the world would not achieve the socially optimal level of emissions as many damages would be omitted. | We agree that this is an important reason for considering a global number and the concept was addressed in section 1.3 of the report. We have expanded the discussion to punctuate this point. |
| Oppenheimer<br><br>Oppenheimer | Damages to the US are discussed in several specific contexts, for instance, sectors not included in this report's SCC results because a basis for producing global numbers is lacking. However, no overall comparison of US-only and global values is highlighted – if it's there the reader must search hard to find it. This may have been seen as appropriate following the guidance to derive values of SCC encompassing global damages.<br><br>Nevertheless, US-only numbers would be interesting material for the report to highlight and discuss. | Section 3.3 presents the available evidence on the distribution of climate change impacts. The DSCIM and GIVE damage functions have a spatial resolution that allows for some geographic disaggregation of future climate impacts across the world. Thus, Section 3.3 presents DSCIM and GIVE-based estimates of damages resulting from temperature-related mortality, agriculture, energy expenditures, sea level rise, and (for DSCIM) labor productivity impacts physically occurring within the U.S. We have expanded the discussion about the limitations of these estimates and provide additional evidence from other modeling efforts such as FrEDI to shed further light on some of the omitted damage categories. Unfortunately, as discussed throughout the report, all of these estimates remain incomplete, omit important damage categories, and do not include the impact of global interconnectivity. EPA will continue to review developments in the literature and seek ways to strengthen the presentation and discussion of the various direct and indirect damages to U.S. populations from climate impacts occurring within U.S. borders and abroad. |
| Schlenker | The report is clear in why it uses global numbers. I support the approach taken. In a global public goods setting, the solution to the problem where every country only focuses on their domestic benefits. Cost will be suboptimal. Comment 2281 [Docket ID EPA-HQ-OAR-2021-2281] provides further arguments for why this is appropriate – I am not a legal scholar so defer to those arguments. | Thank you for this comment. EPA has further expanded the discussion of the importance of accounting for global damages in Section 1.3. |

| | | |
|---|---|---|
| Wagner | The EPA report should explicitly discuss the importance of equity weights in calculating the SC-$CO_2$ relative to the current practice of PPP-adjusted VSL figures. | Thank you for this comment. This issue is discussed in Section A.7. |

**Charge Question 6.b.iii.** ***Do you have recommendations for strengthening the presentation and discussion of other topics in the draft report?***

| REVIEWER | REVIEWER COMMENT | EPA RESPONSE |
|---|---|---|
| Cropper | None. | Thank you. |
| Fisher-Vanden | See above. | Thank you. |
| Forest | Not at this time. | Thank you. |
| Kling | No. | Thank you. |
| Oppenheimer | No. | Thank you. |
| Schlenker | I feel it is clearly written and makes adjustments in response to the recommendation by NASEM. The only recommendation I have is the discussion around Table 3.1.4. It would be informative to get further insights for why the analyses are so different for some sectors, especially agriculture, the sector where DSCIM and GIVE diverge the most. | EPA has expanded on the discussion in the report about the differences in outcomes in each sector across different damage modules presented in the report. Specifically, EPA has expanded on Section 3.1, and also added Appendix 8 (Treatment of Uncertainty) that sheds additional light on the underlying differences and outcomes. |
| Wagner | My biggest direct criticism of the writing and presentation of the EPA report concerns its treatment of risks and uncertainties. | |

| | | |
|---|---|---|
| Wagner | While the report itself goes into detail on the generally impressive effort to model climatic and climate-economic risks and uncertainties, Table ES.1 in the Executive Summary, arguably the most important table of the entire document, appears to take a step backwards in presenting these risks and uncertainties. The prior Obama-era effort presented three columns for the SC-$CO_2$: three different discount rates, plus the 95$^{th}$ percentile of the distribution for the 'central' discount rate (U.S. Government Interagency Working Group on Social Cost of Carbon 2015). While most readers of the report still zeroed in on the 'central' ~$50 value, the table clearly showed the importance of considering the tail of the SC-$CO_2$ distribution.<br><br>The current presentation in the Executive Summary and in Table ES.1 appropriately rounds the numbers to avoid false precision, but it does not present the potentially long right tail of the SC-$CO_2$. Figure 3.1.1 does so on page 69 of the draft. Finding a way to represent this range in the Executive Summary is crucial, and it might well be best accomplished by putting the same figure in the ES.<br><br>Doing so might involve modifying Figure 3.1.1 to represent the full distribution of possible values, akin to Figure 2 in Rennert et al (2022): | We agree that representing the risk and uncertainty in the report is important for understanding the approach to estimating the SC-GHG. We have made efforts to convey more info about the distribution of the SC-GHG in the Executive Summary. However, with the explicit incorporation of risk aversion into the SC-GHG estimates one can no longer interpret the set of Monte Carlo results as an estimate of formal distribution. This presents challenges for replicating the presentation in prior IWG documents. |

**Charge Question 6.c.** ***Do you have longer term recommendations, in addition to any discussed in the subparts above, for potential methodological improvements that warrant consideration in future updates of the SC-GHG estimates (e.g., estimation approaches for improved accounting of interactions and feedback effects within and between modules, valuation of climate change impacts (e.g., estimating willingness-to-pay for mortality risk changes), characterization of climate damages to U.S. populations and various subpopulations (e.g., environmental justice communities))?***

| REVIEWER | REVIEWER COMMENT | EPA RESPONSE |
|---|---|---|
| Cropper | No further comments. This is an excellent report. | Thank you. |

| | | |
|---|---|---|
| Fisher-Vanden | (**LONG-TERM**): The point was raised in the second meeting (and in the report) that it is important to capture global impacts since there are spillovers (and not to take a partial "only damages to the US" approach when generating the SC-GHG estimates). I agree but wonder how this would be captured without the explicit modeling of trade, as discussed above in my comments. | Thank you for the comment. EPA agrees that capturing global trade is important in estimating the SC-GHG. In places where the scientific literature provided climate change damage functions that included estimates of welfare damages with trade, we have incorporated these studies into the estimates. For example, the damges in the GIVE agricultural sector (Moore et al. 2017) are the total welfare changes after allowing for trade adjustments (Global Trade Analysis Project) from shocks to agricultural production from climate change. However, EPA has expanded and clarified the discussion of modeling limitations, especially in Section 3.2 "Omitted Damaged and Other Modeling Limitations." These revisions specifically address feedbacks and interactions. Intra- and international trade are discussed in several sections of the report, and Table 3.2.1 specifically highlights aspects of trade omitted from this analysis. Additional discussion in Section 3.3 describes how some trade, as represented in the DSCIM and GIVE agricultural damage specifications, can mitigate damages. EPA agrees that feedbacks, interactions, and global trade are an important area of further research. EPA will continue to review developments in the literature and look for opportunities to further improve SC-GHG estimation going forward. |
| Forest | My co-evaluators emphasized that the current SC-GHGs is only a partial estimate. By recognizing this, we must put more effort to understand the global response to climate change damages that will be influencing all regions of the world (populated or not). We need to develop additional metrics to account for the non-US impacts and damages. From the climate science side, this will require improving the impacts and damage estimates for all parts of the world and would require specific IPCC research agendas to develop and account for the full global estimates of Social Costs of Greenhouse Gases among all countries. | EPA agrees that measuring impacts and damages for all parts of the world is important. We have expanded the discussion of omitted impacts and spillovers in Sections 3.2, 3.3, and elsewhere in the report. EPA will continue to look for opportunities to expand accounting of impacts and associated damages in future estimates. |
| Kling | No. | Thank you. |
| Oppenheimer | See subparts. | Thank you. |

| | | |
|---|---|---|
| Schlenker | Let me restate some of the longer-term issues that are outstanding, some of which I discussed before:<br>1) Include additional sectors (including migration), as well as correlation between sectoral damage estimates | Thank you for these suggestions. We agree and have expanded the discussion in section 3.2 to emphasize the importance of these and other omitted impacts and associated damages. EPA will continue to follow the literature and look for opportunities to include additional sectors, evaluate extreme weather events, account for feedbacks between modules, and improve the representation of innovation and adaptation in future updates. |
| Schlenker | 2) Several studies suggest that extreme temperatures and precipitation events case especially large damages, so incorporate climate extremes and how they evolve. | |
| Schlenker | 3) Include feedbacks between damage module and socio-economic module, model price effects. | |
| Schlenker | 4) Innovation and adaptation potential – do we correctly capture what will be available going forward. It is an active research area, and I would encourage EPA to incorporate new findings as they become available. | |
| Wagner | My largest long-term comment concerns the treatments of risk aversion and equity weights, reflected in (6a) and (6b) above, respectively. The EPA report appropriately strives to base the SC-$CO_2$ in the long-standing application of the Kaldor-Hicks potential compensation criterion. Equity weights within and across countries might lead to a more direct and, thus, appropriate consideration of differing impacts of climate change. | Thank you for these comments. EPA believes it is important for policy makers to have information available about economic efficiency impacts, distributional implications, and Environmental Justice implications of potential regulatory actions, as appropriate and feasible. While developing information on those three topics can often share underlying analytic methods and data, they are different pieces of information and are best addressed separately to provide transparency. The valuation methods used in this report are consistent with the approach used in the default version of the damage functions and published studies used in the report, other academic literature, advice given to the IWG by experts, and other prominent domestic and international guidance documents that speak to international risk reduction valuation. |
| Wagner | Appropriately applying equity weights, in turn, could be based on one of two methods: calibrating basted on observed behavior of how averse to inequality society is, or based on ethical views of how adverse to inequality society should be (Wagner et al. 2021). Picking the 'correct' equity weights, thus, mirrors the process of picking the correct discount rates, and doing so will be no less important to the resulting SC-$CO_2$. Something similar goes for risk aversion. | |

| **III. Specific Observations** | | |
|---|---|---|
| **Reviewer** | **Comment or Question (Page)** | **EPA RESPONSE** |
| Cropper | No comments. | Thank you. |

| | | |
|---|---|---|
| Fisher-Vanden | No comments. | Thank you. |
| Forest | No comments. | Thank you. |
| Kling | the “fourth” value should be “third” (Page 5) | We were only able to find one "fourth" on p. 5 and it is in a sentence describing the IWG SC-GHG estimate based on the 95th percentile of the 3% d.r. results, which is supposed to be fourth. |
| Kling | clarify that the report uses “income” as equivalent to “GDP” (Page 18) | We have added a footnote to note that: This report uses gross income and gross production interchangeably. Gross national income (GNI) is gross domestic production (GDP) plus net receipts abroad. For most countries GNI and GDP are similar. |
| Oppenheimer | No comments. | Thank you. |
| Schlenker | I think comparison across the three models would be easier if each of the three plots use the same 0-20% scale for the y-axis. (Page 51) | We have revised Figure 2.3.2 so that all panels use the same y-axis scale. |
| Wagner | Aldy, Joseph E., Matthew J. Kotchen, Robert N. Stavins, and James H. Stock. 2021. “Keep Climate Policy Focused on the Social Cost of Carbon.” *Science* 373 (6557): 850–52.<br><br>Anthoff, David, and Johannes Emmerling. 2018. “Inequality and the Social Cost of Carbon.” *Journal of the Association of Environmental and Resource Economists* 6 (2): 243–73. https://doi.org/10.1086/701900.<br><br>Arkolakis, Costas, and Conor Walsh. 2023. “Clean Growth.” Columbia Business School working paper.<br><br>Barrage, Lint, and William D. Nordhaus. 2023. “Policies, Projections, and the Social Cost of Carbon: Results from the DICE-2023 Model.” Working Paper. Working Paper Series. National Bureau of Economic Research. https://doi.org/10.3386/w31112.<br><br>Bauer, Adam Michael, Cristian Proistosescu, and Gernot Wagner. 2023. “Carbon Dioxide as a Risky Asset.” Working Paper 10278. CESifo. https://gwagner.com/cap6/. | |

Bressler, R. Daniel, and Geoffrey Heal. 2022. “Valuing Excess Deaths Caused by Climate Change.” Working Paper 30648. National Bureau of Economic Research.

Carleton, Tamma, and Michael Greenstone. 2021. “Updating the United States Government’s Social Cost of Carbon.” Working Paper No. 2021-04. University of Chicago, Becker Friedman Institute for Economics.

Christensen, P., K. Gillingham, and W. Nordhaus. 2018. “Uncertainty in Forecasts of Long-Run Economic Growth.” *Proceedings of the National Academy of Sciences* 115 (21): 5409–14. https://doi.org/10.1073/pnas.1713628115.

Council of Economic Advisors. 2017. “Discounting for Public Policy: Theory and Recent Evidence on the Merits of Updating the Discount Rate.” Washington, DC. https://obamawhitehouse.archives.gov/sites/default/files/page/files/201701_cea_discounting_issue_brief.pdf.

Daniel, Kent D., Robert B. Litterman, and Gernot Wagner. 2018. “Applying Asset Pricing Theory to Calibrate the Price of Climate Risk.” Working Paper 22795. National Bureau of Economic Research. https://doi.org/10.3386/w22795.

———. 2019. “Declining CO2 Price Paths.” *Proceedings of the National Academy of Sciences* , October, 201817444. https://doi.org/10.1073/pnas.1817444116.

Diaz, Delavane B. 2016. “Estimating Global Damages from Sea Level Rise with the Coastal Impact and Adaptation Model (CIAM).” *Climatic Change* 137 (1): 143–56. https://doi.org/10.1007/s10584-016-1675-4.

Dietz, Simon, Christian Gollier, and Louise Kessler. 2018. “The Climate Beta.” *Journal of Environmental Economics and Management* 87: 258–74.

Dietz, Simon, James Rising, Thomas Stoerk, and Gernot Wagner. 2021. “Economic Impacts of Tipping Points in the Climate System.” *PNAS* 118 (34): e2103081118. https://doi.org/10.1073/pnas.2103081118.

Drupp, Moritz A., Mark C. Freeman, Ben Groom, and Frikk Nesje. 2018. “Discounting Disentangled.” *American Economic Journal: Economic Policy* 10 (4): 109–34. https://doi.org/10.1257/pol.20160240.

Epstein, Larry G., and Stanley E. Zin. 1989. “Substitution, Risk Aversion, and the Temporal Behavior of Consumption and Asset Returns: A Theoretical Framework.” *Econometrica* 57 (4): 937–69. https://doi.org/10.2307/1913778.
———. 1991. “Substitution, Risk Aversion, and the Temporal Behavior of Consumption and Asset Returns: An Empirical Analysis.” *Journal of Political Economy* 99 (2): 263–86.

Gillingham, Kenneth, and James H. Stock. 2018. “The Cost of Reducing Greenhouse Gas Emissions.” *Journal of Economic Perspectives* 32 (4): 53–72. https://doi.org/10.1257/jep.32.4.53.

Greenstone, Michael, and James H. Stock. 2021. “The Right Discount Rate for Regulatory Costs and Benefits.” *Wall Street Journal* , March 4, 2021, sec. Life. https://www.wsj.com/articles/the-right-discount-rate-for-regulatory-costs-and-benefits-11614870636.

Howard, Peter H., and Thomas Sterner. 2017. “Few and Not So Far Between: A Meta-Analysis of Climate Damage Estimates.” *Environmental and Resource Economics* 68 (1): 197–225. https://doi.org/10.1007/s10640-017-0166-z.

IPCC. 2022. “IPCC Sixth Assesment Report, Summary for Policy Makers: Climate Change 2022 Mitigation of Climate Change.” Assessment Report. Intergovernmental Panel on Climate Change. https://report.ipcc.ch/ar6wg3/pdf/IPCC_AR6_WGIII_FinalDraft_FullReport.pdf.

Lemoine, Derek. 2021. “The Climate Risk Premium: How Uncertainty Affects the Social Cost of Carbon.” *Journal of the Association of Environmental and Resource Economists* 8 (1): 27–57.

Lemoine, Derek, and Ivan Rudik. 2017. “Managing Climate Change Under Uncertainty: Recursive Integrated Assessment at an Inflection Point.” *Annual Review of Resource Economics* 9 (1): 117–42. https://doi.org/10.1146/annurev-resource-100516-053516.

Moore, Frances C., and Delavane B. Diaz. 2015. “Temperature Impacts on Economic Growth Warrant Stringent Mitigation Policy.” *Nature Climate Change* 5 (2): 127–31. https://doi.org/10.1038/nclimate2481.

Moore, Frances C., James Rising, Simon Dietz, Moritz Drupp, Ivan Rudik, and Gernot Wagner. 2023. “Structural Modelling Changes Drive the Social Cost of Carbon.” Presented at the CESifo Area Conference on Energy and Climate Economics, Munich, March 10.

National Academy of Sciences. 2017. *Valuing Climate Damages: Updating Estimation of the Social Cost of Carbon Dioxide* . https://www.nap.edu/catalog/24651/valuing-climate-damages-updating-estimation-of-the-social-cost-of.

Newell, Richard G., William A. Pizer, and Brian C. Prest. 2022. "A Discounting Rule for the Social Cost of Carbon." *Journal of the Association of Environmental and Resource Economists* 9 (5): 1017–46.

Proistosescu, Cristian, and Gernot Wagner. 2020. "Uncertainties in Climate and Weather Extremes Increase the Cost of Carbon." *One Earth* 2 (6): 515–17. https://doi.org/10.1016/j.oneear.2020.06.002.

Rennert, Kevin, Frank Errickson, Brian C. Prest, Lisa Rennels, Richard G. Newell, William Pizer, Cora Kingdon, et al. 2022. "Comprehensive Evidence Implies a Higher Social Cost of CO2." *Nature* , September. https://doi.org/10.1038/s41586-022-05224-9.

Sherwood, S. C., M. J. Webb, J. D. Annan, K. C. Armour, P. M. Forster, J. C. Hargreaves, G. Hegerl, et al. 2020. "An Assessment of Earth's Climate Sensitivity Using Multiple Lines of Evidence." *Reviews of Geophysics* 58 (4): e2019RG000678. https://doi.org/10.1029/2019RG000678.

Stern, Nicholas, and Joseph E. Stiglitz. 2021. "The Social Cost of Carbon, Risk, Distribution, Market Failures: An Alternative Approach." Working Paper 28472. National Bureau of Economic Research.

U.S. Government Interagency Working Group on Social Cost of Carbon. 2015. “Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866.”

https://obamawhitehouse.archives.gov/sites/default/files/omb/inforeg/scc-tsd-final-july-2015.pdf.

U.S. Office of Management and Budget (OMB). 2023. “Circular A-4.” https://www.whitehouse.gov/wp-content/uploads/2023/04/DraftCircularA-4.pdf.

Wagner, Gernot. 2021. “Recalculate the Social Cost of Carbon.” *Nature Climate Change* 11 (4):293–94. https://doi.org/10.1038/s41558-021-01018-5.

Wagner, Gernot, David Anthoff, Maureen Cropper, Simon Dietz, Kenneth T. Gillingham, Ben Groom, J. Paul Kelleher, Frances C. Moore, and James H. Stock. 2021. “Eight Priorities for Calculating the Social Cost of Carbon.” *Nature* 590 (7847): 548–50. https://doi.org/10.1038/d41586-021-00441-0.

Wagner, Gernot, and Julio Friedmann. 2023. “3 Ways America Can Spend Biden’s Clean-Energy Windfall Faster.” *Washington Post* , March 13, 2023, sec. Opinions. https://wapo.st/3Td2A63.

Weil, Philippe. 1990. “Nonexpected Utility in Macroeconomics.” *The Quarterly Journal of Economics* 105 (1): 29–42. https://doi.org/10.2307/2937817.