February 13, 2023

Subject: Public comments on U.S. EPA proposed oil and gas methane rule and draft new SC-GHG estimation methodology (Docket ID No. EPA–HQ–OAR–2021–0317)

Dear Administrator Regan,

Thank you for the opportunity to comment on the proposed oil and gas methane rule Standards of Performance for New, Reconstructed, and Modified Sources and Emissions Guidelines for Existing Sources: Oil and Natural Gas Sector Climate Review and its use of social cost of greenhouse gas estimates (SC-GHGs) and EPA's draft new SC-GHG estimation methodology that was first released to the public along with this proposed rule on November 11, 2022.

EPRI is a nonprofit, scientific research organization with a public benefit mission. EPRI strives to advance knowledge and facilitate informed public discussion and decision-making. In addition to extensive research and expertise related to the social cost of carbon and other greenhouse gases, EPRI has a long history of research community leadership and participation in the Intergovernmental Panel on Climate Change (IPCC), U.S. National Climate Assessment, EPA's Science Advisory Board, and National Academy of Science, Engineering, and Medicine (NASEM).

As an independent and objective science organization, EPRI appreciates the importance of facilitating the development of grounded SC-GHG estimates and applications and engaging the public through comment opportunities such as this to help do so. Our comments reflect our review of the draft new SC-GHG methodology and documentation and the application of SC-GHG estimates in the proposed rule in light of the NASEM Social Cost of Carbon Committee recommendations (NASEM, 2016, 2017), technical challenges EPRI had previously identified (EPRI, 2021a), and the overall body of scientific knowledge.

EPRI has been engaged in SC-GHG research for almost two decades and has over forty years of related research experience in the core sciences underlying SC-GHG calculations, including integrated assessment modeling, socioeconomic projections and decarbonization transitions, climate modeling and scenarios, impacts and damages modeling, economics, and climate policy. EPRI's SC-GHG research includes analyzing in detail the models and assumptions used for SC-GHG estimation, as well as detailed assessment of applications using SC-GHG estimates. See the appendix for examples of EPRI's SC-GHG related research, including EPRI's 2021 publication discussing key technical challenges that need to be addressed by any new SC-GHG estimation approach (EPRI, 2021a).

EPRI's expertise and research led to Dr. Steven Rose's participation on the NASEM Social Cost of Carbon Committee as a committee member. EPRI's assessment of the IWG SC-GHG estimation framework used by this and previous administrations (Rose et al, 2017, 2014) was a primary input into the NASEM SCC Committee deliberations and the resulting NASEM studies and their recommendations (NASEM, 2016, 2017). These are the same NASEM studies referenced in the President's January 2021 Executive Order 13990 (Executive Order on Protecting Public Health and the Environment and Restoring Science to Tackle the Climate Crisis) as important methodological resources the interagency working group (IWG) and individual agencies should consider when developing an updated SC-GHG methodology.

EPRI has previously provided public comments on the importance of prioritizing science and developing scientifically reliable SC-GHG estimates before use, as well as identifying key challenges to address in developing a new methodology and estimates (EPRI, 2021a, 2021b); and, most recently, EPRI provided comments on EPA's proposed SC-GHG draft new methodology peer review process and candidates (EPRI, 2022). EPRI also recently published an article discussing the importance of a sound scientific process for producing scientifically reliable SC-GHG estimates, and what that would entail, in order to strengthen public confidence in the estimates and the decisions they inform (Rose, 2022).

After thoroughly reviewing EPA's draft new methodology, we find that the methodology and estimates are not yet scientifically reliable and robust for policy use. The methodology contains multiple significant technical issues and does not satisfy the NASEM recommendations. This should be addressed before the estimates are deployed to inform policy, for this rule and otherwise. The following are key technical issues essential to address:

- **Increase transparency, justification, scientific basis, and incorporation of uncertainty to allow full assessment,**
- **Revise to address inconsistencies within and across modules,**
- **Add missing elements, and further support existing elements, within modules,**
- **Revise to address implausible socioeconomic, emissions, and climate futures,**
- **Revise climate damage calculations to consider incomparability between methodologies and additional available estimates, and**
- **Revise discounting parameter calibrations to be consistent with the full set of relevant theoretical, observational, empirical, and consistency considerations, which would include revising the near-term target rates to 3-5%, the growth rate assumption to higher than implied, and discounting regionally.**

Overall, based on these observations, EPRI recommends the following in order to produce scientifically reliable SC-GHG estimates and policy insights from using the estimates: an improved process, enhanced documentation, a revised methodology, and improved application of SC-GHGs.

Below is a summary of specific recommendations regarding the draft new SC-GHG methodology and documentation, as well as SC-GHG application in the proposed rule. Further below that we discuss each overall and module-specific/cross-module recommendation and our technical observations that underpin the recommendation, as well as insights that inform how to move forward. Thank you again for the opportunity to provide input on this important topic. If you would like to follow-up on our comments to discuss any of the issues and recommendations, please reach out to Steven Rose (srose@epri.com) and David Young (dyoung@epri.com).

Overall recommendations

1. After completing revisions to the draft SC-GHG methodology and documentation as recommended below, provide a separate dedicated public comment opportunity for the revised draft methodology, and a peer review appropriate for a regulatory methodology with significant implications, to ensure the scientific due diligence required to give the public and scientific community confidence in the results and decisions they inform.

2. Revise the draft new SC-GHG methodology documentation to facilitate a comprehensive and thorough assessment of the methodology by first reorientating the documentation to focus on

establishing and communicating the methodology's scientific reliability and robustness; and, second, including significantly more methodological details, intermediate and final results, and assessment, comparison, and justification of methodical choices and results.

3. Based on the documentation available, we recommend the following revisions to the methodology to ensure scientifically reliable and robust estimates:
    a. Revise the methodology to fully satisfy the NASEM recommendations,
    b. Address technical challenges identified by EPRI,
    c. Develop the methodology needed and not constrain consideration to what is available in the peer reviewed literature that was developed and evaluated based on different incentives and criteria,
    d. More fully incorporate current scientific knowledge to account for reasonable alternatives, reconcile lines of evidence, and improve uncertainty representation, and
    e. Revise each module to address observed technical issues (see module-specific recommendations below).

4. Provide additional and more detailed guidance for using SC-GHG estimates to ensure scientifically reliable policy insights, including discussing appropriate use, incorporating SC-GHG uncertainty, and addressing inconsistencies, GHG leakage, and pricing GHGs more than one.

5. In order to provide scientifically reliable benefit-cost insights for the proposed methane rule, revise the benefit-cost calculations to address SC-GHG application technical issues.

Module-specific and cross-module recommendations

6. For the socioeconomic and emissions projections module, we recommend:
    a. Revising to fully address NASEM recommendations,
    b. Revising the socioeconomic and emissions projections for coherency, consistency, and to account for important structural details,
    c. Removing implausible socioeconomic and emissions projections,
    d. Revisiting post-2100 projection assumptions for coherency and consistency with historical behavior,
    e. Providing transparency and justification on linkages to other modules, in particular climate damages and discounting, and
    f. Providing needed additional methodological details and results to facilitate a full assessment.

7. For the climate module, we recommend:
    a. Revising to fully address NASEM recommendations, including undertaking NASEM performance tests,
    b. Expanding evaluation and comparison to justify the approach and better account for uncertainty,
    c. Endogenizing non-GHG radiative forcing to address the current fixed forcing assumption's inconsistency with the broad range of projected futures and to capture non-GHG forcing uncertainty in temperature projections, and

    d. Providing needed additional methodological details and results to facilitate a full assessment.

8. For the climate damages module, we recommend:
    a. Revising to fully address NASEM recommendations,
    b. Assessing the literature used and addressing the methodology comparability issue identified by the NASEM and IPCC,
    c. Considering the fuller literature to more accurately estimate damages and account for uncertainty, and
    d. Providing needed additional methodological details and results to facilitate a full assessment.

9. For the discounting module, we recommend:
    a. Revising to fully address NASEM recommendations,
    b. Revising dynamic discounting approach calibration choices to take into account the full set of relevant considerations, which would include revising the near-term target rates to 3-5%, the growth rate assumption to higher than implied, and discounting regionally,
    c. Removing the feature netting out damages from economic growth to ensure discounting consistency with projected growth,
    d. Revisiting the fixed savings rate assumption for consistency with economic growth and historical evidence, and
    e. Providing needed additional methodological details and justification to facilitate a full assessment.

10. For the SC-GHG estimates results in the documentation, we recommend providing more detailed SC-GHG results, discussion, assessment, and justification to allow for full assessment.

11. For cross-module linkages, we recommend providing transparency, including equations, parameters, and examples regarding module linkages and integration, and including discussion of consistency and uncertainty.

12. For the GHG emissions pulses, we recommended revisiting the large GHG emissions pulse size used (1 GtC for SC-CO_2 calculations) and discussing and assessing non-linearity and justifying choices.

EPRI detailed comments on EPA's draft new SC-GHG methodology and application of estimates

EPRI's overall recommendations

1. **After completing revisions to the draft SC-GHG methodology and documentation as recommended below, provide a separate dedicated public comment opportunity for the revised draft methodology, and a peer review appropriate for a regulatory methodology with significant implications, to ensure the scientific due diligence required to give the public and scientific community confidence in the results and decisions they inform.**

EPRI, in its December 2022 public comments (EPRI, 2022), noted that the overall scientific process and proposed peer review should be enhanced to develop scientifically robust and reliable estimates and for the public to have confidence in the outcome. Establishing the scientific reliability and robustness of the estimates is important to build public and scientific community confidence in the estimates and decisions they inform. The process, documentation, methodology, and peer review all should be enhanced with this goal in mind.

Specifically, the overall scientific process for developing, documenting, reviewing, and using SC-GHG estimates should be guided by good scientific process to ensure a scientifically robust and reliable methodology, estimates, and use of estimates. This includes the following:

- Assessing the available science,
- Providing full methodological transparency,
- Justifying methodological choices,
- Developing the methodology needed and not limiting consideration to what others have done,
- Avoiding incorporating policy preferences or ambitions into calculations (e.g., in discounting) to ensure that estimates inform decisions and will be stable across administrations,
- Establishing the robustness of estimates to alternative assumptions
- Using the estimates appropriately conceptually and mechanically,
- Successfully completing an appropriate scientific review, and
- Engaging the public adequately.

See Rose (2022) for discussion of each of these elements of scientific due diligence. We see opportunities for improving the scientific process, the methodology documentation, the peer review, scientific community and public assessment and engagement, and ultimately public and scientific confidence in the estimates and the decisions they inform. The improvement opportunities include providing significantly more methodology and choice details and justification, intermediate results and justification, additional consideration of alternatives and uncertainties, and an appropriate peer review.

A separate dedicated public comment opportunity on the draft SC-GHG methodology

Providing an explicit dedicated opportunity for public input on the draft new methodology may increase public confidence in the outcome. Taking comments on the draft methodology within a proposed rule with comments received on many things outside the SC-GHGs, is likely to provide inadequate public dialogue on a very important topic. This is a challenging topic with a demanding global and multi-century geographic and temporal scope. Furthermore, its relevance extends well beyond the proposed rule.

In general, **EPRI recommends establishing a clear public engagement process and opportunities to comment in all phases,** including opportunities for public input into the peer review process, and a clearly defined relationship between the public input and the peer review process. Currently, it is unclear how the public can engage and how their input will be used.

A peer review appropriate for a regulatory methodology with significant implications

As discussed in our public comments (EPRI, 2022), the planned peer review should be enhanced to provide the public with confidence in the outcome. As a result, **EPRI recommends that EPA develop a scientific review process appropriate for a regulatory methodology**. See EPRI (2022) in Appendix B for details. Briefly this entails:

- Explicitly requesting peer review of the scientific reliability and robustness of the methodology and estimates,
- Reviewing every detail, choice, and justification, as well as intermediate internal calculations and final estimates,
- Selecting an appropriate peer review panel to carry out the peer review,
- Requiring consensus recommendations from the review panel, including a consensus decision on whether the methodology and estimates are robust and reliable,
- Avoiding use of the new estimates until the peer review panel has established the methodology's scientific reliability, which may require methodology revisions and re-review iterations, and
- A review that follows EPA's peer review guidance (USEPA, 2015).

An appropriate peer review panel

Selecting an appropriate peer review panel is essential. EPRI (2022) **recommends revising the peer review candidate selection process and list to ensure full and objective coverage of the core scientific disciplines underpinning the SC-GHG.** See EPRI (2022) in Appendix B for details. Revising the peer review candidates includes:

- Revising the panel selection criteria for the needed core science expertise and avoiding conflicts of interest and scientific biases,
- Assembling the panel needed in terms of expertise and size, with at least 14 panelists required—two experts for each of the relevant core scientific disciplines (and sub-disciplines related to unique methodologies and areas of science), and
- Providing a transparent process with public input regarding the panel criteria and selection.

2. Revise the draft new SC-GHG methodology documentation to facilitate a comprehensive and thorough assessment of the methodology by first reorientating the documentation to focus on establishing and communicating the methodology's scientific reliability and robustness; and, second, including significantly more methodological details, intermediate and final results, and assessment, comparison, and justification of methodical choices and results.

EPA's documentation for the methodology should be enhanced for a full assessment. We are not able to fully evaluate the methodology based on the current documentation. EPRI recommends that EPA revise the documentation and reissue it for public and scientific review and feedback.

The documentation should be self-contained and provide all the details and results necessary for the public, scientific community, and peer review panel to fully understand and comprehensively evaluate the methodology. This includes assumptions, input data, equations, parameter values, uncertainty specifications from the literature used, and sources, as well as additional intermediate and final results. In addition to additional methodological details and results, the documentation should be improved with additional comparison and assessment of module methodological choices and results, and justification of those choices and results, as well as evaluation and communication of the robustness of results.

The current documentation is primarily descriptive and additional content is needed. Specifically, details on the actual modeling specifics are needed, as well as justification for the methodological choices and the results coming out of the methodology. The documentation should include and have assessed all the methodological details. Some of these details currently only appear in the literature EPA cites or, in many cases, is not available in the cited literature and will need to be assembled by EPA working with the authors of that literature. The methodology details need to be fully communicated in a single document and assessed by EPA and the public and scientific community. Note that, the methodology details need much more scrutiny than provided by journal peer review. For instance, Rennert et al (2022), which is the source for most of EPA's draft new methodology (Table 1) provide important details that need to appear in the EPA methodology for comprehensive transparency and evaluation; however, that study does not provide justification for most of the methodological elements, nor do they provide all the methodological details required by EPA. These additional details would therefore need to be assembled and added by EPA. Similarly, the methodological details from the DCSIM and Howard and Sterner (2017) damage modules EPA uses in the draft methodology should be added to EPA's documentation and assessed by EPA, the public, and the peer review. This level of documentation is what NASEM (2017) meant with its recommendation calling for transparency, scientific basis, and representation of uncertainty (Recommendation 2-2 in NASEM (2017)). In addition to recommending improving the documentation overall to enable complete assessment, below we offer module-specific recommendations for additional needed information.

Table 1. Primary literature used for each of EPA's draft new methodology modules. Source: EPRI.

EPA computation module	Source information
Socioeconomics & emissions projections	Rennert et al (2022)
Climate modeling	Rennert et al (2022)
Climate damages estimation	• DSCIM (Climate Impact Lab, 2022) • GIVE (Rennert et al, 2022) • Howard and Sterner (2017) meta analysis
Discounting future damages	Rennert et al (2022)

3. **Based on the documentation available, we recommend the following revisions to the methodology to ensure scientifically reliable and robust estimates:**

    a. **Revise the methodology to fully satisfy the NASEM recommendations,**
    b. **Address technical challenges identified by EPRI,**
    c. **Develop the methodology needed and not constrain consideration to what is available in the peer reviewed literature that was developed and evaluated based on different incentives and criteria,**
    d. **More fully incorporate current scientific knowledge to account for reasonable alternatives, reconcile lines of evidence, and improve uncertainty representation, and**
    e. **Revise each module to address observed technical issues (see module-specific recommendations below).**

Revise the methodology to fully satisfy the NASEM recommendations

EPA's draft methodology is only partly satisfying the NASEM (2016) and NASEM (2017) recommendations. As noted in EPRI's previous comments regarding the interim SC-GHG methodology (EPRI, 2021b), any revised methodology needs to fully meet **all** of the near-term NASEM (2017) high-level and module specific recommendations. This is because the NASEM committee, in its Phase 1 report (NASEM, 2016), specifically recommended against a partial revision to the methodology used by the previous two administrations, and as the interim approach by this administration, noting that there were many technical issues with the interim approach and that the entire methodology needed to be revised.[1]

In NASEM (2017), the SCC Committee provided high-level and module specific evaluation criteria, recommended specific information that should be provided, and provided explanatory discussion for each recommendation to help the reader interpret and implement the recommendation. See NASEM (2017) for the specific recommendations and discussions. For instance, the NASEM (2017), in NASEM Recommendation 2-2, recommended that future methodologies needed the following:

- **Scientific basis:** Modules, their components, their interactions, and their implementation should be consistent with the state of scientific knowledge as reflected in the body of current, peer-reviewed literature.
- **Uncertainty characterization:** Key uncertainties and sensitivities, including functional form, parameter assumptions, and data inputs, should be adequately identified and represented in each module. Uncertainties that cannot be or have not been quantified should be identified.

[1] The NASEM (2016) Phase 1 recommendation regarding whether to update the equilibrium climate sensitivity distribution should not be interpreted as validation of the framework used by the previous two administrations and as the interim framework by this administration, but instead recognition that a more significant revision is required. Overall, the NASEM SCC Committee was not tasked with peer reviewing the suitability of the SC-GHG framework, nor have the methodology and estimates ever been subjected to a formal scientific review process. The NASEM SCC Committee was asked to "examine potential approaches, along with their relative merits and challenges, for a more comprehensive update to the SCC estimates." In Phase 1 explicitly, the NASEM SCC Committee was simply asked to consider whether the IWG should update one assumption in the IWG Framework—the equilibrium climate sensitivity distribution. The Committee's Phase 1 recommendation on this issue was to not revise only the one assumption because there was much more that needed to be re-considered (NASEM, 2016).

- **Transparency:** Documentation and presentation of results should be adequate for the scientific community to understand and assess the modules. Documentation should explain and justify design choices, including such features as model structure, functional form, parameter assumptions, and data inputs, as well as how multiple lines of evidence are combined. The extent to which features are evidence based or judgment-based should be explicit. Model code should be available for review, use, and modification by researchers.

The current documentation and methodology need to be improved with respect to all three of these high-level NASEM recommended requirements—overall and with respect to the individual modules. The documentation should more fully consider current scientific knowledge, better represent uncertainty, and provide significantly more information (methodological details and intermediate and final results) for transparency and full understanding and assessment. In addition, the current methodology should fully satisfy NASEM (2017) individual module recommendations, such as providing sectoral, regional, and future policy details (Socioeconomics and Emissions Module Recommendations 3-1 and 3-2), generating spatially disaggregated climate information and evaluating model performance with respect to specific experiments (Climate Module Recommendations 4-1, 4-2, and 4-5), and transparently and quantitatively characterizing damage function calibrations and presenting disaggregated total and incremental damage projections over time (Damages Module Recommendation 5-1).

Note that, the NASEM "near-term" timeframe was three years. With over five years having passed since the NASEM (2017) report, the scientific basis has evolved, and some of the NASEM (2017) longer-term recommendations are also possible to implement. Also, EPA is now in a position to improve upon the attempts of others to implement the NASEM near-term recommendations (e.g., Rennert et al., 2022).

In addition to fully addressing the NASEM (2017) methodological recommendations, EPA should satisfy the NASEM (2016) recommendation regarding facilitating and encouraging policy analysis consideration of SC-GHG estimate uncertainty (see SC-GHG application discussion below).

Address technical challenges identified by EPRI (2021)

EPA's draft methodology should also more fully address the technical challenges identified by EPRI (2021a) and communicated through public comment (EPRI, 2021b). These include the following challenges by module and for SC-GHG application:

- *Socioeconomics and emissions projections*: representing uncertainty (especially in socioeconomic structure that has implications for emissions and damage vulnerability), accounting for the plausibility of projected futures, and considering the likelihood of futures.
- *Climate modeling*: evaluating modeling alternatives, capturing climate and earth system dynamics uncertainty.
- *Climate damages*: understanding, assessing, reconciling differences in methods and biases (comparability issue noted by NASEM, 2017 and evaluated and confirmed by IPCC WGII, 2022), data sufficiency for identifying the shape of damage functions, representing uncertainty (including dealing with model specification sensitivity and estimated errors), accounting for adaptation potential (micro and macro), aggregating damages across types and regions, the robustness of results, and transparency (e.g., calibration, sources).
- *Discounting*: considering and discussing the full set of the technical factors relevant to potential discounting specifications (e.g., type of investment, type of economic values estimated,

comparison to other costs and benefits, consistency across policy decisions within and across agencies, consistency with economic growth assumptions over time, scenario, and region).

- *Improving the use of SC-GHG estimates*: addressing fundamental technical issues in SC-GHG applications that affect the scientific reliability of GHG reduction benefit and net benefit calculations and conclusions.

The draft methodology should more fully address these challenges. Throughout our comments these opportunities are noted and discussed.

Revise and extend the methodology to provide needed scientific reliability

EPRI recommends EPA revise the methodology to provide the needed scientific reliability. EPA has chosen to constrain its module choices to what others have already done in the peer reviewed literature. This is an issue for two reasons. First, peer literature is created and evaluated for intellectual novelty, not scientific reliability and robustness, which requires consideration and synthesis of the body of current knowledge and the uncertainty represented. Second, combining pieces from different studies can lead to inconsistencies and incoherencies. EPA's draft new methodology has this issue and should be revised to resolve such inconsistencies and incoherency within (e.g., socioeconomics and emissions) and across modules, including in the linkages between modules (e.g., socioeconomic and damage modules that need socioeconomic structural details relating to the size and composition of sectors over time that is not available from the socioeconomic module, discounting that needs consumption growth rates that are not produced by the socioeconomic module, and damage modules that need regional climates and sea-level rise (SLR) that are not produced by the climate and SLR projections).

Account for knowledge available

For scientific reliability, and as recommended by NASEM (2017), the methodology should account for the scientific knowledge available. There is clearly more information available than what is currently being considered by the methodology. The present draft methodology is based on a small number of academic studies (Table 1). There is additional information, including alternative assumptions and specifications and additional lines of evidence, that should be integrated to establish the methodology's scientific basis and capture uncertainty (e.g., with respect to population structure, economic structure, climate response, and damage estimation). See module specific comments below for examples.

Address substantive module-specific methodological issues and cross-module issues

We find substantive technical issues in and between each of the modules of the draft new SC-GHG methodology – socioeconomic and emissions projections, climate modeling, climate damages modeling, and discounting, as well as inter-module linkages and integration. Below we provide recommendations and guidance for improving each.

The technical issues that we have identified in the draft methodology preclude drawing objective conclusions about the bias in the draft new estimates. EPA current suggests that the draft new SC-GHG estimates are "conservative" and likely underestimates. The technical issues we find with the current methodology and the nascent state of the art for modeling adaptation (IPCC WGII, 2022), as well as the fact that not all omissions from the current methodology are additional net damages, imply that a conclusion on bias—in either direction—is not currently possible.

4. Provide additional and more detailed guidance for using SC-GHG estimates to ensure scientifically reliable policy insights, including discussing appropriate use, incorporating SC-GHG uncertainty, and addressing inconsistencies, GHG leakage, and pricing GHGs more than one.

The guidance provided in the draft methodology documentation regarding use of the draft SC-GHG estimates should be improved and expanded. Note that, it should be clarified whether this documentation is intended to be the application guidance requested through the President's January 2021 Executive Order. Regardless, what is provided in the documentation should address several critical technical issues that EPRI has previously identified that affect the scientific reliability of the insights generated when SC-GHG estimates are used in policy (Rose and Bistline, 2016; Bistline and Rose, 2017; Rose, 2017a, Rose, 2017b; EPRI, 2021a).

First, it is critical for EPA to define appropriate application as policies with incremental global emissions implications. Past US Government SC-GHG documentation has been very clear on this. The SC-GHG calculations are for incremental changes in global emissions. With larger changes, we cannot assume constant SC-GHG estimates due to the larger changes in climate and socioeconomic conditions (Rose, 2017a.

In addition, further discussion should be added regarding discount rate consistency across benefit-cost analysis calculations (e.g., compliance costs, SC-GHGs, air quality benefits, energy security benefits), including pursuing consistency as NASEM (2017) recommended. The shadow price of capital discussion currently included in the documentation is related, but its applicability relies on strong and speculative assumptions. Also, as we discuss subsequently, the damage calculations in the draft SC-GHG modeling are not trade-offs in types of consumption, but instead trade-offs between aggregate consumption and investment, which changes the applicability of the shadow price of capital concept.

The use guidance also should be revised to reflect the NASEM (2016) recommendation to facilitate and encourage accounting for uncertainty in SC-GHG estimates by providing tail values in a table format (e.g., 1^{st} and 99^{th} or 5^{th} and 95^{th} percentile values). See Table 2 (from NASEM, 2016).

Finally, the important SC-GHG application issues EPRI has identified in past and current applications should be addressed in EPA's documentation (Rose and Bistline, 2016; Bistline and Rose, 2017; Rose, 2017a, Rose, 2017b; EPRI, 2021a). These technical issues affect net benefits calculations and conclusions, as well as decarbonization cost-effectiveness. Overall, EPRI recommends the following be avoided:

- Using the SC-GHG estimates for policies with non-incremental effects on global emissions,
- Valuing/pricing a GHG molecule multiple times across policies (within agencies, across agencies, and across federal, regional, and state policies),
- Partial monetization of benefits and costs that can be misleading (e.g., NEPA analyses),
- Ignoring GHG leakage beyond policy boundaries that affects climate benefits,
- Inconsistencies in assumptions, treatment of uncertainty, and the types of values compared across cost and benefit calculations, and
- Ignoring SC-GHG uncertainty for a given discount rate structure.

Table 2. NASEM (2016) illustration for how to communicate uncertainty and in SC-GHG estimates in order to facilitate use of estimates to capture SC-GHG uncertainty in analyses. Source: NASEM (2016) Table 5-1.

	Discount Rate								
Year	5.00%			3.00%			2.50%		
	Low	Avg.	High	Low	Avg.	High	Low	Avg.	High
2020	--	--	--	--	--	--	--	--	--
2025	--	--	--	--	--	--	--	--	--
…									
2050	--	--	--	--	--	--	--	--	--

5. In order to provide scientifically reliable benefit-cost insights for the proposed methane rule, revise the benefit-cost calculations to address SC-GHG application technical issues.

First, the draft new SC-GHG estimates should be vetted and peer reviewed properly and successfully to establish their scientific reliability and robustness before being used at all in rulemakings, even as sensitivities.

Second, technical issues found when assessing past policy applications of SC-GHG estimates (Rose and Bistline, 2016; EPRI, 2021) are evident in the proposed rule's Regulatory Impact Analysis (RIA) and should be addressed in applying the interim and draft new estimates to improve the scientific reliability of the RIA's climate benefits and net benefits calculations.

Specifically, we recommend revising the RIA analysis as follows:

- ***Address inconsistencies in benefit and cost calculation assumptions and uncertainty:*** There are inconsistencies in the assumptions used and treatment of uncertainty in calculating the SC-GHG estimates, future emissions changes, and compliance costs. For instance, CH_4 emissions activity data is based on DOE's Energy Information Administration Annual Energy Outlook (AEO) projection, while the SC-GHG estimates are based on a set of other economic and energy system projections, where AEO and the SC-GHG projections have been shown previously to be inconsistent both in terms of the projected future and the socioeconomic uncertainty captured (e.g., Rose and Bistline, 2016). Compliance cost calculation economic assumption consistency should also be evaluated, e.g., input and output price assumptions.
- ***Address net benefit calculation discounting inconsistencies:***
    - EPA's RIA Table 5-2 presents present value (PV) climate benefits where the annual benefits have been discounted with a 3% discount rate. These values are then compared to PV compliance costs calculated with a 7% discount rate. For consistency, and a meaningful 7% PV net benefit calculation, climate benefit PV calculations with 7% are needed that, along with the consistent 7% PV compliance costs, can be used to derive appropriate 7% PV net benefit estimates.
    - EAV values should be revisited, first, in terms of whether they should be included at all; and, second, if included, revising them for consistency across calculations. EPA's RIA computes annualized cost values (labeled "EAV") with 3% and 7% discount rates, while computing annualized (EAV) climate benefits with 2.5%, 3%, and 5%. While there are reasons for the SC-CH_4 estimates to be computed with different discount rates than the

compliance costs, the EAV and PV calculations for costs and benefits should use the same discounting when aggregating annual values over time in the EAV and PV calculations for comparison. Note, however, the EAV calculations can be misleading given the way they are calculated now with inconsistent discounting. They are also unnecessary given the availability of the PV calculations. PV is more readily understood and is sufficient once corrected for discounting consistency.

- ***Expand the analysis to account for SC-GHG uncertainty for each given discounting structure:*** The RIA's Table 5-2 uses only the mean SC-CH_4 values computed with a 3% constant discount rate. As recommended by NASEM (2016), the analysis should consider SC-CH_4 uncertainty for this discount rate (e.g., the 1st and 99th or 5th and 95th percentiles of the SC-CH_4 results with 3%). In addition, the net benefit calculations should be done with the other SC-CH_4 distributions (e.g., 1st, mean, and 99th) with 2.5% and 5% discount rates.
- ***Account for emissions leakage:*** Potential changes in GHG and non-GHG emissions (e.g., VOCs, sulfur) beyond the regulated sources in the economy would affect the net climate benefits of the proposed rule. These potential effects should be evaluated by EPA. Such effects seem likely given the energy market effects (production and price changes) estimated by EPA in the RIA, which EPA concludes are significant.
- ***Avoid pricing CH_4 more than once across policies*:** The proposed rule appears to be pricing the same CH_4 molecules more than once across the administration's policies. For instance, mineral extraction policies considering potential oil and gas GHG emissions would also be valuing some of the same emissions as this proposed rule.

EPRI module-specific and cross-module recommendations

This section consists of EPRI's module-specific and cross-module comments based on the information currently available in EPA's documentation. A comprehensive assessment can only be provided once the additional information required for a full evaluation of the draft methodology is available.

6. For the socioeconomic and emissions projections module, we recommend:

a. Revising to fully address NASEM recommendations,
b. Revising the socioeconomic and emissions projections for coherency, consistency, and to account for important structural details,
c. Removing implausible socioeconomic and emissions projections,
d. Revisiting post-2100 projection assumptions for coherency and consistency with historical behavior,
e. Providing transparency and justification on linkages to other modules, in particular climate damages and discounting, and
f. Providing needed additional methodological details and results to facilitate a full assessment.

Revise to fully address NASEM recommendations

The draft methodology does not presently satisfy all the NASEM (2017) near-term recommendations for the socioeconomic and emissions module. First, the module documentation should fully satisfy the transparency, scientific basis, and uncertainty consideration recommendations (NASEM Recommendation 2-2). The current module documentation should be enhanced to facilitate a full evaluation of the module. EPA's documentation should assess the literature EPA is using, provide methodological details, equations, and parameters, provide more detailed results, justify the methodological choices in that literature and associated with its integration into EPA's overall framework, and justify the more detailed results. Overall, to facilitate a comprehensive and thorough assessment, EPA's documentation should go well beyond what's currently provided in the literature cited. In addition, as recommended by NASEM, the module needs to more fully consider the broader literature that represents current scientific knowledge and uncertainty, and the module should provide sectoral, regional, and future policy details (NASEM Recommendations 3-1 and 3-2).

Revise the socioeconomic and emissions projections for coherency, consistency, and to account for important structural details

Rennert et al (2022), which is used by EPA for this module, does not achieve the internal consistency and coherency needed. The approach relies heavily on three separate expert elicitations, but details are missing for understanding and assessment (e.g., , expert samples, framing, debiasing, questions posed, steps taken to facilitate consistency). The details are important for evaluating the projections individually and as a set and need to be communicated and justified.

In addition, the current approach does not include socioeconomic structural details that have important implications for projected emissions, damages, and discounting. For instance, population composition is important (e.g., regional age and sex distributions) to economic growth as well as estimating climate damages, especially related to health. The current documentation should discuss the assumed structure of regional populations over time. The projections should also have economic structure and coherency (i.e., economic sectors, technologies, energy use, goods and service demands, trade) that will affect emissions, damages, and discounting. Furthermore, EPA's projections should consider climate policy details (i.e., regional emissions reduction effort, timing, and policy instrument types). Climate policy details have been shown to have a significant impact on economic structure over time (regional sector sizes and growth, sector compositions, demands), costs (GDP, consumption, prices, etc), and regional transformation that impacts emissions, damages, and discounting (Riahi et al, 2022; IEA, 2021; IEA, 2019; Rose et al, 2017; Clarke et al, 2014; Weyant and Kriegler, 2014; Fisher et al, 2007). Finally, the EPA projections should consider structural transition uncertainty.

See Figures 1 and 2 for examples of the importance of structural detail and uncertainty regarding how economies will evolve that is a function of uncertainty regarding climate policy and non-policy economic system dynamics. For instance, sub-global uncertainty for a single global emissions pathway is significant with many sub-global economies consistent with any global emissions pathway. See Figure 2 for an example of structural coherency and uncertainty, policy design relevance to economic structure, policy cost feedbacks on regional consumption, and implausibility. Figure 2 suggests significant uncertainty in the size and composition of the US energy system, as well as the consumption per capita costs to the US economy for a single 2°C compatible global emissions pathway (top row of Figure 2). This uncertainty is due to non-policy uncertainties inherent in economic development and deep uncertainty about climate policy design. Figure 2 also includes sub-global transition uncertainty results for individual global emissions pathways consistent with limiting warming to between 2°C and 1.5°C (Almost 1.5°C) and 1.5°C that illustrate that sub-global uncertainty can be affected by the level of global ambition.

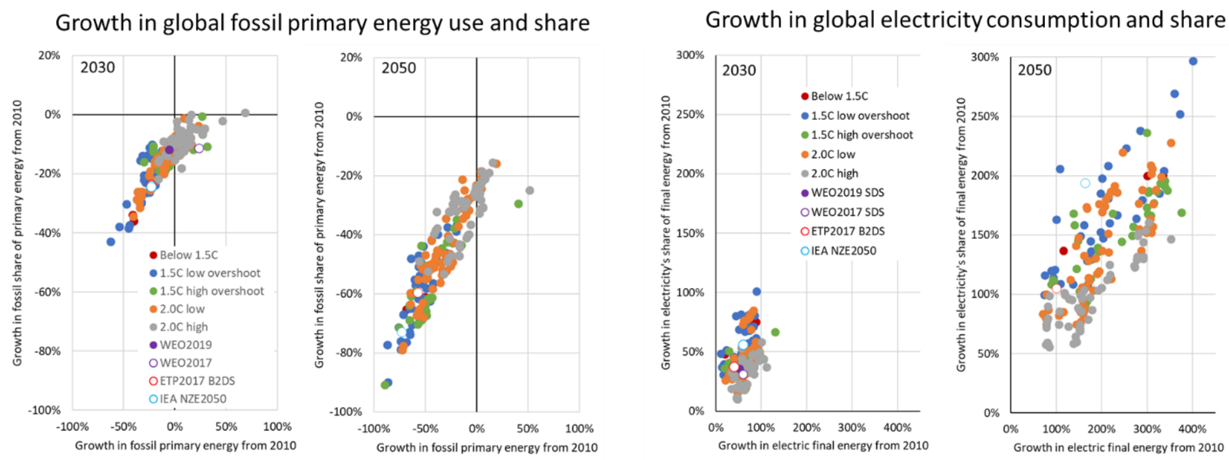


Figure 1: Growth in global fossil primary energy use (left) and electrification (right) to 2030 and 2050 for global emissions pathways limiting warming to 1.5°C to 2°C. Results show potential growth in fossil energy use or electricity consumption (x-axis) and dependency (y-axis). Results based on strong assumptions regarding global economy-wide GHG mitigation cooperation and available low-carbon technologies. Source: Developed from Rose and Scott (2020).

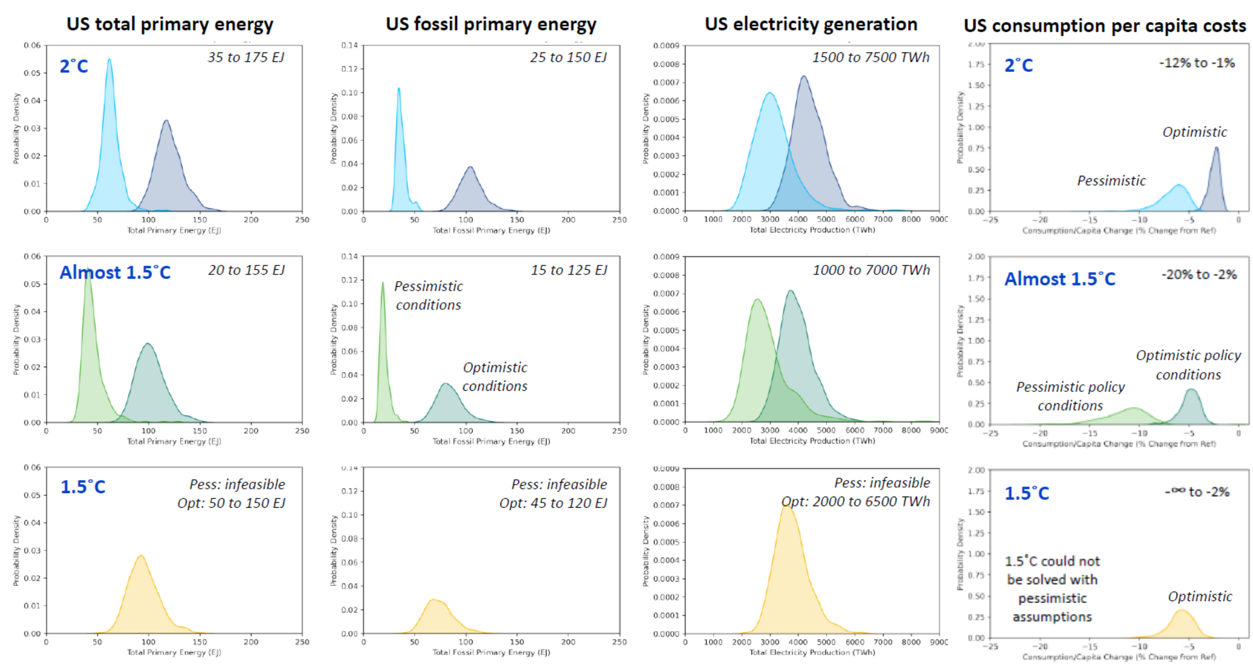
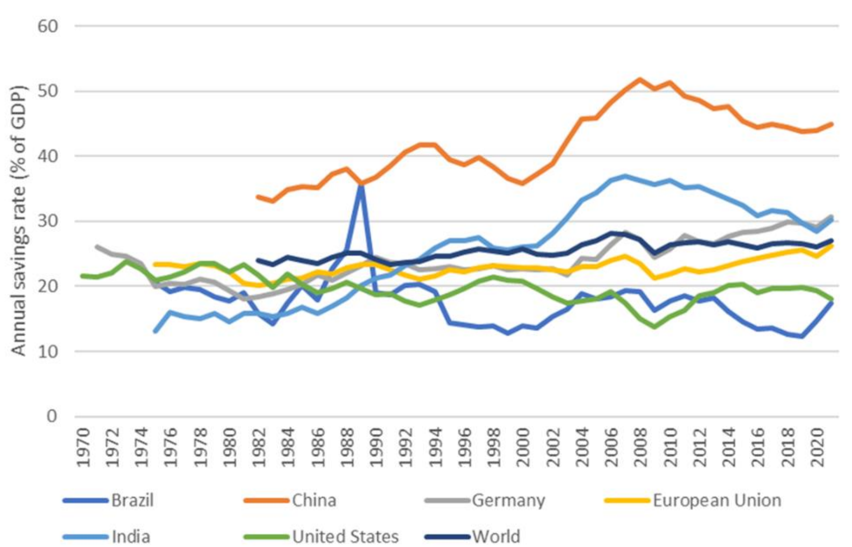


Figure 2. Illustration of socioeconomic structure and coherency and decarbonization sub-global uncertainty and implausibility. Results based on probabilistic global modeling evaluating potential sub-global transition uncertainty for individual global emissions pathways consistent with limiting global warming to 2°C (top row), between 2°C and 1.5°C (middle row), and 1.5°C (bottom row) with uncertain regional climate policy and non-policy conditions. Only U.S. results are shown. Optimistic climate policy conditions assume global cost-effective mitigation cooperation following regional pledges to 2030, access to carbon dioxide removal (CDR), and global land GHG mitigation incentives. Pessimistic policy conditions assume regional unilateral mitigation, and no access to CDR, and incentives for land mitigation. The 1.5°C pathway was only feasible under optimistic policy conditions. Source: Rose et al (forthcoming).

The EPA documentation notes that Rennert et al (2022) assigns probabilities to future policies, but details regarding specific regional policies and weights are needed for evaluation, as is information on how they are impacting the economy (structure and costs) and how that is captured. In general, climate policy economic composition implications (e.g., regional mitigation costs, energy transition, energy consumption, electrification, food demand) should be considered in the draft approach.

The GDP-aggregate consumption relationship is also important and should be clearly communicated in the documentation, and justified. A footnote later in EPA's documentation (footnote 99) notes that the savings rate is assumed fixed and GDP and consumption growth are therefore identical. This is a strong and important assumption given that consumption growth per capita is used in discounting. A fixed savings rate is also not supported by historical data (Figure 3), which illustrates that world and regional savings rates change over time, savings rates vary by region, and growth in saving rate could be increasing or decreasing depending on the region. Also, the specific implied/assumed savings rate should be noted (globally or regionally). This matters because it defines aggregate consumption levels and therefore damage levels and SC-GHG values, which depend on the size of the economy. It should also be clarified how consumption is used in the damage calculations. Overall, the fixed savings rate assumption should be revisited, better communicated, and justified.



	Growth in rate	Average rate (%)
Brazil	-27%	18
China	29%	42
Germany	24%	24
European Union	8%	23
India	101%	26
United States	-13%	20
World	11%	26

Figure 3. Savings rate (% of GDP) for the world and select regions—annual values (figure) and growth in rate and average rate over time periods (table). Growth in rate based on 5-year averages from first and last five years in each data series. Averages are across available annual data for each series. Source: World Bank, World Development Indicators, https://databank.worldbank.org/source/world-development-indicators.

Non-CO_2 GHG emissions source and policy assumption details are also needed for evaluation of the non-CO_2 emissions modeling—CH_4, N_2O, and F-gases. Note that the emissions are assumed fixed for all other Kyoto GHGs (e.g., F-gases) across all alternative population and income projections. The modeling is also assuming non-GHG radiative forcing is fixed across socioeconomic projections, which implies that the drivers—activity, emissions, land use—are fixed. This includes land albedo and aerosol forcings and aerosol precursor emissions, such as sulfur dioxide, black carbon, and organic carbon. Fixing aerosol radiative forcing is particular problematic given that this type of forcing can have a net cooling affect and is the largest source of uncertainty in global radiative forcing that drives global temperature change (IPCC, 2021). In addition, precursor emissions will be affected by climate policy, and modeling of non-GHG forcing impacts has been shown to affect the achievement of global policy goals, GHG emissions pathways, and decarbonization costs (Rose et al., 2013).

Lastly, the module should consider additional information and tools to help it better represent socioeconomic structure and uncertainty, and as points of comparison for evaluating projections. Additional information to be considered includes IPCC AR5 scenarios (Clarke et al, 2014), IPCC SR1.5 scenarios (Huppmann et al, 2018), IPCC AR6 scenarios (Byers et al, 2022), other population projections (e.g., UN), IEA scenarios (IEA, 2021, 2019), new probabilistic socioeconomic projections from MIT (Morris et al., 2022), and forthcoming probabilistic socioeconomic projections from EPRI-MIT work that considers policy design and non-policy uncertainty and specific regional GHG ambition (Rose et al, forthcoming). EPA's module methodology needs probabilistic socioeconomic structural and policy detail, coherency, and plausibility.

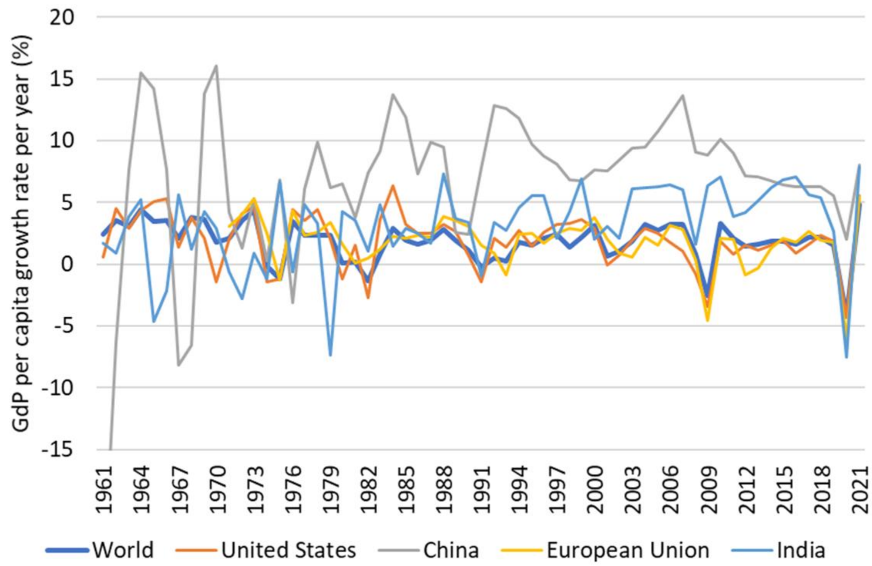
Remove implausible socioeconomic and emissions projections

Pathway implausibility is an issue for the current approach, and pathways should be evaluated for plausibility, and implausible pathways removed. For instance, EPA's documentation notes that their mean global emissions projection has global CO_2 emissions peaking this decade. Given historical and current emissions trends and policy trends, this is very unlikely and arguably implausible. Thus, this result should have a zero or very low probability assigned to it; and, all the results below this mean (with even earlier global peaking and more aggressive declines) should be assigned zero weights, or even lower probabilities. See Rose and Scott (2018, 2020) who evaluate 1.5°C and 2°C global emissions pathway characteristics and assumptions and find that all 1.5°C pathways are implausible (e.g., SSP1-1.9, IEA NZE, and others) and implausibility is also an issue for 2°C global emissions pathways (e.g., SSP1-2.6, IEA SDS, and others). Similarly, very high emissions projections need to also be vetted for plausibility. See, for instance Hausfather and Peters (2020) and EPRI (2021a) that call into question the plausibility of pathways like RCP8.5, SSP5-8.5, SSP3-7.0, and the high emissions pathway used in the interim methodology.

The pathway plausibility assessment should also consider projected climate change outcomes. It is very unlikely that the world will see very high global temperature change in the distant future (i.e., above 4°C) as is currently produced in some of EPA's climate projections. For instance, EPA's draft methodology documentation Figure 2.2.2 shows temperature change reaching about 8°C by 2300 in some projections. Society is likely to respond and manage the climate before then. This would rule out these climate pathways (and their corresponding socioeconomic pathways) from consideration or assign even lower probabilities to them. This type of plausibility assessment is needed to identify meaningful projections and weight them appropriately.

Revisit post-2100 projection assumptions for coherency and consistency with historical behavior

Important post-2100 projection assumptions need transparency, evaluation, and justification. For instance, Rennert et al (2022) assume that global economic growth rates decline after 2100. This is a strong assumption that needs justification. The assumption impacts discounting (especially given the proposed revised lower near-term discount rates), emissions, and likely damage calculations (though we cannot currently tell without additional methodological details). While many projections in the literature make this assumption, long-run records do not exhibit this decline. See Figure 4 for a sample of growth rates over the last 60 years. Given the SC-GHG modeling's 300-year projections, the very long-run data record should inform this assumption (even longer than that shown in Figure 4).



	Average
World	1.9
US	1.9
China	6.7
EU	1.8
India	3.2

Figure 4. Historical GDP per capital growth rates for the world and select region—annual (figure) and average over 1961-2021 (table). Source: World Bank, World Development Indicators, https://databank.worldbank.org/source/world-development-indicators.

Provide transparency and justification on linkages to other modules, in particular climate damages and discounting

Module documentation should be revised to clearly communicate inter-module linkages. The equations for how the socioeconomic projections are explicitly integrated into the damages and discounting modules are needed, as are discussions regarding how the socioeconomic projections' affect societal vulnerability, adaptation, and net economic damages and discounting (e.g., consumption per capita growth).

Provide needed additional methodological details and results to facilitate a full assessment

The socioeconomic module documentation should add the following additional information:

- All module methodological details, as well as assessment and comparison to the literature, and justification,
- Implemented equations and parameters,
- Presentation and evaluation of the quantitative relationship between population, economic growth, and emissions projections,

- Presentation and evaluation of individual projections for country income, population, and emissions (fossil and energy CO_2, non-CO_2, land CO_2) levels and intensities to 2300,
- Discussion and justification for the implied/assumed/modeled evolution of the structure of global and regional economies, populations, and climate policies (country ambition, timing, and design (sector, instrument)) from now to 2300, and
- The addition of minimum and maximum values to all figures.

7. For the climate module, we recommend:

a. Revising to fully address NASEM recommendations, including undertaking NASEM performance tests,
b. Expanding evaluation and comparison to justify the approach and better account for uncertainty,
c. Endogenizing non-GHG radiative forcing to address the current fixed forcing assumption's inconsistency with the broad range of projected futures and to capture non-GHG forcing uncertainty in temperature projections, and
d. Providing needed additional methodological details and results to facilitate a full assessment.

Revise to fully address NASEM recommendations, including undertaking NASEM performance tests

The module methodology should satisfy all the NASEM (2017) near-term recommendations for the climate module. First, the module documentation should be enhanced to satisfy the transparency, scientific basis, and uncertainty consideration recommendations (NASEM Recommendation 2-2). The documentation should assess the literature they are using, provide methodological details, equations, and parameters, provide additional detailed results, and justify the methodological choices in that literature and associated with its integration into EPA's overall framework, as well as justify detailed results. In addition, the module should provide spatially disaggregated climate information (and account for uncertainties) and evaluate climate model performance with respect to the specific experiments NASEM (2017) recommended (NASEM Recommendations 4-1, 4-2, and 4-5).

Expand evaluation and comparison to justify the approach and better account for uncertainty

The draft climate modeling approach utilizes one reduced complexity climate model (FaIR). Additional specifications should be incorporated to fully capture the structural and parametric uncertainty seen in the literature. Additional comparisons can help identify the missing uncertainty and facilitate its incorporation. EPA is currently only comparing central tendencies, for only a few outputs, and for just two reduced complexity models (e.g., Fig 2.2.3). We have found that not only do the means differ across models, but the probabilistic responses do as well. The current comparisons to the central tendencies of MAGICC and Hector should be expanded to distributional comparisons and to comparisons with other reduced complexity models, e.g., MIT Earth System Model (Sokolov et al, 2018) and other reduced complexity models (Nichols et al, 2021). For example, we find that MAGICC is a warmer model, with distributions higher than FaIR (means and tails). See Figure 5 for an illustration. This type of information and additional climate response uncertainty should be incorporated into EPA's modeling. FaIR also is not representing the low end of the IPCC AR6 climate sensitivity distribution as well as MAGICC (see EPA's documentation Table 2.2.2). This should be evaluated and potentially revised to better capture this tail.

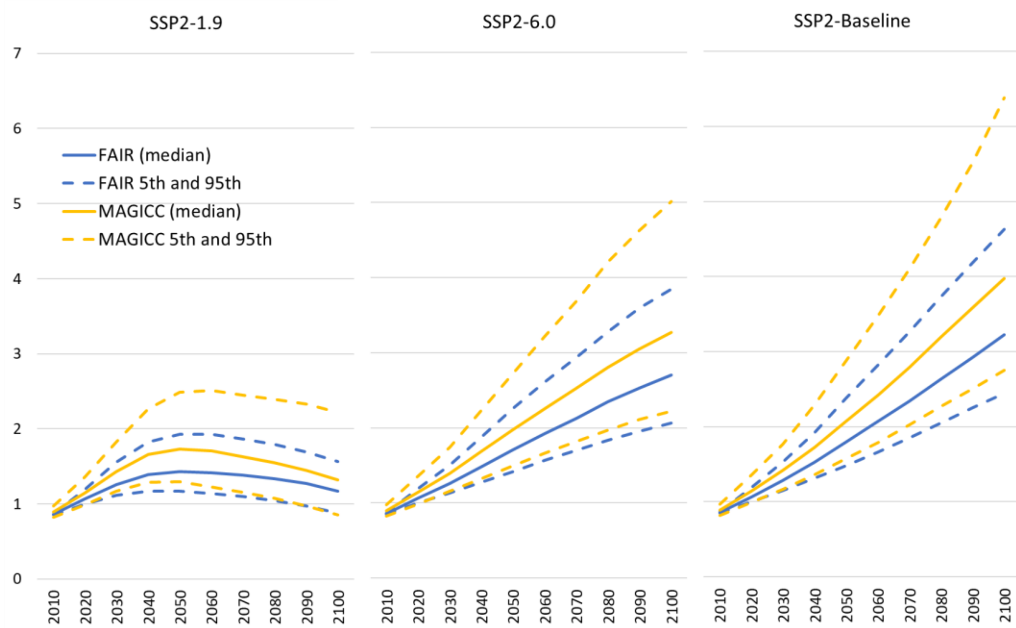


Figure 5. FaIR and MAGICC global mean temperature change projections (median, 5th and 95th percentiles) for three different standardized emissions and forcing inputs. Source: IPCC database.

EPA's current climate modeling approach does not explicitly consider regional climate response uncertainty as recommended by NASEM (2017) Recommendation 4-5. This is a key missing uncertainty given the projected variation found in regional climate responses from complex climate models (IPCC WGI Interactive Atlas, 2021). See Figure 6 and Table 3 for examples of the importance of regional difference in climate change as well as regional climate change uncertainty. There is some consideration of regional climate change within the overall EPA framework with elements of the DCSIM damages, but regional climate uncertainty is not considered overall and consistently, and what is considered within the entire framework is not transparent and cannot currently be evaluated.

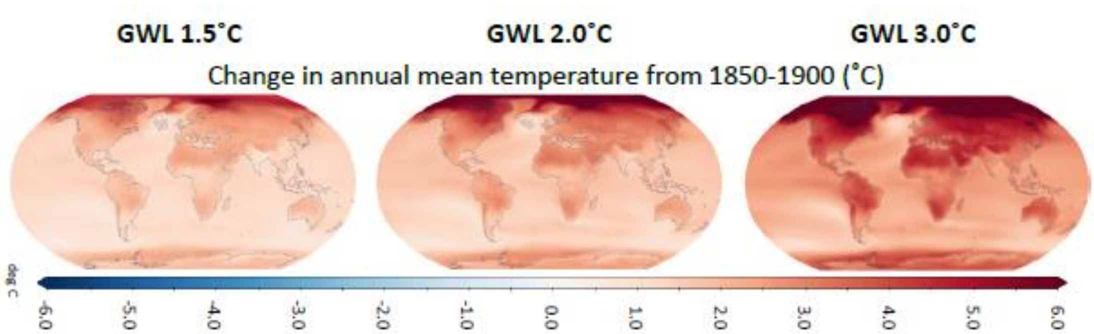


Figure 6. Example of variation in regional climate change responses for global warming levels of 1.5°C, 2°C, and 3°C. Average result across models shown. Source: Rose and Diaz (2021), constructed from IPCC WGI Interactive Atlas (2021), https://interactive-atlas.ipcc.ch/.

Table 3. Examples of regional climate change uncertainty for regional mean temperature. Ranges from complex climate models shown for global warming levels of 1.5°C, 2°C, 3°C, and 4°C. Source: Rose and Diaz (2021), constructed from IPCC WGI Interactive Atlas (2021), https://interactive-atlas.ipcc.ch/.

Table 3. Sample of continental temperature and precipitation ranges by GWL. Ranges are 5th and 95th percentiles from climate model inter-comparison results. Constructed from IPCC (2021) Interactive Atlas.

Climate Variable	Region	Global Warming Level			
		1.5ºC	2ºC	3ºC	4ºC
Mean temperature (ºC)	North America	4 to 8	5 to 9	6 to 11	8 to 11
	Africa	24 to 26	24 to 27	25 to 28	26 to 29

As discussed earlier, climate projection plausibility assessment is needed to identify meaningful climate (and socioeconomic and emissions) projections and to weight them appropriately. EPA's current temperature anomaly projections reach as high as 8°C by 2300 (EPA's Figure 2.2.2). Above 4°C is unlikely given that society is likely to respond and manage the climate before then.

Endogenize non-GHG radiative forcing to address inconsistency with the broad range of projected futures and to capture non-GHG forcing uncertainty in temperature projections

EPA's modeling assumes that non-GHG radiative forcings are fixed across all results (all socioeconomic and climate projections). This is a strong assumption that is not well supported by evidence. Non-GHG forcing includes land albedo and aerosol forcings, and implies that land use and aerosol precursor emissions, such as sulfur dioxide, black carbon, and organic carbon are fixed. However, exogenous, fixed non-GHG forcing is inconsistent with the widely varying socioeconomic and GHG emission projections used in EPA's modeling. Fixing aerosol radiative forcing is problematic and should be revised. This type of forcing is a large source, and the largest source, of uncertainty in global radiative forcing that drives global temperature change (IPCC, 2021). Furthermore, aerosol precursor emissions will be affected by climate policy, and modeling of non-GHG forcing impacts has shown that it will affect achieving policy goals, GHG emissions pathways, and decarbonization costs (Rose et al., 2013).

Provide needed additional methodological details and results to facilitate a full assessment

The climate module documentation should add the following additional information:

- All module methodological details, as well as assessment and comparison to the literature, and justification,
- Implemented equations and parameters,
- In addition to the current charts, provide climate system variable results without emissions uncertainty so that the climate responses and uncertainty are isolated and can be evaluated (like in Rose et al (2017, 2014) as recommended by NASEM (2017)),
- Similarly, provide SLR results without emissions and climate uncertainties (like in Rose et al (2017, 2014) as recommended by NASEM (2017)),
- Provide intermediate and single projection results, comparison, and assessment to 2100 and 2300 (e.g., concentrations, radiative forcing (CO_2, non-CO_2), reference and pulse responses),

with distributional comparisons to other models (like in Rose et al (2017, 2014) as recommended by NASEM (2017)),

- Provide results from the additional NASEM model performance tests with comparisons, where comparisons include comparison to the more complex GCMs/ESMs as well,
- Compare, discuss, and justify all results – only a subset of results are compared now (e.g., CO_2 concentrations, global mean temperature change),
- Clarify how the ocean diffusivity parameterization is varied with equilibrium climate sensitivity (ECS) – the two are jointly distributed; however, this is not accounted for in the interim methodology with the PAGE model and is resulting in unreasonable sensitivity in the PAGE climate projections to ECS (Rose et al, 2017),
- Equations, discussion, and justification regarding how sub-global climate information is created in the damage module from global mean temperature,
- Clear discussion and justification regarding consideration of regional SLR and the process, equations, and uncertainty for integrating global SLR into the damage modules, and
- The addition of minimum and maximum values to all figures, and
- Standardized y-axis' when multiple graphs appear in one figure to facilitate comparison.

8. For the climate damages module, we recommend:

a. Revising to fully address NASEM recommendations,
b. Assessing the literature used and addressing the methodology comparability issue identified by the NASEM and IPCC,
c. Considering the fuller literature to more accurately estimate damages and account for uncertainty, and
d. Providing needed additional methodological details and results to facilitate a full assessment.

Revise to fully address NASEM recommendations

The module methodology should satisfy all the NASEM (2017) near-term recommendations for the climate damages module. First, the module documentation should be enhanced to satisfy the transparency, scientific basis, and uncertainty consideration recommendations (NASEM Recommendation 2-2). The documentation should assess the literature they are using, provide methodological details, equations, and parameters, provide additional detailed results, and justify the methodological choices in that literature and associated with its integration into EPA's overall framework, as well as justify detailed results from the module (NASEM Recommendation 5-1).

In particular, details and justification should be provided for each damage module specification, and for each damage sector specification. Currently, the documentation is only providing high-level descriptions. Damage functional forms and calibrations for all three damage modules, total and by sector as appropriate, derived from the literature and used in EPA's calculations need to be explicitly written out, with derivation and calibration procedures fully documented, uncertainty specifications fully documented, and discussions provided that include comparison, and justification (NASEM Recommendation 5-1).

Also, integration details, including equations, are needed to elucidate how damage module results are calculated and linked across the framework. Regarding the socioeconomic projections, the documentation should clarify how the global (and regional) projected GDP and population enter into each damage sector calculation, any sub-global socioeconomic assumptions used and discussion of assumed relationships (e.g., weightings) over time and socioeconomic projections (e.g., assumed relationships between energy expenditures and GDP, agricultural consumption share for GDP), as well as how annual damages are computed as a function of the socioeconomic projections and each damage category's cost metric, which varies across damage categories (e.g., energy expenditures, welfare, labor productivity, infrastructure costs). Similar clarification is needed for how global temperature and SLR are integrated into each damage sector, including sub-global climate and SLR assumptions and assumed relationships (e.g., weightings) over time and climate projections (e.g., regional climate change, regional SLR).

Related to integration, it is unclear whether the socioeconomic and damage modules are consistent, and whether there is consistency across the three damage formulations. The needed details are currently missing for assessing consistency. The information currently provided suggests that this could be an issue that needs to be corrected, e.g., size, composition, value, and prices for economic sectors (agriculture, electricity, energy, labor). Not only is there a consistency question overall in terms of the socioeconomic conditions imagined across modules, but there are specific assumptions that need to be revisited as well for consistency. This includes the fixed savings rate assumption already noted. It also includes DSCIM's agriculture results (Hultgren et al, 2022) 0.45 multiplier adjustment "to account for crop switching and trade protective effects." This factor is fixed across all socioeconomic projections and over time despite the large variation in the projections. Similarly, the GIVE agricultural sector assumes that the agricultural sector is a fixed proportion of the economy across all socioeconomic futures and over time based on a single historical year (Rennert et al., 2022).

In addition, adaptation details should be added. At the moment, adaptation is only described in broad terms. However, there is large variation in the specific kinds and extent of adaptation represented across the damage modules, and damage sectors within each module, that should be explicitly described and assessed.

Also, to further improve transparency and facilitate full assessment, the documentation should provide disaggregated total and incremental damage projections results by module and over time (NASEM Recommendation 5-1). NASEM (2017) refers to Rose et al (2017, 2014) and its disaggregated module-specific results for the methodology used by this and the previous two administrations as the type of disaggregated and undiscounted damage module results needed for transparency and assessment.

Finally, to properly establish the scientific basis of the module and improve the representation of uncertainty, the broader literature should be considered and integrated, with comparability taken into account (discussed below). Significantly more information is available in the literature, but not currently used or discussed.

Assess literature used and addressing the methodology comparability issue identified by the NASEM and IPCC

Both NASEM (2017) and IPCC WGII (2022) specifically call out damage estimate incomparability as an issue that needs to be considered and addressed when using the climate damages literature. EPA's damage module is using damage estimates from very different approaches but is not considering the comparability issue.

In broad terms, the literature includes damage estimates from very different methodologies—statistical, structural, and meta analyses. The stark methodological differences raise questions about whether the results are comparable and can be readily combined and treated as alternatives or instead should be viewed as different lines of evidence that need to be formally integrated with one informing and/or constraining the other. Within the EPA module, DCSIM is based on statistical analyses, GIVE is based on structural analyses, and Howard and Sterner (2017) is a meta analysis.

IPCC WGII (2022) also found that the different methodologies produced notably different global damage estimates (Figure 7). These systematic differences in results and methods, including biases and uncertainty specifications, led the IPCC to conclude that a robust range of global damage estimates could not be identified with confidence (IPCC WGII, 2022). Incomparability would also affect treating estimates from alternative methodologies as substitutes as is currently done in EPA's damages module with the three damage specifications treated as equals. Note that the IPCC also concluded with high confidence that evaluating and reconciling differences in methodologies is a research priority for facilitating use of the different lines of evidence.

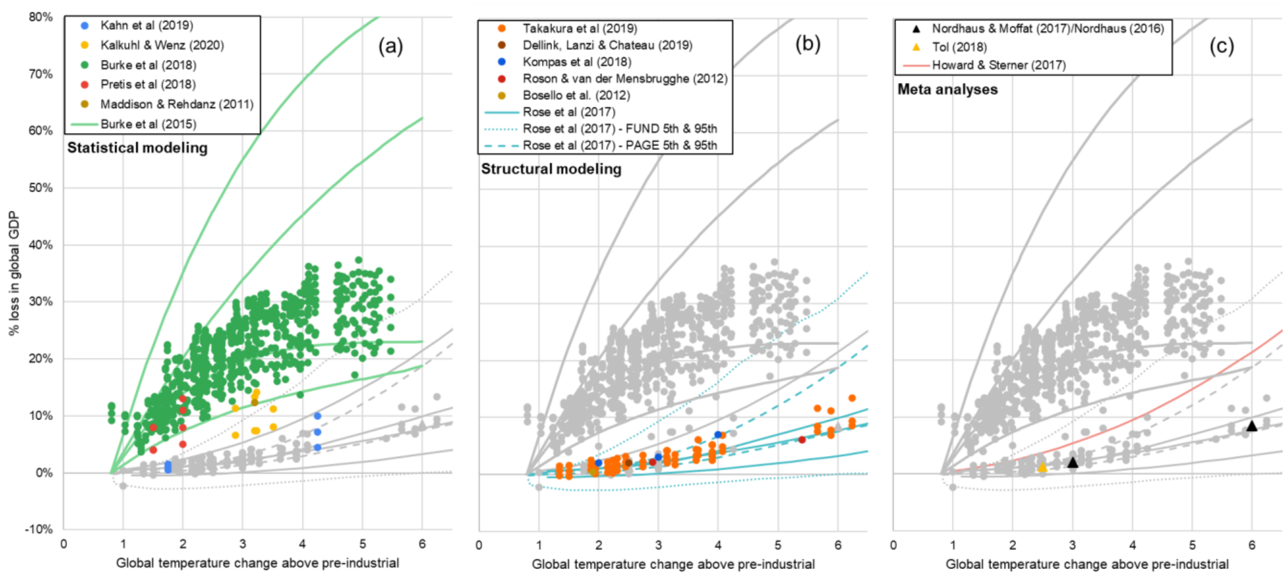


Figure 7. Global aggregate economic impact estimates by global warming level and methodology type (% global GDP loss, all estimates from the same paper have the same color). Source: IPCC WGII (2022) Chapter 16 *Cross-Working Group Box: Estimating Global Economic Impacts from Climate Change.*

In addition to considering the comparability issue and its impact on how to use the different literature, EPA should assess and discuss the methodological details in the literature they are using. For instance, DCSIM's high spatial resolution (25,000 world regions) raises questions about aggregation and interactions across regions and sectors, including markets that cross regional boundaries. Also, EPA should discuss the reliability of projecting historical relationships with weather based on a few decades of data into the future for centuries to represent multi-decadal climate change impacts on very different future societies, and adaptation responses and how they are constrained by the historical data and weather relationships. Finally, the documentation needs to be explicit about how statistical uncertainty is considered with EPA's DCSIM representation.

The individual studies used in GIVE also need assessment, discussion, and clear transparency on how they are implemented. For instance, Moore et al (2017) estimate global agricultural damages at 1ºC, 2ºC, and 3ºC. What is the derived functional form EPA is using, how was it derived, and how is it extrapolated above 3ºC? Furthermore, are there regional damage functions and how is economic growth integrated? Regarding integration with the socioeconomic module, as noted earlier, Rennert et al (2022) appear to assume in GIVE that the agricultural sector's share of GDP is fixed to an historical year. This assumption is not supported by data at the global or regional level. Furthermore, Moore et al (2017) treats crop modeling and econometric yield responses to climate change identically with how they are used in their computable general equilibrium (CGE) economic modeling, which could be problematic. Conceptually, they are different, with the former representing potential changes in intrinsic yields of cultivars, and the latter representing potential changes in output yields that reflect changes in total productivity, this includes changes in cultivars, as well as other production inputs like fertilizer and land use and their prices and commodity demand responses. This conceptual difference implies that the information should be applied differently. An additional issue is that Moore et al (2017) represent results from one CGE model, but there are many more that have evaluated global agricultural damages with a range of findings (e.g., Nelson et al, 2014; Reilly et al, 2007). This work also highlights the importance of capturing the sequence of relevant uncertainties: regional climate response uncertainty, crop system response uncertainty to climate change, and net economic response uncertainty. See Figure 9 (discussed below) for an example of additional agricultural damage results EPA should be considering, comparing to, and integrating.

Regarding Howard and Sterner (2017), EPA should consider that the Howard and Sterner meta analysis does not quality control for the studies included in their input data (outside of removing duplicates). In particular, and there is no consideration of the comparability issue between statistical and structural approaches. Assessment of the input studies for quality and comparability would have helped identify which specific studies EPA should be using on their own or in a revised meta analysis.

In addition to assessing the methods in the literature used, more detailed results and discussion should be added for transparency and to properly assess the damage module. For instance, results by damage sector and region, undiscounted, over time; and discussion of differences is essential. For example, agriculture is a large portion of EPA's GIVE results, but a very small part of the DCSIM results. Why? Do they both make sense? How do they compare to other analyses?

Consider the fuller literature to more accurately estimate damages and account for uncertainty

The damage module should consider more of the literature available. It currently considers only a small fraction. There are relevant alternatives globally and for individual damages categories. See, for instance, Figures 7 for an example of additional global damages estimates available in the literature from IPCC WGII (2022), Figure 8 for an example of additional global health estimates, and Figure 9 for an example of additional global agricultural estimates. Limited justification is provided for the current three module choices and the exclusion of other information. Furthermore, the current documentation is

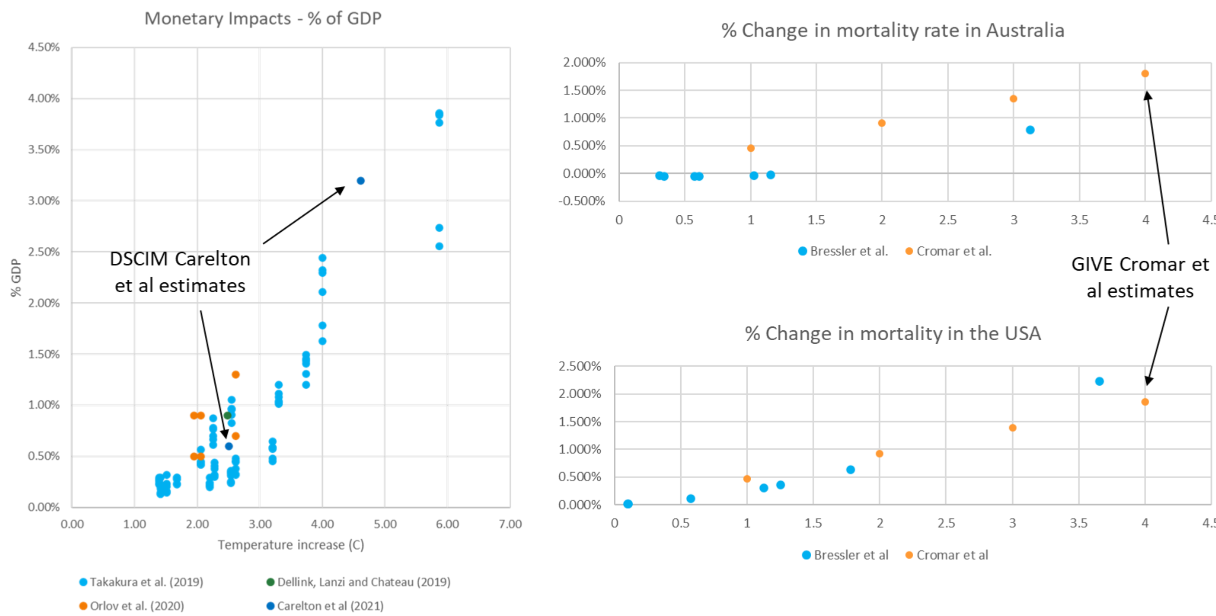


Figure 8. Examples of other global sector damage and impacts estimates related to human health. Shown are a sample of global monetary health climate damage estimates (left) and regional physical mortality from climate change estimates (right). Carelton et al and Cromar et al are highlighted since they are the health damage studies respectively integrated into the DSCIM and GIVE damage modules used in the EPA draft methodology. Source: EPRI.

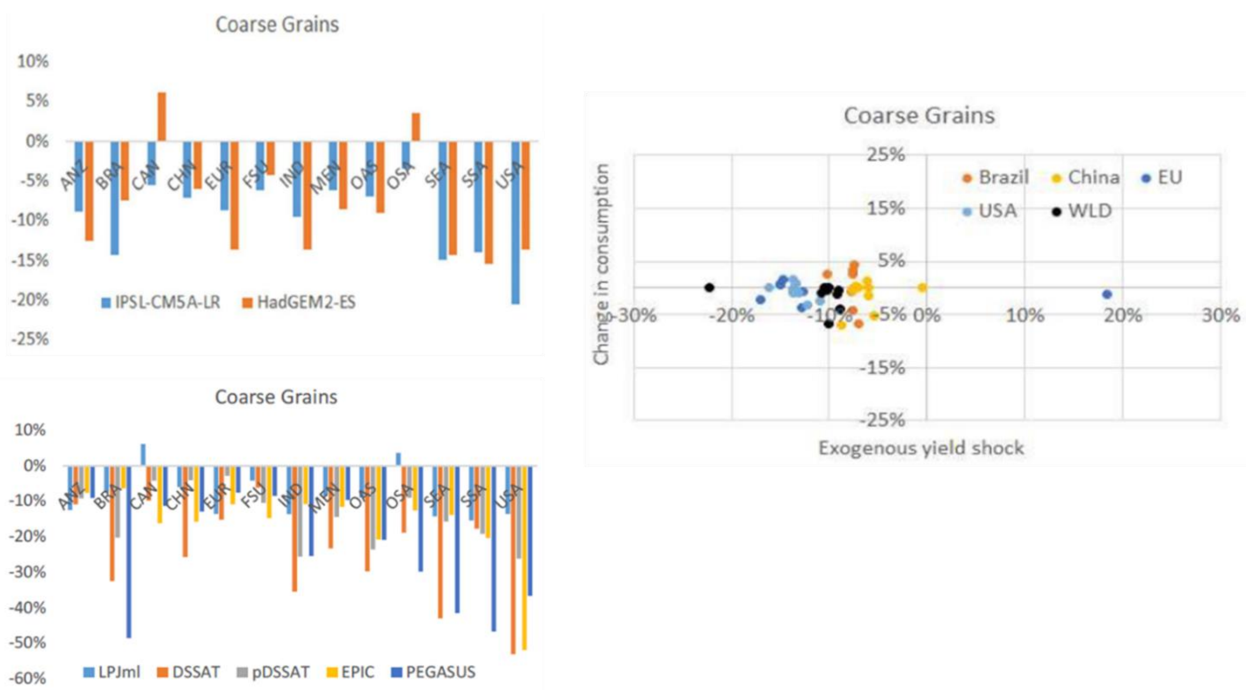


Figure 9. Examples of other global sectoral damage estimates related to agriculture. Shown are a sample of global modeling results for estimated regional coarse grain crop yield changes for different potential regional climate responses and a given crop model (upper left), regional coarse grain potential crop yield changes for different crop models and a given regional climate (lower left), and potential regional economic cost estimates for coarse grain climate yield responses for different economic models and a given global climate, regional climate response, and crop model—3˚C warming, HadGEM2-ES, and LPJmL (right). Source: EPRI developed from Nelson et al (2014).

primarily descriptive—i.e., here is what we did. The documentation needs to assess options and justify what is used and how it is represented and integrated.

Because of the narrow consideration of the literature, uncertainty is not being captured as well as it should be. Uncertainty in damage outcomes includes consideration of uncertainty in regional climates, physical responses, adaptation, and net monetary implications. Note that some of the current damage sectors underlying the EPA module are not capturing uncertainty in damage responses at all. These are uncertainties separate from socioeconomic, climate, and SLR uncertainties. They are uncertainties in damages for a given socioeconomic, climate, and SLR projection.

Lastly, we note that the current sectoral damage approaches in DCSIM and GIVE do not capture potential interactions between damage categories—like agriculture and health. Some of the other frameworks in the literature do account for interactions and should be used to discuss this issue, if not incorporate interactions.

Provide needed additional methodological details and results to facilitate a full assessment

The damages module documentation should add the following additional information:

- All module methodological details, assessment and comparison to the literature, and justification, including implementation equations and parameters,
- Damage results without socioeconomic, climate, and SLR uncertainty to elucidate the damage specific response and uncertainty representations,
- Detailed undiscounted damage results over time, by country and damage category, and for different projections, as well as for incremental temperature change (like in Rose et al (2017, 2014) as recommended by NASEM (2017)),
- Detailed results by drivers other than global temperature (e.g., income and population) (like in Rose et al (2017, 2014) as recommended by NASEM (2017))
- Integration details, including equations, to elucidate how module results are calculated and linked across the framework (e.g., use of socioeconomic, climate, and SLR projections),
- Discussion of consistency across the socioeconomic and damage modules, as well as across the alternative damage formulations,
- Minimum and maximum values to all figures, and
- Standardized y-axis' when multiple graphs appear in one figure to facilitate comparison.

9. For the discounting module, we recommend:

   a. Revising to fully address NASEM recommendations,
   b. Revising dynamic discounting approach calibration choices to take into account the full set of relevant considerations, which would include revising the near-term target rates to 3-5%, the growth rate assumption to higher than implied, and discounting regionally,
   c. Removing the feature netting out damages from economic growth to ensure discounting consistency with projected growth,
   d. Revisiting the fixed savings rate assumption for consistency with economic growth and historical evidence, and

e. Providing needed additional methodological details and justification to facilitate a full assessment.

Revise to fully address NASEM recommendations

The current documentation for the discounting module should be enhanced to facilitate evaluation (NASEM Recommendation 2-2). It currently relies on the literature cited for essential details that need transparency, assessment, and justification. The calibration and calculation details need to be explicitly laid out for every aspect of the discounting approach. For instance, details are needed on the specific lines of evidence regarding observed rates, use of the probabilistic socioeconomic scenarios in the calibration, and assumptions and constraints during calibration (e.g., calibrating such that a "decline in certainty-equivalent discount rate path matches the latest empirical evidence").

Revise dynamic discounting approach calibration choices to take into account the full set of relevant considerations, which would include revising the near-term target rates to 3-5%, the growth rate assumption to higher than implied, and discounting regionally

NASEM (2017) recommended a dynamic discounting approach and it is good to see EPA propose using such an approach in their draft methodology. However, appropriate calibration choices are critical for proper implementation of the dynamic discounting approach. This includes the calibration choices regarding the near-term target discount rate, assumed economic growth rate, pure rate of time preference parameter (PRTP, commonly labeled rho), and elasticity of marginal utility of consumption parameter (commonly labeled eta). See Table 4 for EPA's calibration choices for their three near-term target rate calibrations and their assumed rho (ρ) and eta (η).

Table 4. EPA draft dynamic discounting calibration parameters. Source: EPA SC-GHG draft new methodology documentation**.**

Table 2.4.2: Calibrated Ramsey Formula Parameters

Near-Term Target Certainty-Equivalent Rate	ρ	η
1.5%	0.01%	1.02
2.0%	0.20%	1.24
2.5%	0.46%	1.42

Source: Rennert et al. (2022b)

A large set of factors are relevant to calibration and should be taken into account: theory, very long-run observations, empirical evidence, type of investment/trade-off estimated, duration of investment modeled, methodology, economic growth projections, and discounting in other benefit-cost calculations. Each of these factors constrains the calibration in some way, and all of them need to be considered.

For instance, the type of investment being modeled is extremely long-run. CO_2 is an investment in future climate change with an over 100-year return due to its very long life in the atmosphere and carbon cycle effects. Also, discounting needs to be consistent with the economic growth projections. The discount rate needs to ensure the investment implied by the projected economic growth. It is an equilibrium condition over time that needs to hold. The modeling is also projecting for centuries into the future, thus we need to evaluate centuries (or as far back as data allows) when drawing insights from historical observations, such as regarding observed market rates and economic growth. Theory, observations, and empirical evidence also tell us that rho is positive (people prefer current over future consumption) and eta is greater than one (the marginal utility of consumption is decreasing). Theory also suggests that eta less than 1.5 implies a very large savings rate of 67%, which is inconsistent with observations, as well as implies an unrealistic burden on current generations (Arrow, 1999). Furthermore, rho values of 0.1% (0.001) have been controversial due to their suggestion that consumers are close to indifferent between current and future consumption (e.g., Stern, 2006; Nordhaus, 2006). This critique would certainly apply to 0.01% (0.0001) as used by EPA (see Table 4). Note that, the discussion here is a very different context from that associated with Stern and Nordhaus. In their case, the discussion was about determining optimal global climate ambition. In this case, the discussion is simply about creating objective SC-GHG estimates that can be used to inform policy, not make it (Rose, 2022).

Regarding near-term target rates, rates of 3% to 5% are consistent with very long-run annual average observed rates, the types of investments being estimated within the damage module, the duration of the investment being modeled with GHGs, and discounting in other benefit-cost calculations. The 3% value specifically is consistent with very-long-run annual average observed rates for social security from 1870 to about 2005 (Figure 10). This type of investment is an appropriate benchmark because it has a very long investment horizon, reflects observed long-run trade-offs in consumption, and the very long historical data record captures long-run behavior consistent with the long-run SC-GHG modeling framework. This would be the appropriate near-term target rate if the damage calculations are truly consumption trade-offs. The 5% value, on the other hand, is consistent with viewing the damage calculations being modeled as investment trade-offs. It is also consistent with the very long investment horizon, long run historical observations for long run private investment trade-offs (e.g., public dam projects or nuclear waste), and long-run economic modeling, including modeling that considers trade-offs with benefits and costs and market and non-market damages (e.g., Nordhaus, 2010, 2017; Manne and Richels, 1992).

As for the economic growth assumed in calibration, a rate of approximately 2% for a global calibration is consistent with very-long run historical evidence (Figure 4). For example, the global average annual growth rate from 1960 to today is 1.9%. Given that the SC-GHG modeling is projecting centuries into the future, we need to evaluate growth rate behavior as far back as possible to inform our calibration choice regarding very long-run tendencies. Assessing economic growth rates over the last few decades (e.g., Rennert et al, 2022) is insufficient and inconsistent with the objective to estimate extremely long-run futures and outcomes.

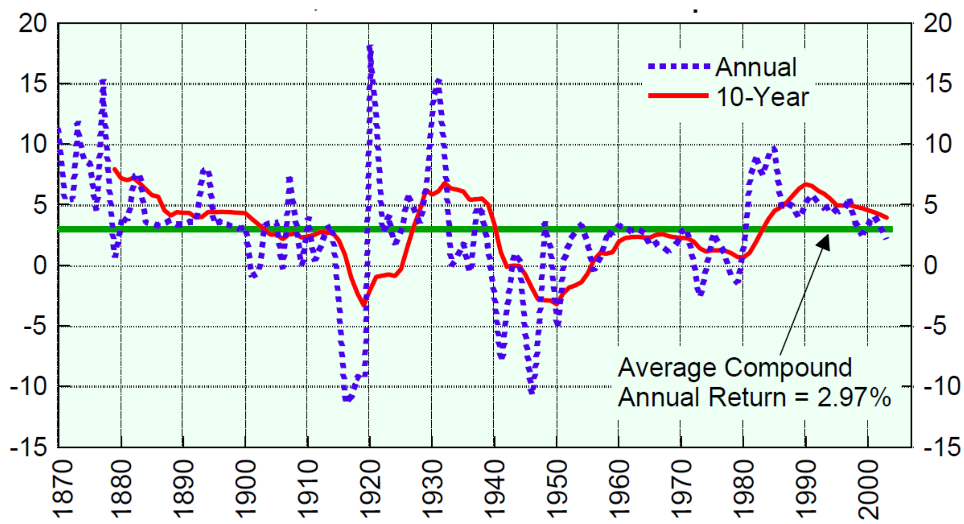


Figure 10. Government real interest rate for social security—annual percent and annualized 10-year compound return from 1870 to approximately 2005. Source: Girola (2005).

Taken together, the full set of factors imply very different calibration choices compared to what EPA proposed:

- **Near-term target discount rates should be in the range of 3% to 5% (vs. 1.5% to 2.5% currently proposed by EPA), and**
- **The assumed economic growth rate during calibration should be around 1.9% - 2% for a global calibration (vs. the annual average rate of 1.45% implied by EPA's current calibration).**

Revising these two calibration choices (relative to EPA's), results in very different rho and eta candidates that enforce the temporal equilibrium condition (see Table 5). For each near-term target rate, Table 5 explores potential calibrations with lower to higher rho values (Calibrations 1 through 4). Table 5 shows that the rho and eta values with near-term target rates of 3% to 5% differ notably from the values with near-term rates below 3%. Note, however, that near-term target rates of 2% and lower are not viable candidates when the assumed economic growth rate is 2%. This is because they do not satisfy the requirement that rho be positive and eta greater than one. Note also that very low rho values (e.g., 0.1% and 0.01%) are questionable given observed behavior regarding preferences for current consumption versus deferred consumption. Additional assessment is required to determine if near-zero rho values are consistent with empirical estimates for rho.

To illustrate the importance of the assumed economic growth rate in the calibration, the lower table in Table 5 provides candidate calibrations assuming an economic growth rate of 1.45%. From this exercise, we find that valid calibration candidates with a near-term target rate ≤ 2% cannot be produced. Thus, the validity of EPA's calibrations depends upon the economic growth assumption and its consistency with historical evidence. As shown in Figure 4, a growth rate of 1.45% is not consistent with very long-run observations.

Table 5. Exploration of Ramsey formula rho (ρ) and eta (η) global calibrations varying the near-term target discount rate and assumed global per capita consumption growth rate. Invalid calibrations indicated by red and questionable calibrations indicated by orange. Source: EPRI.

		Calibration 1		Calibration 2		Calibration 3		Calibration 4	
Near-term target discount rate	Assumed per capita consumption growth rate	PRTP (ρ)	Elasticity (η)	PRTP (ρ)	Elasticity (η)	PRTP (ρ)	Elasticity (η)	PRTP (ρ)	Elasticity (η)
1.0%	2.0%	0.1%	0.45	0.5%	0.25	1.0%	0.00	2.0%	-0.50
1.5%	2.0%	0.1%	0.70	0.5%	0.50	1.0%	0.25	2.0%	-0.25
2.0%	2.0%	0.1%	0.95	0.5%	0.75	1.0%	0.50	2.0%	0.00
2.5%	2.0%	0.1%	1.20	0.5%	1.00	1.0%	0.75	2.0%	0.25
3.0%	2.0%	0.1%	1.45	0.5%	1.25	1.0%	1.00	2.0%	0.50
4.0%	2.0%	0.1%	1.95	0.5%	1.75	1.0%	1.50	2.0%	1.00
5.0%	2.0%	0.1%	2.45	0.5%	2.25	1.0%	2.00	2.0%	1.50

		Calibration 1		Calibration 2		Calibration 3		Calibration 4	
Near-term target discount rate	Assumed per capita consumption growth rate	PRTP (ρ)	Elasticity (η)	PRTP (ρ)	Elasticity (η)	PRTP (ρ)	Elasticity (η)	PRTP (ρ)	Elasticity (η)
1.0%	1.45%	0.1%	0.62	0.5%	0.34	1.0%	0.00	2.0%	-0.69
1.5%	1.45%	0.1%	0.97	0.5%	0.69	1.0%	0.34	2.0%	-0.34
2.0%	1.45%	0.1%	1.31	0.5%	1.03	1.0%	0.69	2.0%	0.00
2.5%	1.45%	0.1%	1.66	0.5%	1.38	1.0%	1.03	2.0%	0.34
3.0%	1.45%	0.1%	2.00	0.5%	1.72	1.0%	1.38	2.0%	0.69
4.0%	1.45%	0.1%	2.69	0.5%	2.41	1.0%	2.07	2.0%	1.38
5.0%	1.45%	0.1%	3.38	0.5%	3.10	1.0%	2.76	2.0%	2.07

EPA's near-term target rates, however, are based on comparisons to 10-year Treasury rate behavior over the last few decades (1991-2020). In part, this seems to be based on a separate discussion regarding potential updates to OMB's Circular A-4 guidance for discounting consumption effects at 3%, which has historically been based on 10-year Treasury rates. Comparing to 10-year Treasury or other relatively short run observed investment rates over the last few decades, or even fifty years, is impractical given the century long GHG investments being modeled and multi-century SC-GHG modeling horizon. In addition to needing to compare to investments longer than 10 years, we need to go back centuries, or as far as possible, into historical observations to properly capture variability over time for the discounting parameterization for this multi-century modeling.

EPA also views their damage calculations as modeling trade-offs in consumption. Consumption trade-offs, however, do not appear to be what is computed in the damage calculations. None of the damage modules or sectoral approaches within them appear to be producing final results that are trade-offs between types of consumption (i.e., households substituting consumption A for B). Instead, the damage categories appear to be computing changes in private investment, aggregate consumption, or trade-offs with utility. The first two types of trade-offs are actually claims against GDP, with the final calculations either direct trade-offs within investment or trade-offs between aggregate consumption and investment in the macro economy. These are the kinds of final damage calculations we see with agriculture, sea-level rise losses and costs, energy expenditures, and health labor productivity. On the other hand, damage categories that are trades-off with utility (e.g., health mortality) are conceptually a fraction of utility which is a function of aggregate consumption-investment. Thus, all the damage calculations appear to be consistent with trade-offs at the macroeconomic level. Historically, very long-run integrated assessment modeling that considers market and non-market damages, discount them as macroeconomic investment and utility trade-offs, with near term target rates of ~5% (e.g., Nordhaus, 2010, 2017; Manne and Richels, 1992).

EPA's discounting calibration process also appears to assume declining certainty-equivalent discount rates, arguing that structural change has occurred over the last few decades (1991-2020 vs before) with a new equilibrium and lower rates that will persist. It is a strong assumption to assume that the lower rates will persist for 300 years. It should be clarified how this is actually implemented. More importantly, however, this assumption should be revisited using the very long run historical data record for very long-run investments (over 30 years), which is more appropriate information for informing this assumption in this type of framework.

Finally, we note that global discounting should be made consistent with the projected regional economic growth. Regional discounting, using the regional economic growth projections, are needed for discounting that enforces the temporal equilibrium requirement for each region and provides discounting consistent with projected growth. Figure 4 illustrates the large differences in regional historical growth. These differences are projected in the socioeconomic projections as well and the discounting should be consistent.

Ultimately, dynamic discounting should vary with socioeconomic scenario, time, and region for economic coherency—discount rates that are consistent with projected growth over space and time.

Remove the feature netting out damages from economic growth to ensure discounting consistency with projected growth

EPA notes on page 55 that "When using the Ramsey formula to estimate the SC-GHG, the per capita consumption growth rate, g_t is calculated net of baseline climate change damages as estimated by the damage modules described in Section 2.3." First, the equation and specific adjustment values should be explicitly communicated, and discussion and justification added regarding the implementation. Second, calculating the economic growth rate net of damages is problematic and should be removed. If damages are changing the projected economic growth rates, then the resulting discount rate is no longer consistent with assumed growth and the required equilibrium condition that insures that deferred consumption is sufficient for projected growth no longer holds. Finally, introducing economic growth damages here is inconsistent with the discussion on page 49 of the documentation regarding the inconclusive evidence on damages to growth that EPA uses to explain why damages to growth are not represented in the damage module. It is also worth noting that this approach suggests that EPA views the damages as claims on investment that impact growth, which is inconsistent with use of consumption near-term target interest rates.

Revisit the fixed savings rate assumption for consistency with economic growth and historical evidence

As discussed earlier, the fixed savings rate assumption that determines the consumption per capita growth rate used in the discounting should be revisited and revised. This has significant implications for growth rates used in EPA's discounting.

Provide needed additional methodological details and justification to facilitate a full assessment

The discounting module documentation should add the following additional information:

- All module methodological details, assessment and comparison to the literature, and justification, including implementation equations and parameters,
- Details on the discounting calibration are needed from the literature used to make EPA's documentation self-contained, as are details and justification for the module's implementation in the framework, and
- Specific annual discount rate pathways for the individual economic growth projections – Figure 2.4.1 in the draft methodology documentation is too stylized (time-averaged, mean and percentiles across socioeconomic projections) for understanding and evaluating the module.

10. For the SC-GHG estimates results in the documentation, we recommend providing more detailed SC-GHG results, discussion, assessment, and justification to allow for full assessment.

EPA's documentation currently provides only a few SC-GHG results and just descriptive discussion. To properly evaluate the modeling, additional detailed results are needed, as well as explanations for what is produced, and justification for what is found. For instance, discussion, assessment, and justification are needed for differences in results across damage modules (e.g., the differences in the SC-GHG distributions across damage modules, the large differences in DCSIM versus GIVE health and agricultural SC-GHG values). Are the differences appropriate and defensible? Furthermore, sectoral SC-GHG distribution results are needed, and should be assessed, as are results for other discount rates and years.

11. For cross-module linkages, we recommend providing transparency, including equations, parameters, and examples regarding module linkages and integration, and including discussion of consistency and uncertainty.

As noted in the module discussions above, the explicit linkages between modules should be clarified and specified in the documentation. How results are flowing from one module to another and how they are specifically integrated within each module should be fully transparent. Furthermore, discussion of the linkages is needed in the text, especially with respect to consistency and uncertainties. For instance, as mentioned earlier, sub-global uncertainty for a single global emissions pathway is significant with many sub-global societies consistent with any global pathway. See, for instance, Figure 2.

12. For the GHG emissions pulses, we recommended revisiting the large GHG emissions pulse size used (1 GtC for SC-CO_2 calculations) and discussing and assessing non-linearity and justifying choices.

EPA's draft SC-CO_2 modeling uses a relatively large emissions pulse of one billion metric tons of carbon (1 GtC/year) to compute the SC-CO_2 estimates. This is a pulse of 3.67 billion metric tons of carbon dioxide (3.67 GtCO_2/year). Thus, the \$/tCO_2 estimates reported as EPA's SC-CO_2 values in a particular year are actually the average per metric ton annual damage over 3.67 billion metric tons of CO_2 emitted in that particular year. Note that, the pulse sizes used for computing the social costs of methane and nitrous oxide are currently unclear. First off, transparency is needed on the pulses used. Second, justification is needed, which includes discussing potential bias given non-linearities in both the climate and damage modules from deriving an average per ton SC-GHG result from implementing a large pulse.

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Appendix B: EPRI public comments on EPA's Social Cost of Greenhouse Gasses (SC-GHG) peer review process and candidates. Submitted December 1, 2022 to EPA's peer review contractor. Available at https://www.epri.com/sc-ghg.

December 1, 2022

Subject: SC-GHG Peer Review

Dear Versar (U.S. EPA contractor for SC-GHG Peer Review Panel),

Thank you for the opportunity to comment on the peer review for the draft social cost of greenhouse gases (SC-GHG) estimation methodology released by U.S. EPA on November 11, 2022 (USEPA, 2022). As a science organization, EPRI appreciates that the President's administration is taking steps to facilitate the development of science-based SC-GHG estimates and applications such as reconstituting the SC-GHG Interagency Working Group (IWG) and engaging the public through comment opportunities such as this. EPRI has been studying SC-GHG methodologies specifically for almost two decades and has over forty years of research experience in the core science underlying SC-GHG calculations. EPRI's SC-GHG research includes analyzing in detail the models and assumptions used for SC-GHG estimation, as well as detailed assessment of applications using SC-GHG estimates. EPRI's expertise and research led to participation on the National Academy of Science, Engineering, and Medicine (NASEM) Social Cost of Carbon Committee as a committee member. EPRI's assessment of the IWG SC-GHG estimation framework used by this and previous administrations (Rose et al, 2017, 2014) was a primary input into the NASEM SCC Committee deliberations and the resulting NASEM studies (NASEM, 2016, 2017). These are the same NASEM studies referenced in the President's January 2021 Executive Order 13990 (Executive Order on Protecting Public Health and the Environment and Restoring Science to Tackle the Climate Crisis) as important methodological resources the IWG should consider when developing an updated SC-GHG methodology.

EPRI is a nonprofit, scientific research organization with a public benefit mission. EPRI strives to advance knowledge and facilitate informed public discussion and decision-making. EPRI has recognized scientific expertise in the social costs of carbon and other greenhouse gases, climate scenarios, integrated assessment modeling, socioeconomic and energy system transformation, and climate policy evaluation, as well as a long history of research community leadership and participation in the Intergovernmental Panel on Climate Change (IPCC), National Climate Assessment, and NASEM. See the [Appendix A] for examples of EPRI's SC-GHG related research, including EPRI's 2021 publication identifying needed repairs to the "interim" SC-GHG estimation methodology and current applications to ensure scientific reliability, as well as discussion of key technical challenges that need to be addressed by any new SC-GHG estimation approach (EPRI, 2021b).

EPRI has previously provided public comments to the administration discussing the importance of prioritizing science and developing scientifically reliable estimates before use, as well as identifying key challenges to address in developing a new methodology and estimates (EPRI, 2021a, 2021b). EPRI also recently published an article discussing the importance of a sound scientific process to producing scientifically reliable SC-GHG estimates and what that would entail, including successfully completing an appropriate peer review (Rose, 2022).

EPRI observes that EPA's proposed peer review and overall scientific process is insufficient to develop scientifically robust and reliable estimates and insufficient for the public to have confidence in the outcome. Based on EPRI's research and experience in this area, the process needs to:

1. **Revise the peer review candidate selection process and list to ensure full and unbiased coverage of the core scientific disciplines underpinning the SC-GHG,**
2. **Expand the peer review process to a scientific review process appropriate for a regulatory methodology with significant implications,**
3. **Substantially increase opportunities for public engagement and input, and**
4. **Improve the overall scientific process for developing and using updated SC-GHG estimates.**

The remainder of our comments discuss each of these recommendations in more detail.

Revising the peer review candidate selection process and list to ensure full and unbiased coverage of the core scientific disciplines underpinning the SC-GHG

An appropriate panel selection process is needed. Such a process would include **appropriate reviewer selection criteria** that emphasizes the needed disciplinary expertise to evaluate the science represented within SC-GHG calculations. Estimating SC-GHG values is a complex undertaking building off multiple scientific disciplines. Creating such estimates requires core scientific expertise explicitly in each of the underlying sciences relevant to the different modules or components associated with doing SC-GHG calculations:

- Global population, economic, and emissions projections
- Global climate system dynamics
- Other global earth system dynamics (e.g., regional climate change, sea level rise)
- Climate change physical impacts (e.g., crop productivity, health, water)
- Climate economic impacts estimation
- Discounting methodologies.

A peer review panel should include expertise related to the science associated with each of the SC-GHG modeling elements above to ensure appropriate scientific review of the underlying approaches for representing each element. In addition, given the need to represent current scientific knowledge and capture uncertainty, the panel should also have familiarity with the literature and alternative methods, and literature assessment experience bringing together information from different methodologies and lines of evidence. Furthermore, a peer review panel requires reviewers who are not invested in a specific approach or methodology and/or balancing is needed across selected reviewers to ensure representation and reconciliation of the different approaches and methodologies. Finally, a peer review panel requires reviewers who are free of conflicts of interest with respect to policy positions and advocacy organizations.

Appropriate panel selection to cover these disciplines and attributes also requires **transparent panel selection and public input**. Transparent panel selection includes transparency regarding nominees, the evaluation of nominees in identifying candidates, and final panel selection. Public input on all aspects of panel selection is also needed—e.g., selection criteria, panel size and composition.

Appropriate panel composition in this case implies a panel of at least fourteen panelists. This would allow for at least two experts for each of the relevant core scientific disciplines (and sub-disciplines related to unique methodologies and areas of science). The core scientific disciplinary (and sub-disciplinary) expertise needed includes the following:

- *Integrated assessment model building* – experts in building structural and aggregate integrated assessment models. These are not researchers that are users of these models (e.g., running the DICE model), or doing tangential analysis evaluating the addition of a new feature, but those who have significant model building experience and know the decisions that need to be made in terms of model structure, equation specification, parameters, input data, and uncertainty specification and evaluation.
- *Economic projections and model builders* – experts in building global economic projections and models. These are not researchers that are users of these models (e.g., running a CGE model), or doing tangential analysis evaluating the addition of a new feature, but those who have significant model building experience and know the decisions that need to be made in terms of model structure, equation specification, parameters, input data, and uncertainty specification and evaluation.
- *Demographic projections* – experts who project future global populations and demographic groups (e.g., related to age, race, and gender)
- *Discounting* – experts in alternatives and technical considerations associated with discounting future economic effects.
- *Climate and other earth science* – experts in global and reduced complexity climate modeling, downscaling, carbon-cycle modeling, regional climate change, and sea level rise.
- *Climate impacts* – experts in evaluating potential physical and economic impacts of climate change for different types of impacts, as well as experts in different economic impacts estimation methodological approaches and their differences (statistical and structural methodologies).

Note that cost-benefit analysis and environmental economics are not listed as core expertise. They are not core sciences for SC-GHG calculations and tangential to the primary expertise needed to assess a proposed SC-GHG estimation methodology. The former is an application of SC-GHG estimates, and the latter too general and not focused on the specific expertise and skills needed.

Overall, **the selection criteria and process to date are not providing the expertise needed** for an appropriate review and for scientifically reliable estimates. EPRI observes:

- The **candidate selection implementation is lacking transparency** regarding who was nominated, by whom, and the scoring each nominee received and why. Nor has the candidate selection process been subject to comment.
- The **panel selection process from the candidates is unknown**, including clarifying how public input will be used.
- The **current candidates do not represent all the expertise and depth of expertise needed**. The current candidates list is inadequate (in terms of missing core expertise and/or multiple experts

per area) in the following: integrated assessment modeling, economic modeling, demographic projections, discounting, climate modeling, sea level rise, and impacts estimation.

- The current list exhibits **conflicts of interest** due to some being authors of key elements of EPA's draft methodology, others having close affiliations with the organizations developing key research used in the proposed draft methodology, previous affiliations with the IWG and EPA's NCEE, and conflicts in terms of affiliations with advocacy organizations.
- The current list includes **candidates invested in a particular modeling approach** and potentially biased towards that approach**.**

For comparison, the NASEM SCC Committee consisted of twelve members and would have benefitted from being larger to fully cover the required core expertise with multiple experts for each (NASEM, 2016, 2017). Another useful point of comparison is EPA's SAB biogenic emissions accounting methodology expert review panel (Khanna et al, 2012, 2017). Like with SC-GHG calculations, this panel required diverse physical and social science expertise. In this case it required expertise in, among other things, soil science, climate science, forestry, crop science, economics, and the carbon cycle, to adequately review EPA's proposed biogenic emissions accounting methodology. Not only did this panel require diverse expertise, it appropriately assembled that expertise with a panel of eighteen experts, the panelists were given a clear charge, the panel was required to produce consensus recommendations, and the public had clear engagement opportunities to inform the panel and review process.

Given these observations, **EPRI recommends that the selection criteria be revised, and a new set of candidates be selected**, with a transparent process to down-select to **at least fourteen panelists covering the core scientific areas** identified above with multiple experts per area, and with **public transparency and the opportunity to engage and provide input.**

Expanding the peer review process to a scientific review process appropriate for a regulatory methodology with significant implications

EPRI observes that the proposed peer review process is unclear on its purpose and falls short of a full scientific review process appropriate for a regulatory methodology.

First, **clarification is needed on what is under review? In particular, is this the IWG's proposed new SC-GHG methodology in response to the president's EO 13990 request?** There is confusion about this in the public and within the scientific community that is unnecessary and needs to be resolved. Peer reviews that state clear objectives and scope at the beginning of a review process help bring the necessary transparency to build trust with the public and scientific community. When expectations are well understood, stakeholders avoid misunderstandings and participants can work more effectively to meet objectives. It is important that the relationship between the EPA and IWG efforts be clearly defined. This includes clarification on whether EPA's draft new methodology and peer review are the IWG's proposed new SC-GHG methodology and peer review; and, if not, how specifically EPA's draft methodology and peer review relate to the IWG's methodology development and its peer review. For instance, will there be a separate IWG methodology peer review and how will it use the EPA draft new methodology and peer review process results? Or, is this peer review process intended to address both? The latter is problematic, especially if the peer review process is inadequate (discussed next).

Second, the nature of **how the peer review will be conducted** has not been communicated or subjected to comment. For instance, what is the specific charge to the panel? What are the panel's steps in the peer review and the product? What is the timing for the review? Will panel consensus recommendations be required, and if not, why? Will a successful panel consensus determination of scientific reliability be required for using updated estimates, and if not, why? It is also worth noting that the peer review process thus far is inconsistent with EPA's peer review guidance (USEPA, 2015), e.g., allowing for public comment on the proposed charge, expertise required, and panel composition.

Third, the **review panel selection process thus far lacks transparency** and the **expertise represented in the candidate list is insufficient.** The importance of these issues is discussed above.

Fourth, **public input opportunities and the process** for providing input and how that input will be used are currently unknown.

Finally, we note that EPA is **not seeking peer review input on appropriate application of SC-GHG estimates**. This is a substantial shortfall in the process. EPRI's research has shown that there are significant issues with current use of SC-GHG estimates that undermine benefit-cost analysis insights as well as result in costly economically inefficient decarbonization policy (e.g, EPRI, 2022; EPRI, 2021b; Rose and Bistline, 2016; Bistline and Rose, 2018).

EPRI recommends that EPA develop a scientific review process appropriate for a regulatory methodology. This would be a review process that emphasizes scientific integrity and robustness to achieve public credibility for guiding decisions with significant social and financial implications. This is a substantially higher bar than a journal article review. Such a peer review is more rigorous and critical, reviewing every detail, choice, and justification, as well as intermediate internal calculations and final estimates. It also requires the review panel to produce **consensus recommendations** agreed to by all the reviewers, including a consensus decision on whether the methodology and estimates are scientifically robust and reliable. Furthermore, **use of the new estimates would be prohibited** until the review panel has established the new methodology's scientific reliability. Getting to this point may require EPA to revise the methodology in response to review panel feedback and then review of the modified methodology by the panel. This revise and re-review iteration process should be repeated as necessary to reach scientific reliability.

An appropriate peer review process would also require **selecting an appropriate panel** to carry out the peer review, as well as **clear public engagement process and opportunities to comment**. Lastly, it should follow **EPA's peer review guidance** (USEPA, 2015).

Substantially increasing opportunities for public engagement and input

Public engagement is important for constructive feedback and public confidence in the outcome. This entails **providing explicit opportunities for dedicated public input on the draft new methodology, opportunities for public input into the peer review process, and a clearly defined relationship between the public input and the peer review processes.** Ideally, public input should happen before peer review, not concurrent with it, and not after it.

EPRI observes that there are **few opportunities and communications on how the public can engage and how their feedback will be used**. It is unclear whether EPA is requesting public input on the draft new methodology through the recently proposed oil and gas methane rule. This is problematic because the SC-GHG methodology comments will be confounded by the comments being received on all aspects of the proposed methane rule.

EPRI recommends establishing a clear public engagement process and opportunities to comment in all phases, to ensure that the full relevant scientific literature can be brought to bear in the review.

Improving the overall scientific process for developing and using updated estimates

The overall scientific process for developing and using SC-GHG estimates needs to be guided by scientific due diligence **from start to finish to ensure a scientifically robust and reliable methodology, estimates, and use of estimates**. The peer review is just one part of a larger scientific process. The larger process includes assessing the science, providing transparency, justifying choices, developing a methodology fit for this purpose, separating science from policy, establishing robustness of estimates, using the estimates properly, successfully completing an appropriate scientific review, and engaging the public. Not doing these things leaves the estimates vulnerable to scientific, political and public criticism, and even manipulation. See Rose (2022) for discussion of each of these elements of scientific due diligence.

We see clear **opportunities for improving the overall scientific process to facilitate the peer review, scientific community and public assessment and engagement, and ultimately public confidence**. The improvement opportunities include providing additional methodology and choice details and justification, additional intermediate results and justification, and additional consideration of alternatives and uncertainties. This, of course, is in addition to executing an appropriate scientific peer review and providing clear and sufficient public engagement opportunities.

In summary, for 50 years EPRI has found that a scientifically robust process can deliver reliable estimates and build public confidence in the outcome. Collaboration is at the core of EPRI's public mission, and our comments aim to enhance government collaboration with the scientific community to support the development of scientifically robust and reliable estimates and well-informed decision-making.

Thank you again for the opportunity to provide input into this important activity. For questions related to our comments, or the research and insights discussed, please contact Steven Rose (srose@epri.com) and David Young (dyoung@epri.com).

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