April 11, 2018

To: Office of Surface Mining Reclamation and Enforcement, U.S. Department of the Interior

Subject: Comments on the Failure to Use the Social Cost of Greenhouse Gases in the Environmental Assessment for Modifying the Federal Mining Plan at Bull Mountains Mine No. 1

Submitted by: Environmental Defense Fund, Institute for Policy Integrity at New York University School of Law, Sierra Club, Union of Concerned Scientists[1]

This environmental assessment (EA) prepared by the Office of Surface Mining and Reclamation Enforcement (OSM) on modifying the federal mining plan for Bull Mountains Mine No. 1, proposes extending operations at a mine by an additional 9 years and producing 86.7 million tons of coal.[2] While the EA quantifies the tons of greenhouse gas emissions related to this project, OSM fails to use the social cost of greenhouse gas metric to fully account for the climate effects of these emissions. OSM explicitly chose not to monetize the impact of emissions by using the social costs of greenhouse gases in its analysis for a number of flawed reasons. The agency's refusal is arbitrary and unlawful in light of a growing body of case law holding that failure to monetize a project's costs is impermissible if the agency relies on the project's monetized benefits to justify its action. The refusal is also arbitrary in light of the growing consensus around the appropriate social cost of greenhouse gas values to use in environmental impact statements.

These comments explain why each of OSM's reasons for not using the social cost of greenhouse gases in the DEIS fails, and why the DEIS leaves the public and decisionmakers in the dark about the climate effects of the project, in violation of NEPA. Specifically:

1. NEPA requires a "reasonably thorough discussion" and "necessary contextual information" on climate impacts. The social cost of greenhouse gases provides such information, while the mere recitation of so many tons of carbon that will be emitted by the project fails to provide the public and decisionmakers with the required information. Moreover, when an agency monetizes a project's potential benefits—as OSM does here—the potential climate costs must be treated with proportional rigor.
2. The social cost of greenhouse gases metric is appropriate for a project-level EIS with emissions of this magnitude. The metric can be applied to any action that significantly increases greenhouse gas emissions, not just to rulemakings. The uncertainty around factors like catastrophic outcomes that cannot currently be fully monetized is not a reason not to use the metric, but rather a reason to treat available values as lower-bound estimates of the true climate costs of emissions.
3. The Interagency Working Group's 2016 estimates of the social cost of greenhouse gases remain the best available values for federal agencies to use in analyses.

[1] Our individual organizations may separately submit other comments regarding other aspects of the EA.

[2] Office of Surface Mining Reclamation and Enforcement, *Bull Mountains Mine No. 1 Federal Mining Plan Modification: Environmental Assessment* at 69 (2018) (hereinafter "EA").

1. NEPA Requires a "Reasonably Thorough Discussion" and "Necessary Contextual Information" on Climate Impacts, Which the Social Cost of Greenhouse Gases Provides

OSM fails to discuss the actual climate impacts of the project, even though it quantifies the tons of greenhouse gas emissions from the mine's present and future operations. OSM neither quantitatively nor qualitatively discusses the damages to which these additional tons of greenhouse gases would contribute. Meanwhile, OSM has monetized effects like billions of dollars' worth in revenue.[3] Failing to similarly monetize the climate costs of the project is inconsistently arbitrary and deprives the public and decisionmakers of the information and context they need to weigh all the project's potential effects. OSM is wrong that there is "no . . . requirement to apply the SCC protocol to project decisions" like this one;[4] in fact, it is required by NEPA.

NEPA Requires Monetizing Climate Effects If Other Costs and Benefits Are Monetized

NEPA requires "hard look" consideration of beneficial and adverse effects of each alternative option for major federal government actions. The U.S. Supreme Court has called the disclosure of impacts the "key requirement of NEPA," and held that agencies must "consider and disclose the actual environmental effects" of a proposed project in a way that "brings those effects to bear on [the agency's] decisions."[5] Courts have repeatedly concluded that an EIS must disclose relevant climate effects.[6] Though NEPA does not require a formal cost-benefit analysis,[7] agencies' approaches to assessing costs and benefits must be balanced and reasonable. Courts have warned agencies that "[e]ven though NEPA does not require a cost-benefit analysis," an agency cannot selectively monetize benefits in support of its decision while refusing to monetize the costs of its action.[8]

In *High Country Conservation Advocates v. Forest Service*, the U.S. District Court of Colorado found that it was "arbitrary and capricious to quantify the *benefits* of the lease modifications and then explain that a similar analysis of the *costs* was impossible when such an analysis was in fact possible."[9] The court explained that, to support a decision on coal mining activity, the agencies had "weighed several specific economic benefits—coal recovered, payroll, associated purchases of supplies and services, and royalties," but arbitrarily failed to monetized climate costs using the readily available social cost of carbon protocol.[10]

Even more directly relevant here, in *Montana Environmental Information Center v. Office of Surface Mining* (*MEIC v. OSM*), the U.S. District Court of Montana followed the lead set by *High Country* and likewise held an environmental assessment to be arbitrary and capricious because it quantified the

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[3] EA at 69-70, appendix G.

[4] EA at D-6.

[5] *Baltimore Gas & Elec. Co. v. Natural Res. Def. Council*, 462 U.S. 87, 96 (1983).

[6] As the Ninth Circuit has held: "[T]he fact that climate change is largely a global phenomenon that includes actions that are outside of [the agency's] control . . . does not release the agency from the duty of assessing the effects of *its* actions on global warming within the context of other actions that also affect global warming." *Ctr. for Biological Diversity v. Nat'l Highway Traffic Safety Admin.*, 538 F.3d 1172, 1217 (9th Cir. 2008); *see also Border Power Plant Working Grp. v. U.S. Dep't of Energy*, 260 F. Supp. 2d 997, 1028-29 (S.D. Cal. 2003) (failure to disclose project's indirect carbon dioxide emissions violates NEPA).

[7] 40 C.F.R. § 1502.23 ("[T]he weighing of the merits and drawbacks of the various alternatives need not be displayed in a monetary cost-benefit analysis.").

[8] *High Country Conservation Advocates v. Forest Service*, 52 F. Supp. 3d 1174, 1191 (D. Colo. 2014); *accord. MEIC v. Office of Surface Mining*, 15-106-M-DWM, at 40-46 (D. Mt., August 14, 2017) (holding it was arbitrary for the agency to quantify benefits in an EIS while failing to use the social cost of carbon to quantify costs, as well as arbitrary to imply there would be no effects from greenhouse gas emissions).

[9] 52 F. Supp. 3d at 1191.

[10] *Id.*

benefits of action (such as employment payroll, tax revenue, and royalties) while failing to use the social cost of carbon to quantify the costs.[11] That decision centered on a previous EA conducted by OSM for modification of the same mining plan for Bull Mountains Mine No. 1.[12] OSM has failed to meaningfully address that court's ruling on the arbitrary failure to use the social cost of greenhouse gas metrics.

Both *High Country* and *MEIC v. OSM* were in line with *Center for Biological Diversity v. National Highway Traffic Safety Administration*.[13] In that case, the U.S. Court of Appeals for the Ninth Circuit ruled that, because the agency had monetized other uncertain costs and benefits of its vehicle fuel efficiency standard—like traffic congestion and noise costs—its "decision not to monetize the benefit of carbon emissions reduction was arbitrary and capricious."[14] Specifically, it was arbitrary to "assign[ ] no value to *the most significant benefit* of more stringent [vehicle fuel efficiency] standards: reduction in carbon emissions."[15] When an agency bases a rulemaking on cost-benefit analysis, it is arbitrary to "put a thumb on the scale by undervaluing the benefits and overvaluing the costs."[16]

In this EA, OSM continues to monetize the same basic economic benefits as in *MEIC v. OSM*—hundreds of millions of dollars' worth in income, royalties, taxes, and revenue[17]—and so is required to be consistent in monetizing other significant effects, including climate costs. OSM seemingly tries to skirt the precedent set by *MEIC v. OSM* by identifying these economic benefits as "economic impacts." The EA reads, "any increased economic activity, in terms of revenue, employment, labor income, total value added, and output . . . is simply an economic impact, rather than an economic benefit, inasmuch as such impacts might be viewed by another person as negative or undesirable impacts."[18] However, in *MEIC v. OSM*, the District Court of the District of Montana dismissed this same argument as "a distinction without a difference."[19] Despite OSM's attempts to use terminology to distinguish the impacts it wants to monetize from those impacts it would prefer not to monetize, NEPA regulations group all these impacts under the same category of "effects": economic and social impacts are listed as "effects" alongside ecological and health impacts, and all these effects must be discussed in as much detail as possible in an environmental impact statement.[20] It is arbitrary to apply inconsistent protocols for analysis of some effects compared to others, and to monetize some effects but not others that are equally monetizeable.

Moreover, in obligating agencies to take "hard look" at projects' climate impacts, NEPA requires more than simply disclosing the volume of anticipated emissions.[21] As discussed further below, under NEPA,

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[11] 15-106-M-DWM, at 40-46, Aug. 14, 2017 (also holding that it was arbitrary to imply that there would be zero effects from greenhouse gas emissions).

[12] *Id.* at 35.

[13] Three other cases from different courts that have declined to rule against failures to use the social cost of carbon in NEPA analyses are all distinguishable by the scale of the action or by whether other effects were quantified and monetized in the analysis. *See League of Wilderness Defenders v. Connaughton*, No. 3:12-cv-02271-HZ (D. Ore., Dec. 9, 2014*); EarthReports v. FERC*, 15-1127, (D.C. Cir. July 15, 2016); *WildEarth Guardians v. Zinke*, 1:16-CV-00605-RJ, at 23-24, (D. N.M. Feb. 16, 2017).

[14] 538 F.3d 1172, 1203 (9th Cir. 2008).

[15] *Id.* at 1199.

[16] *Id.* at 1198.

[17] EA at G-6.

[18] *Id.* at D-6 ("any increased economic activity, in terms of revenue, employment, labor income, total value added, and output, that is expected to occur with the proposed action is simply an economic impact, rather than an economic benefit, inasmuch as such impacts might be viewed by another person as negative or undesirable impacts due to potential increase in local population, competition for jobs, and concerns that changes in population will change the quality of the local community").

[19] *Supra* note 8 at 40, n.9.

[20] 40 C.F.R. §1508.8.

[21] *Supra* notes 5-6.

agencies must provide details on discrete effects of a project's impacts within the relevant context. The social cost of greenhouse gases provides this critical information.

The Social Cost of Greenhouse Gases Reflects the Value of Discrete Climate Damages, and Gives Necessary Context to Climate Damages

OSM argues that "the SCC [social cost of carbon] protocol does not measure the actual incremental impacts of a project on the environment."[22] This statement reveals a deep misunderstanding of the design and proper application of the social cost of greenhouse gases. Not only is the social cost of greenhouse gas methodology ideally suited for valuing the marginal climate damages of individual projects, but the monetization directly reflects the "actual incremental impacts" of emissions on climate change. Monetization is actually a more useful way under NEPA to present the information to decisionmakers and the public than a qualitative description of discrete effects or a mere tallying of the tons of emissions.

The social cost of greenhouse gases directly reflects the discrete effects of climate change.[23] The three integrated assessment models used to calculate the social cost of greenhouse gases together incorporate such damage categories as: agricultural and forestry impacts, coastal impacts due to sea level rise, impacts to the energy and water sectors, impacts from extreme weather events, vulnerable market sectors impacted by changes in energy use, human health impacts including malaria and pollution, outdoor recreation impacts and other non-market amenities, impacts to human settlements and ecosystems, and some catastrophic impacts.[24] Though some important damage categories are currently omitted due to insufficient data and modeling,[25] the integrated assessment models do a reasonable job of capturing many of the discrete climate effects that decisionmakers and the public care about.

Monetizing climate damages provides the informational context required by NEPA, while a purely quantitative estimate of tons or a qualitative description of discrete climate effects like sea-level rise provide little context. Courts review NEPA documents "under an arbitrary and capricious standard," which requires "a reasonably thorough discussion of the significant aspects of the probable environmental consequences," to "foster both informed decisionmaking and informed public participation."[26] In particular, "the impact of greenhouse gas emissions on climate change is precisely the kind of cumulative impact analysis that NEPA requires," and it is arbitrary to fail to "provide the necessary contextual information about the cumulative and incremental environmental impacts."[27]

To "provide the necessary contextual information," economic theory shows that one useful tool is monetization of environmental impacts. As Professor Cass Sunstein has explained, drawing from the work of recent Nobel laureate economist Richard Thaler, a well-documented mental heuristic called "probability neglect" causes people to irrationally reduce small probability risks entirely down to zero.[28]

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[22] EA at D-6.

[23] As a comparison, while a carbon price developed for a carbon tax arguably measures the value of a constrained resource (i.e., carbon emission allowances), the integrated assessment models used to calculate the social cost of greenhouse gases directly measures climate damages.

[24] See descriptions of the IAMs at pages 6-8 of the Interagency Working Group on the Social Cost of Carbon's 2010 Technical Support Document.

[25] Peter Howard, *Omitted Damages: What's Missing from the Social Cost of Carbon* (2014), *available at* http://costofcarbon.org/files/Omitted_Damages_Whats_Missing_From_the_Social_Cost_of_Carbon.pdf.

[26] *Ctr. for Biological Diversity*, 538 F.3d at 1194 (citations omitted). *See also Montana Envtl. Info. Ctr. v. Office of Surface Mining*, cv 15-106-M-DWM, at 12-13 (D.Mt., Aug. 14, 2017).

[27] *Ctr. for Biological Diversity,* 538 F.3d at 1217; *see also Montana Envtl. Info. Ctr.,* cv 15-106-M-DWM at 45.

[28] Cass R. Sunstein, *Probability Neglect: Emotions, Worst Cases, and Law*, 112 Yale L. J. 61, 63, 72 (2002).

In this case, for example, many decisionmakers and interested citizens would wrongly reduce down to zero the climate risks associated with the 0.44% of total global emissions that OSM calculates will be emitted directly and indirectly from the project,[29] simply due to the leading zeros before the decimals. Yet the monetized expected cost of the climate risks associated with those same emissions—hundreds of millions of dollars—is less likely overlooked. As the Environmental Protection Agency's website explains, "abstract measurements" of so many tons of greenhouse gases can be rather inscrutable for the public, unless "translat[ed] . . . into concrete terms you can understand."[30] Monetization contextualizes the significance of the additional tons of emissions.

Similarly, non-monetized effects are often irrationally treated as worthless.[31] On several occasions, courts have struck down administrative decisions for failing to give weight to non-monetized effects.[32] Most relevantly, in *Center for Biological Diversity v. NHTSA*, the U.S. Court of Appeals for the Ninth Circuit found it arbitrary and capricious to give zero value "to the most significant benefit of more stringent [fuel economy] standards: reduction in carbon emissions."[33]

OSM is required by NEPA to provide enough context to ensure that the public and decisionmakers would not overlook the associated climate risks. Monetization is one way that OSM could provide the necessary context to foster both informed decisionmaking and informed public participation.[34] As the OSM itself has explained in a previous environmental impact statement from 2015, including the social cost of greenhouse gases in a NEPA document "provide[s] further context and enhance[s] the discussion of climate change impacts in the NEPA analysis."[35] In that 2015 EIS, OSM noted that the social cost of greenhouse gases is representative of "net" climate-induced effects, meaning the estimates take into account both costs and benefits from climate change.[36] OSM's use of the social cost of greenhouse gases in 2015 proves that the metric is readily available and appropriate for NEPA analyses of this type of action.

Finally, the social cost of greenhouse gas metric provides useful context even without a full cost-benefit analysis. OSM argues that without a complete cost-benefit analysis, including the so-called "social benefits of coal-fired energy production," applying the social cost of greenhouses gases would be inappropriate and inaccurate.[37] OSM is wrong. To begin, while the agency does not define what it means by "the social benefits of energy production," basic economic theory dictates that the value of coal in

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[29] DEIS at 489-490.

[30] EPA, Greenhouse Gas Equivalencies Calculator, https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator (last updated Sept. 2017).

[31] Richard Revesz, *Quantifying Regulatory Benefits,* 102 Cal. L. Rev. 1424, 1434-35, 1442 (2014).

[32] *See id.* at 1428, 1434.

[33] 538 F.3d at 1199.

[34] While the regulations promulgated by the Council on Environmental Quality to implement NEPA do not require a "monetary cost-benefit analysis," 40 C.F.R. § 1502.23, monetization nevertheless remains an available tool for contextualizing information. As the Council on Environmental Quality has explained, monetization may be "appropriate and relevant" and, in particular, "the Federal social cost of carbon . . . provides a harmonized, interagency metric that can give decision makers and the public useful information for their NEPA review." CEQ, *Final Guidance on Consideration of Greenhouse Gas Emissions and the Effects of Climate Change in National Environmental Policy Act Reviews* 32-33 & fn.86 (2016), *available* at https://obamawhitehouse.archives.gov/sites/whitehouse.gov/files/documents/nepa_final_ghg_guidance.pdf.

[35] Office of Surface Mining Reclamation and Enforcement, *Final Environmental Impact Statement—Four Corners Power Plant and Navajo Mine Energy Project* at 4.2-26 to 4.2-27 (2015), *available at* https://www.wrcc.osmre.gov/initiatives/fourCorners/documents/FinalEIS/Section%204.2%20-%20Climate%20Change.pdf.

[36] *Id.* at 4.2-25 ("The social cost of carbon (SCC) is a monetization of the effects associated with an incremental increase in carbon emissions. It is intended to quantify climate change-induced effects to net agricultural productivity, human health, property damage from increased flood risk, the value of ecosystem services and other factors.").

[37] EA at D-7.

the marketplace already is the best approximation of how much consumers value the welfare they derive from using the energy generated by coal. And the EA already includes several monetized metrics relating to the value of coal in the marketplace. For example, OSM calculates $73.4 million in federal and state royalties[38] which, assuming a 12.5% royalty rate on surface coal, would imply an approximate value in the marketplace of the coal produced at around $587 million. In short, the EA already contains monetized values relating to the value to consumers of the coal to be mined.

Regardless, whether or not an agency attempts to conduct a full cost-benefit analysis, NEPA requires that agencies disclose environmental effects with sufficient detail and context. As this section has explained, simply tallying the volume of emissions fails to give the public and decisionmakers the required information about the magnitude of discrete climate effects from those emissions. The social cost of greenhouse gas metric provides that necessary context. OSM's inadequate transparency regarding the exact economic output from the coal mined cannot serve as a justification for further obscuring the economic and environmental impacts of this proposal by omitting use of the social cost of greenhouse gas metrics.

2. The Social Cost of Greenhouse Gas Metric Is Appropriate for a Project-Level EIS with Emissions of this Magnitude

OSM next offers various arguments against using the social cost of greenhouse gases in this particular EA. OSM claims that the metric is only appropriate for rulemakings, and that the metric measures long-term effects and so applying it to an 9-year mine extension would result in uncertainties. In other similar NEPA documents, OSM has also often argued that there is no way to tell if a particular action's effects are significant enough to warrant use of the metric.[39] Each of these attacks fundamentally misunderstands the social cost of greenhouse gas metric.

First, despite OSM's claims that the social cost of greenhouse gases only apply to rulemakings,[40] the social cost of greenhouse gas methodology is well suited to measure the marginal climate damages of individual projects. These protocols were developed to assess the cost of actions with "marginal" impacts on cumulative global emissions, and the metrics estimate the dollar figure of damages for one extra unit of greenhouse gas emissions. This marginal cost is calculated using integrated assessment models. These models translate emissions into changes in atmospheric greenhouse concentrations, atmospheric concentrations into changes in temperature, and changes in temperature into economic damages. A range of plausible socio-economic and emissions trajectories are used to account for the scope of potential scenarios and circumstances that may actually result in the coming years and decades. The marginal cost is attained by first running the models using a baseline emissions trajectory, and then running the same models again with one additional unit of emissions. The difference in damages between the two runs is the marginal cost of one additional unit. The approach assumes that the marginal damages from increased emissions will remain constant for small emissions increases relative to gross global emissions. In other words, the monetization tools are in fact perfectly suited to measuring the marginal effects of individual projects or other discrete agency actions. In fact, as recently

[38] *Id.* at G-6.

[39] *E.g.*, Montana Dept. of Envtl. Quality & Office of Surface Mining Reclamation and Enforcement, *Western Energy Company's Rosebud Mine Area F Draft Environmental Impact Statement* at 474 (2017) ("There are no impact and intensity thresholds available to characterize the significance of the effect of a single action on global climate change.").

[40] EA at D-6.

as 2015, OSM reaffirmed in a different EIS that, though the metric was first developed for cost-benefit analysis in federal rulemaking, it was nonetheless useful and appropriate for NEPA analyses.[41]

Second, OSM argues that because the social cost of carbon protocol was designed to estimate impacts "over long time frames," there are too many "uncertainties associated with assigning a specific and accurate SCC resulting from 9 additional years of operation" at Bull Mountain.[42] This statement misunderstands both the social cost of carbon and the nature of uncertainty around the estimate. While the social cost of greenhouse gases does calculate the economic impacts of climate damages stretching out for several centuries over the lifespan of carbon emissions, the methodology estimates a specific value for the cost of emissions from each individual year. There are year-by-year estimates for the per-ton cost of emissions for each of the 8 additional years of operation at Rosebud mine.

As for uncertainty, agencies in general—and OSM in this particular instance—should remember that uncertainty is *not* a reason to abandon the social cost of greenhouse gas methodologies;[43] quite the contrary, uncertainty supports higher estimates of the social cost of greenhouse gases, because most uncertainties regarding climate change entail tipping points, catastrophic risks, and unknown unknowns about the damages of climate change. Because the key uncertainties of climate change include the risk of irreversible catastrophes, applying an options value framework to the regulatory context strengthens the case for ambitious regulatory action to reduce greenhouse gas emissions. There are numerous well-established, rigorous analytical tools available to help agencies characterize and quantitatively assess uncertainty, such as Monte Carlo simulations, and the IWG's social cost of greenhouse gas protocol incorporates those tools. For more details, please see the attached technical appendix on uncertainty.

Finally, any implication that the significance of this action's effects on global climate change is somehow uncertain would violate NEPA's standards for a hard look review. While there may not be a bright-line test for significance, the emissions OSM estimates for this project—190 million metric tons of carbon dioxide-equivalent emissions[44]—are clearly significant and warrant monetization. This is especially true since, once emissions have been quantified (as they have been here), the additional step of monetization through application of the Interagency Working Group's 2016 estimates entails nothing more than a simple arithmetic calculation.[45]

In *High Country*, the District Court for the District of Colorado found that it was arbitrary for the Forest Service not to monetize the "1.23 million tons of carbon dioxide equivalent emissions [from methane] the West Elk mine emits annually."[46] That suggests that emissions in quantities far below what OSM estimates here are significant and warrant monetization. In *Montana Environmental Information Center*, the District Court for the District of Montana found it was arbitrary for the Office of Surface Mining not to monetize the 23.16 million metric tons per year emitted from the Bull Mountain expansion;[47] the tons quantified in this EA from the Bull mountain expansion are nearly identical. In *Center for Biological Diversity*, the Ninth Circuit found that it was arbitrary for the Department of Transportation not to monetize the 35 million metric ton difference in lifetime emissions from increasing the fuel efficiency of

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[41] Four Corners EIS, *supra* note 35, at 4.2-25.

[42] EA at D-7.

[43] *Center for Biological Diversity v. NHTSA*, 538 F.3d 1172, 1200 (9th Cir. 2008) ("[W]hile the record shows that there is a range of values, the value of carbon emissions reductions is certainly not zero.").

[44] EA at 53.

[45] Agencies simply need to multiply their estimate of tons in each year by the IWG's 2016 values for the corresponding year of emissions (adjusted for inflation to current dollars). If the emissions change occurs in the future, agencies would then discount the products back to present value.

[46] 52 F. Supp. 3d at 1191 (quoting an e-mail comment on the draft statement for the quantification of tons).

[47] 15-106-M-DWM, at 36-37.

motor vehicles:[48] given the estimated lifetime of vehicles sold in the years 2008-2011 (sometimes estimated at about 15 years on average), this could represent as little two million metric tons per year, well below the annual emissions at stake here. In a recent environmental impact statement from the Bureau of Ocean Energy Management published in August 2017, the agency explained that the social cost of carbon was "a useful measure" to apply to a NEPA analysis of an action anticipated to have a difference in greenhouse gas emissions compared to the no-action baseline of about 25 million metric tons over a 5-year period,[49] or about 5 million metric tons per year. Once again, OSM's estimate for the Bull Mountain expansion is much higher.

Under any reasonable social cost of greenhouse gases, the direct and indirect emissions from the Bull Mountain expansion will cause hundreds of millions of dollars in climate damages. Tellingly, OSM had no problem monetizing, for example, the $35,000 in additional state revenue from surface leases under the proposed action (in addition to millions of dollars estimated for other monetized economic benefits).[50] Certainly, a potential climate cost of hundreds of millions of dollars is also significant, particularly in the context of a document the very purpose of which is to evaluate a project's *environmental* impacts.

3. The Interagency Working Group Estimates Remain the Best Available Values for Federal Agencies to Use in Analyses

One of OSM's justifications for not using the social cost of greenhouse gases is the disbandment of the Interagency Working Group on the Social Cost of Greenhouse Gases (IWG) and the withdrawal of the group's guidance on using the social cost of greenhouse gases metric. OSM also claims that the IWG's social cost of greenhouse gases estimates fail to take into account the benefits of coal-generated energy. However, as we explain below, the IWG's social cost of greenhouse gas estimates remain the best available assessments for federal agencies to use in evaluating climate impacts.

New Executive Order Encourages Continued Monetization of the Social Cost of Greenhouse Gases

Executive Order 13,783 officially disbanded the IWG and withdrew its technical support documents that underpinned their range of estimates.[51] Nevertheless, Executive Order 13,783 assumes that federal agencies will continue to "monetiz[e] the value of changes in greenhouse gas emissions" and instructs agencies to ensure such estimates are "consistent with the guidance contained in OMB Circular A-4."[52] Consequently, while OSM and other federal agencies no longer benefit from ongoing technical support from the IWG on use of the social cost of greenhouse gases, by no means does the new Executive Order imply that agencies should not monetize important effects in their regulatory analyses or environmental impact statements. In fact, Circular A-4 instructs agencies to monetize costs and benefits whenever feasible.[53] The Executive Order does not prohibit agencies from relying on the same choice of models as the IWG, the same inputs and assumptions as the IWG, the same statistical methodologies as the IWG, or the same ultimate values as derived by the IWG. To the contrary, because the Executive Order requires consistency with Circular A-4, as agencies follow the Circular's standards for using the best available data and methodologies, they will necessarily choose similar data, methodologies, and

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[48] 538 F.3d at 1187.

[49] BOEM, *Liberty Development and Production Plan Draft EIS* at 3-129, 4,50 (2017) (89,940,000 minus 64,570,000 is about 25 million).

[50] EA at G-6.

[51] Exec. Order. No. 13,783 § 5(b), 82 Fed. Reg. 16,093 (Mar. 28, 2017).

[52] *Id.* § 5(c).

[53] OMB, Circular A-4 at 27 (2003) ("You should monetize quantitative estimates whenever possible.").

estimates as the IWG, since the IWG's work continues to represent the best available estimates.[54] The Executive Order does not preclude agencies from using the same range of estimates as developed by the IWG, so long as the agency explains that the data and methodology that produced those estimates are consistent with Circular A-4 and, more broadly, with standards for rational decisionmaking.

Similarly, the Executive Order's withdrawal of the CEQ guidance on greenhouse gases does not —and legally cannot—remove agencies' statutory requirement to fully disclose the environmental impacts of greenhouse gas emissions. As CEQ explained in its withdrawal, the "guidance was not a regulation," and "[t]he withdrawal of the guidance does not change any law, regulation, or other legally binding requirement."[55] In other words, when the guidance originally recommended the appropriate use of the social cost of greenhouse gases in environmental impact statements,[56] it was simply explaining that the social cost of greenhouse gases is consistent with longstanding NEPA regulations and case law, all of which are still in effect today.

Notably, some agencies under the Trump administration have continued to use the IWG estimates even following the Executive Order. For example, in August 2017, the Bureau of Ocean Energy Management called the social cost of carbon "a useful measure" and applied it to analyze the consequences of offshore oil and gas drilling,[57] and in July 2017, the Department of Energy used the Interagency Working Group's 2016 estimates for carbon and methane emissions to analyze energy efficiency regulation, describing the social cost of methane as having "undergone multiple stages of peer review."[58] OSM here complains that the range of calculations generated by the IWG's four estimates of the social cost of carbon is too wide and so "provides little benefit in assisting the authorized officer's decision for project level analysis."[59] Yet, in the Bureau of Ocean Energy Management's August 2017 EIS of an oil and gas development project, the agency "used four sets of SC-CO_2 values" as developed by IWG: "three values based on the average SCC from three integrated assessment models, discounted at 2.5%, 3% and 5%, as well as a fourth value corresponding to the 95th percentile of the frequency distribution of SCC estimates at the 3% discount rate."[60] Again, in that EIS, the Bureau of Ocean Energy Management (OSM's sister agency within the Department of the Interior) found that range of calculations to be "a useful measure to assess" greenhouse gas emissions and to "inform agency decisions."

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[54] Richard L. Revesz et al., *Best Cost Estimate of Greenhouse Gases*, 357 SCIENCE 6352 (2017) (explaining that, even after Trump's Executive Order, the social cost of greenhouse gas estimate of around $50 per ton of carbon dioxide is still the best estimate).

[55] 82 Fed. Reg. 16,576, 16,576 (Apr. 5, 2017).

[56] *See* CEQ, *Revised Draft Guidance on Consideration of Greenhouse Gas Emissions and the Effects of Climate Change in National Environmental Policy Act Reviews* at 16 (Dec. 2014), *available at* https://obamawhitehouse.archives.gov/sites/default/files/docs/nepa_revised_draft_ghg_guidance_searchable.pdf ("When an agency determines it appropriate to monetize costs and benefits, then, although developed specifically for regulatory impact analyses, the Federal social cost of carbon, which multiple Federal agencies have developed and used to assess the costs and benefits of alternatives in rulemakings, offers a harmonized, interagency metric that can provide decisionmakers and the public with some context for meaningful NEPA review. When using the Federal social cost of carbon, the agency should disclose the fact that these estimates vary over time, are associated with different discount rates and risks, and are intended to be updated as scientific and economic understanding improves."); *see also* CEQ, *Final Guidance for Federal Departments and Agencies on Consideration of Greenhouse Gas Emissions and the Effects of Climate Change in National Environmental Policy Act Reviews* at 33 n.86 (Aug. 2016), *available at* https://obamawhitehouse.archives.gov/sites/whitehouse.gov/files/documents/nepa_final_ghg_guidance.pdf.

[57] Draft Envtl. Impact Statement: Liberty Development Project at 3-129, 4-246 (Aug. 2017).

[58] Energy Conservation Program: Energy Conservation Standards for Walk-In Cooler and Freezer Refrigeration Systems, 82 Fed. Reg. 31,808, 31,811, 31,857 (July 10, 2017).

[59] EA at D-7.

[60] Draft Envtl. Impact Statement: Liberty Development Project at 4-246 (Aug. 2017).

For more detail on why the IWG's 2016 estimates remain the best values currently available to federal agencies and why the IWG's choice of a central estimate of global damages calculated at a 3% discount rate is appropriate under *Circular A-4*, please see the attached comments on the social cost of greenhouse gases submitted last year to the Bureau of Land Management. Those comments to BLM also explain why the so-called "interim protocols" recently developed by some other agencies are not, in fact, "[i]n compliance with OMB Circular A-4,"[61] and so would not be appropriate to use here.

Omitted Categories of Damages Should Be Discussed Qualitatively

OSM faults the social cost of carbon for failing to include "all costs or benefits from carbon emissions."[62] Alleged benefits of carbon emissions, such as from increased fertilization, are in fact already included in the IWG's estimates and are probably even overstated in those estimates. Many of the assumptions about climate benefits built into the integrated assessment models used by the IWG are now outdated; for example, recent work demonstrates that the benefits to agriculture from climate change assumed by the developers of FUND are, in fact, far lower.[63] Other research has also shown that the predicted amenity benefits from climate change, like agricultural benefits, are also highly controversial.[64]

As for omitted damages, there certainly are key damages, including catastrophic outcomes, that are not yet fully monetized in the IWG's social cost of greenhouse gas estimates. In fact, one reason that IWG published not only "central" estimates but also estimates from the 95th percentile of the distribution was to reflect that omitted damage categories could significantly increase the estimates. As noted above, the social cost of greenhouse gases should be seen as a conservative lower-bound estimate of the greenhouse gas impacts. Even while this metric represents the best and most rigorous effort that the U.S. government has engaged in thus far to realistically quantify the impacts of these emissions, it is very likely to underrepresent the true extent of those impacts. Indeed, we strongly encourage further efforts to make the social cost of greenhouse gases more robust.

Nevertheless, the fact that this metric does not capture the entire scope of greenhouse gas impacts does *not* mean that federal agencies should not use it. Rather, agencies should qualitatively discuss any significant omitted category of costs or benefits while continuing to use the IWG estimates as a lower bound of the costs of greenhouse gas emissions.[65]

Sincerely,

Susanne Brooks, Director of U.S. Climate Policy and Analysis, Environmental Defense Fund
Tomás Carbonell, Senior Attorney and Director of Regulatory Policy, Environmental Defense Fund
Rachel Cleetus, Ph.D., Lead Economist and Climate Policy Manager, Union of Concerned Scientists
Denise Grab, Western Regional Director, Institute for Policy Integrity, NYU School of Law*
Jayni Hein, Policy Director, Institute for Policy Integrity, NYU School of Law*
Peter H. Howard, Ph.D., Economic Director, Institute for Policy Integrity, NYU School of Law*
Athan Manuel, Director, Lands Protection Program, Sierra Club

[61] *Cf.* EA at D-6.

[62] EA at D-6.

[63] F.C. Moore et al., *New science of climate change impacts on agriculture implies higher social cost of carbon*, 8 Nature Communications 1607 (2017).

[64] Howard, *Omitted Damages, supra* note 25; W.M. Hannemann, *What Is the Economic Cost of Climate Change?* (2008); D. Maddison & K. Rehdanz, *The impact of climate on life satisfaction*, 70 Ecological Economics 2437-2445 (2011); K. Rehdanz & D. Maddison, *Climate and happiness*, 52 Ecological Economics 111-125 (2005).

[65] Howard and Sylvan (2015) and Pindyck (2016) find that that the general consensus is that damages are much higher than IAMs currently show, and as a consequence, so are their corresponding SCC estimates.

Martha Roberts, Senior Attorney, Environmental Defense Fund
Iliana Paul, Policy Associate, Institute for Policy Integrity, NYU School of Law*
Richard L. Revesz, Director, Institute for Policy Integrity, NYU School of Law*
Jason A. Schwartz, Legal Director, Institute for Policy Integrity, NYU School of Law*
Jeffrey Shrader, Economics Fellow, Institute for Policy Integrity, NYU School of Law*
Peter Zalzal, Director of Special Projects and Senior Attorney, Environmental Defense Fund

For any questions regarding these comments, please contact jason.schwartz@nyu.edu.
* No part of this document purports to present New York University School of Law's views, if any.

Attached: Joint Comments to the Bureau of Land Management on the Social Cost of Greenhouse Gases

Technical Appendix: Uncertainty

Contrary to the arguments made by many opposed to strong federal climate action, uncertainty about the full effects of climate change *raises* the social cost of greenhouse gases and warrants *more* stringent climate policy.[66] Integrated assessment models (IAMs) currently used to calculate the SCC show that the net effect of uncertainty about economic damage resulting from climate change, costs of mitigation, future economic development, and many other parameters raises the SCC compared to the case where models simply use our current best guesses of these parameters.[67] Even so, IAMs still underestimate the impact of uncertainty on the SCC by not accounting for a host of fundamental features of the climate problem: the irreversibility of climate change, society's aversion to risk and other social preferences, option value, and many catastrophic impacts.[68] Rather than being a reason not to take action, uncertainty increases the SCC and should lead to more stringent policy to address climate change.[69]

Types of Uncertainty in the IAMs

IAMs incorporate two types of uncertainty: parametric uncertainty and stochastic uncertainty. Parametric uncertainty covers uncertainty in model design and inputs, including the selected parameters, correct functional forms, appropriate probability distribution functions, and model structure. With learning, these uncertainties should decline over time as more information becomes available.[70] Stochastic uncertainty is persistent randomness in the economic-climate system, including various environmental phenomena such as volcanic eruptions and sun spots.[71] Uncertainties are present in each component of the IAMs: socio-economic scenarios, the simple climate model, the damage and abatement cost functions, and the social welfare function (including the discount rate).[72]

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[66] Peterson (2006) states "Most modeling results show (as can be expected) that there is optimally more emission abatement if uncertainties in parameters or the possibility of catastrophic events are considered." Peterson, S. (2006). Uncertainty and economic analysis of climate change: A survey of approaches and findings. *Environmental Modeling & Assessment*, *11*(1), 1-17.

[67] Tol, R. S. (1999). Safe policies in an uncertain climate: an application of FUND. *Global Environmental Change*, *9*(3), 221-232; Peterson, S. (2006). Uncertainty and economic analysis of climate change: A survey of approaches and findings. *Environmental Modeling & Assessment*, *11*(1), 1-17; Interagency Working Group on the Social Cost of Greenhouse Gases, Technical Update (2016) (hereinafter 2016 TSD).

[68] Pindyck, R. S. (2007). Uncertainty in environmental economics. *Review of environmental economics and policy*, *1*(1), 45-65; Golub, A., Narita, D., & Schmidt, M. G. (2014). Uncertainty in integrated assessment models of climate change: Alternative analytical approaches. *Environmental Modeling & Assessment*, *19*(2), 99-109; Lemoine, D., & Rudik, I. (2017). Managing Climate Change Under Uncertainty: Recursive Integrated Assessment at an Inflection Point. *Annual Review of Resource Economics* 9:18.1-18.26.

[69] *See* cites *supra* note 68.

[70] Learning comes in multiple forms: passive learning of anticipated information that arrives exogenous to the emission policy (such as academic research), active learning of information that directly stems from the choice of the GHG emission level (via the policy process), and learning of unanticipated information (Kann and Weyant, 2000; Lemoine and Rudik, 2017).

[71] Kann, A., & Weyant, J. P. (2000). Approaches for performing uncertainty analysis in large-scale energy/economic policy models. *Environmental Modeling & Assessment*, *5*(1), 29-46; Peterson (2006), *supra* note 66; Golub et al. *supra* note 68.

A potential third type of uncertainty arises due to ethical or value judgements: normative uncertainty. Peterson (2006) *supra* note 66; Heal, G., & Millner, A. (2014). Reflections: Uncertainty and decision making in climate change economics. *Review of Environmental Economics and Policy*, *8*(1), 120-137. For example, there is some normative debate over the appropriate consumption discount rate to apply in climate economics, though widespread consensus exists that using the social opportunity cost of capital is inappropriate (see earlier discussion). Preference uncertainty should be modeled as a declining discount rate over time (see earlier discussion), not using uncertain parameters. Kann & Weyant, *supra* note 71.

[72] Peterson (2006), *supra* note 66; Pindyck (2007), *supra* note 68; Heal & Millner, *supra* note 71.

When modeling climate change uncertainty, scientists and economists have long emphasized the importance of accounting for the potential of catastrophic climate change.[73] Catastrophic outcomes combine several overlapping concepts including unlucky states of the world (i.e., bad draws), deep uncertainty, and climate tipping points and elements.[74] Traditionally, IAM developers address uncertainty by specifying probability distributions over various climate and economic parameters. This type of uncertainty implies the possibility of an especially bad draw if multiple uncertain parameters turn out to be lower than we expect, causing actual climate damages to greatly exceed expected damages.

Our understanding of the climate and economic systems is also affected by so-called "deep uncertainty," which can be thought of as uncertainty over the true probability distributions for specific climate and economic parameters.[75] The mean and variance of many uncertain climate phenomena are unknown due to lack of data, resulting in "fat-tailed distributions"—i.e., the tail of the distributions decline to zero slower than the normal distribution. Fat-tailed distributions result when the best guess of the distribution is derived under learning.[76] Given the general opinion that bad surprises are likely to outweigh good surprises in the case of climate change,[77] modelers capture deep uncertainty by selecting probability distributions with a fat upper tail which reflects the greater likelihood of extreme events.[78] The possibility of fat tails increases the likelihood of a "very" bad draw with high economic costs, and can result in a very high (and potentially infinite) expected cost of climate change (a phenomenon known as the dismal theory).[79]

Climate tipping elements are environmental thresholds where a small change in climate forcing can lead to large, non-linear shifts in the future state of the climate (over short and long periods of time) through positive feedback (i.e., snowball) effects.[80] Tipping points refer to economically relevant thresholds after which change occurs rapidly (i.e., Gladwellian tipping points), such that opportunities for adaptation and intervention are limited.[81] Tipping point examples include the reorganization of the Atlantic meridional overturning circulation (AMOC) and a shift to a more persistent El Niño regime in the Pacific Ocean.[82]

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[73] Nordhaus, W. D. (2008). A question of balance: Weighing the options on global warming policies. Yale University Press; Kopp, R. E., Shwom, R. L., Wagner, G., & Yuan, J. (2016). Tipping elements and climate–economic shocks: Pathways toward integrated assessment. *Earth's Future*, *4*(8), 346-372.

[74] Kopp et al. (2016), *supra* note 73.

[75] *Id.*

[76] Nordhaus, W. D. (2009). An Analysis of the Dismal Theorem (No. 1686). Cowles Foundation Discussion Paper; Weitzman, M. L. (2011). Fat-tailed uncertainty in the economics of catastrophic climate change. Review of Environmental Economics and Policy, 5(2), 275-292; Pindyck, R. S. (2011). Fat tails, thin tails, and climate change policy. *Review of Environmental Economics and Policy*, *5*(2), 258-274.

[77] Mastrandrea, M. D. (2009). Calculating the benefits of climate policy: examining the assumptions of integrated assessment models. Pew Center on Global Climate Change Working Paper; Tol, R. S. (2012). On the uncertainty about the total economic impact of climate change. *Environmental and Resource Economics*, *53*(1), 97-116.

[78] Weitzman (2011), *supra* note 76, makes clear that "deep structural uncertainty about the unknown unknowns of what might go very wrong is coupled with essentially unlimited downside liability on possible planetary damages. This is a recipe for producing what are called 'fat tails' in the extreme of critical probability distributions."

[79] Weitzman, M. L. (2009). On modeling and interpreting the economics of catastrophic climate change. The Review of Economics and Statistics, 91(1), 1-19; Nordhaus (2009), *supra* note 76; Weitzman (2011), *supra* note 76.

[80] Tipping elements are characterized by: (1) deep uncertainty, (2) absence from climate models, (3) larger resulting changes relative to the initial change crossing the relevant threshold, and (4) irreversibility. Kopp et al. (2016), *supra* note 73.

[81] *Id.*

[82] *Id.*; Kriegler, E., Hall, J. W., Held, H., Dawson, R., & Schellnhuber, H. J. (2009). Imprecise probability assessment of tipping points in the climate system. *Proceedings of the national Academy of Sciences*, *106*(13), 5041-5046; Diaz, D., & Keller, K. (2016). A potential disintegration of the West Antarctic Ice Sheet: Implications for economic analyses of climate policy. *The American*

Social tipping points—including climate-induced migration and conflict—also exist. These various tipping points interact, such that triggering one tipping point may affect the probabilities of triggering other tipping points.[83] There is some overlap between tipping point events and fat tails in that the probability distributions for how likely, how quick, and how damaging tipping points will be are unknown.[84] Accounting fully for these most pressing, and potentially most dramatic, uncertainties in the climate-economic system matter because humans are risk averse and tipping points—like many other aspects of climate change—are, by definition, irreversible.

How IAMs and the IWG Account for Uncertainty

Currently, IAMs (including all of those used by the IWG) capture uncertainty in two ways: deterministically and through uncertainty propagation. For the deterministic method, the modeler assumes away uncertainty (and thus the possibility of bad draws and fat tails) by setting parameters equal to their most likely (median) value. Using these values, the modeler calculates the median SCC value. Typically, the modeler conducts sensitivity analysis over key parameters—one at a time or jointly—to determine the robustness of the modeling results. This is the approach employed by Nordhaus in the preferred specification of the DICE model[85] used by the IWG.

Uncertainty propagation is most commonly carried out using Monte Carlo simulation. In these simulations, the modeler randomly draws parameter values from each of the model's probability distributions, calculates the SCC for the draw, and then repeats this exercise thousands of times to calculate a mean social cost of carbon.[86] Tol, Anthoff, and Hope employ this technique in FUND and PAGE—as did the IWG (2010, 2013, and 2016)—by specifying probability distributions for the climate and economic parameters in the models. These models are especially helpful for assessing the net effect of different parametric and stochastic uncertainties. For instance, both the costs of mitigation and the damage from climate change are uncertain. Higher costs would warrant less stringent climate policies, while higher damages lead to more stringent policy, so theoretically, the effect of these two factors on climate policy could be ambiguous. Uncertainty propagation in an IAM calibrated to empirically motivated distributions, however, shows that climate damage uncertainty outweighs the effect of cost uncertainty, leading to a stricter policy when uncertainty is taken into account than when it is ignored.[87] This can be seen in the resulting right-skewed distribution of the SCC (see Figure 1 in IWG (2016)) where the mean (Monte Carlo) SCC value clearly exceeds the median (deterministic) SCC value.

The IWG was rigorous in addressing uncertainty. First, it conducted Monte Carlo simulations over the above IAMs specifying different possible outcomes for climate sensitivity (represented by a right

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Economic Review, *106*(5), 607-611. See Table 1 of Kopp et al. (2016) *supra* note 73, for a full list of known tipping elements and points.

[83] Kriegler et al. (2009), *supra* note 82; Cai, Y., Lenton, T. M., & Lontzek, T. S. (2016). Risk of multiple interacting tipping points should encourage rapid CO2 emission reduction; Kopp et al. (2016) *supra* note 73.

[84] Peter Howard, *Omitted Damages: What's Missing from the Social Cost of Carbon* 5 (Cost of Carbon Project Report, 2014), http://costofcarbon.org/; Kopp et al. (2016) *supra* note 73.

[85] Nordhaus, W. & Sztorc, P. (2013). DICE 2013: Introduction & User's Manual. Retrieved from Yale University, Department of Economics website: http://www.econ.yale.edu/~nordhaus/homepage/documents/Dicemanualfull

[86] In alternative calculation method, the modeler "performs optimization of polices for a large number of possible parameter combinations individually and estimates their probability weighted sum." Golub et al. *supra* note 68. In more recent DICE-2016, Nordhaus conducts a three parameter analysis using this method to determine a SCC confidence interval. Given that PAGE and FUND model hundred(s) of uncertainty parameters, this methodology appears limited in the number of uncertain variables that can be easily specified.

[87] Tol (1999), *supra* note 67, in characterizing the FUND model, states, "Uncertainties about climate change impacts are more serious than uncertainties about emission reduction costs, so that welfare-maximizing policies are stricter under uncertainty than under certainty."

skewed, fat tailed distribution to capture the potential of higher than expected warming). It also used scenario analysis: five different emissions growth scenarios and three discount rates. Second, the IWG (2016) reported the various moments and percentiles—including the 95th percentile—of the resulting SCC estimates. Third, the IWG put in place an updating process, e.g., the 2013 and 2016 revisions, which updates the models as new information becomes available.[88] As such, the IWG used the various tools that economists have developed over time to address the uncertainty inherent in estimating the economic cost of pollution: reporting various measures of uncertainty, using Monte Carlo simulations, and updating estimates as evolving research advances our knowledge of climate change. Even so, the IWG underestimate the SCC by failing to capture key features of the climate problem.

Current IAMs Underestimate the SCC by Failing to Sufficiently Model Uncertainty

Given the current treatment of uncertainty by the IWG (2016) and the three IAMs that they employ, the IWG (2016) estimates represent an underestimate of the SCC. DICE clearly underestimates the true value of the SCC by effectively eliminating the possibility of bad draws and fat tails through a deterministic model that relies on the median SCC value. Even with their calculation of the mean SCC, the FUND and PAGE also underestimate the metric's true value by ignoring key features of the climate-economic problem. Properly addressing the limitations of these models' treatment of uncertainty would further increase the SCC.

First, current IAMs insufficiently model catastrophic impacts. DICE fails to model both the possibility of bad draws and fat tails by applying the deterministic approach. Alternatively, FUND and PAGE ignore deep uncertainty by relying predominately on the thin-tailed triangular and gamma distributions.[89] The IWG (2010) only partially addresses this oversight by replacing the ECS parameter in DICE, FUND, and PAGE with a fat-tailed, right-skewed distribution calibrated to the IPCC's assumptions (2007), even though many other economic and climate phenomenon in IAMs are likely characterized by fat tails, including climate damages from high temperature levels, positive climate feedback effects, and tipping points.[90] Recent work in stochastic dynamic programming tends to better integrate fat tails – particularly with respect to tipping points (see below) – and address additional aversion to this type of uncertainty (also known as ambiguity aversion); doing so can further increase the SCC under uncertainty.[91]

In contrast to their approach to fat tails, the IAMs used by the IWG (2010; 2013; 2016) sometimes address climate tipping points, though they do not apply state-of-the-art methods for doing so. In early versions of DICE (DICE-2010 and earlier), Nordhaus implicitly attributes larger portions of the SCC to tipping points by including certainty equivalent damages of catastrophic events - representing two-thirds to three-quarter of damages in DICE – calibrated to an earlier Nordhaus (1994) survey of

[88] IWG (2010).

[89] Howard (2014), *supra* note 84. While both FUND and PAGE employ thin tailed distributions, the resulting distribution of the SCC is not always thin-tailed. In PAGE09, the ECS parameter is endogenous, such that the distribution of the ECS has a long tail following the IPCC (2007). *See* Chen, Z., Marquis, M., Averyt, K. B., Tignor, M., & Miller, H. L. (2007). Contribution of working group I to the fourth assessment report of the intergovernmental panel on climate change. *Cambridge, UK and New York: Cambridge University Press, 996p*. Similarly, while Anthoff and Tol do not explicitly utilize fat-tail distributions, the distribution of net present welfare from a Monte Carlos simulation is fat tailed. Anthoff, D., & Tol, R. S. (2014). The Climate Framework for Uncertainty, Negotiation and Distribution (FUND): Technical description, Version 3.8. Available at www.fund-model.org. Explicitly modeling parameter distributions as fat tailed may further increase the SCC.

[90] Weitzman (2011), *supra* note 76; Kopp et al. (2016) *supra* note 73.

[91] Lemoine, D., & Traeger, C. P. (2016a). Ambiguous tipping points. *Journal of Economic Behavior & Organization*, *132*, 5-18; Lemoine & Rudik (2017), *supra* note 68. IAM modelers currently assume that society is equally averse to known unknown and known unknowns. Lemoine & Traeger, *id*.

experts.[92] In PAGE09, Hope also explicitly models climate tipping points as a singular, discrete event (of a 5% to 25% loss in GDP) that has a probability (which grows as temperature increases) of occurring in each time period.[93] Though not in the preferred versions of the IAMs employed by the IWG, some research also integrates specific tipping points into these IAMs finding even higher SCC estimates.[94] Despite the obvious methodological basis for addressing tipping points, the latest versions of DICE[95] and FUND exclude tipping points in their preferred specifications. Research shows that if these models were to correctly account for the full range of climate impacts—including tipping points—the resulting SCC estimates would increase.[96]

The IWG approach also fails to include a risk premium—that is, the amount of money society would require in order to accept the uncertainty (i.e., variance) over the magnitude of warming and the resulting damages from climate change relative to mean damages (IWG, 2010; IWG, 2015)). The mean of a distribution, which is a measure of a distribution's central tendency, represents only one descriptor or "moment" of a distribution's shape. Each IAM parameter and the resulting SCC distributions have differing levels of variance (i.e., spread around the mean), skewness (i.e., a measure of asymmetry), and kurtosis (which, like skewness, is another descriptor of a distribution's tail) as well as means.[97] It is generally understood that people are risk averse in that they prefer input parameter distributions and (the resulting) SCC distributions with lower variances, holding the mean constant.[98] While the IWG assumes a risk-neutral central planner by using a constant discount rate (setting the risk premium to zero), this assumption does not correspond with empirical evidence,[99] current IAM assumptions,[100] the

[92] Nordhaus, W. D., & Boyer, J. (2000). Warning the World: Economic Models of Global Warming. MIT Press (MA); Nordhaus, W. D. (2008). A question of balance: Weighing the options on global warming policies. Yale University Press; Howard (2014), *supra* note 84; Kopp et al. (2016) *supra* note 73.

[93] Hope (2006) also calibrated a discontinuous damage function in PAGE-99 used by IWG (2010). Howard (2014), *supra* note 84.

[94] Kopp et al. (2016) *supra* note 73.

[95] For DICE-2013 and DICE-2016, Nordhaus calibrates the DICE damage function using a meta-analysis based on estimates that mostly exclude tipping point damages. Howard, P. H., & Sterner, T. (2016). Few and Not So Far Between: A Meta-analysis of Climate Damage Estimates. *Environmental and Resource Economics*, 1-29.

[96] Using FUND, Link and Tol (2010) find that a collapse of the AMOC would decrease GDP (and thus increase the SCC) by a small amount. Earlier modeling of this collapse in DICE find a more significance increase. Keller, K., Tan, K., Morel, F. M., & Bradford, D. F. (2000). Preserving the ocean circulation: implications for climate policy. *Climatic Change*, *47*, 17-43; Mastrandrea, M. D., & Schneider, S. H. (2001). Integrated assessment of abrupt climatic changes. *Climate Policy*, *1*(4), 433-449; Keller, K., Bolker, B. M., & Bradford, D. F. (2004). Uncertain climate thresholds and optimal economic growth. *Journal of Environmental Economics and management*, *48*(1), 723-741. With respect to thawing of the permafrost, Hope and Schaefer (2016), Economic impacts of carbon dioxide and methane released from thawing permafrost. *Nature Climate Change*, *6*(1), 56-59, and Gonzalez-Eguino and Neumann (2016), González-Eguino, M., & Neumann, M. B. (2016). Significant implications of permafrost thawing for climate change control. *Climatic Change*, *136*(2), 381-388, find increases in damages (and thus an increase in the SCC) when integrating this tipping element into the PAGE09 and DICE-2013R, respectively. Looking at the collapse of the West Antarctic Ice sheet, Nicholls et al. (2008) find a potential for significant increases in costs (and thus the SCC) in FUND. Nicholls, R. J., Tol, R. S., & Vafeidis, A. T. (2008). Global estimates of the impact of a collapse of the West Antarctic ice sheet: an application of FUND. *Climatic Change*, *91*(1), 171-191. Ceronsky et al. (2011) model three tipping points (collapse of the Atlantic Ocean Meridional Overturning Circulation, large scale dissociation of oceanic methane hydrates; and a high equilibrium climate sensitivity parameter), and finds a large increase in the SCC in some cases. Ceronsky, M., Anthoff, D., Hepburn, C., & Tol, R. S. (2011). *Checking the price tag on catastrophe: The social cost of carbon under non-linear climate response* (No. 392). ESRI working paper.

[97] Golub, A., & Brody, M. (2017). Uncertainty, climate change, and irreversible environmental effects: application of real options to environmental benefit-cost analysis. *Journal of Environmental Studies and Sciences*, 1-8; see Figure 1 in IWG (2016).

[98] In other words, society prefers a narrow distribution of climate damages around mean level of damages X to a wider distribution of damages also centered on the same mean of X because they avoid the potential for very high damages even at the cost of eliminating the chance of very low damages.

[99] IWG, 2010, at fn 22; Cai et al., 2016, *supra* note 83, at 521.

NAS (2017) recommendations, nor with the IWG's own discussion (2010) of the possible values of the elasticity of the marginal utility of consumption. Evidence from behavioral experiments indicate that people and society are also averse to other attributes of parameter distributions – specifically to the thickness of the tails of distributions – leading to an additional ambiguity premium (Heal and Millner, 2014).[101] Designing IAMs to properly account for the risk and ambiguity premiums from uncertain climate damages would increase the resulting SCC values they generate.

Even under the IWG's current assumption of risk neutrality, the mean SCC from uncertainty propagation excludes the (real) option value of preventing marginal CO_2 emissions.[102] Option value reflects the value of future flexibility due to uncertainty and irreversibility; in this case, the irreversibility of CO2 emissions due to their long life in the atmosphere.[103] If society exercises the option of emitting an additional unit of CO2 emissions today, "we will lose future flexibility that the [mitigation] option gave" leading to possible "regret and…a desire to 'undo'" the additional emission because it "constrains future behavior."[104] Given that the SCC is calculated on the Business as Usual (BAU) emission pathway, option value will undoubtedly be positive for an incremental emission because society will regret this emission in most possible futures.

Though sometimes the social cost of carbon and a carbon tax are thought of as interchangeable ways to value climate damages, agencies should be careful to distinguish two categories of the literature. The first is the economic literature that calculates the optimal carbon tax in a scenario where the world has shifted to an optimal emissions pathway. The second is literature that assesses the social cost of carbon on the business-as-usual (BAU) emissions pathway; the world is currently on the BAU pathway, since optimal climate policies have not been implemented. There are currently no numerical estimates of the risk premium and option value associated with an incremental emission on the BAU emissions path.

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[100] The developers of each of the three IAMs used by the IWG (2010; 2013; 2016) assume a risk aversion society. Nordhaus and Sztorc, 2013, *supra*; Anthoff, D., & Tol, R. S. (2010). The Climate Framework for Uncertainty, Negotiation and Distribution (FUND): Technical description, Version 3.5. Available at www.fund-model.org; Anthoff, D., & Tol, R. S. (2014). The Climate Framework for Uncertainty, Negotiation and Distribution (FUND): Technical description, Version 3.8. Available at www.fund-model.org; Hope, C. (2013). Critical issues for the calculation of the social cost of CO2: why the estimates from PAGE09 are higher than those from PAGE2002. *Climatic Change*, *117*(3), 531-543.

[101] According to Heal and Millner (2014), *supra*, there is an ongoing debate of whether ambiguity aversion is rational or a behavioral mistake. Given the strong possibility that this debate is unlikely to be resolved, the authors recommend exploring both assumptions.

[102] Arrow, K. J., & Fisher, A. C. (1974). Environmental preservation, uncertainty, and irreversibility. *The Quarterly Journal of Economics*, 312-319; Dixit, A.K., Pindyck, R.S., 1994. *Investment Under Uncertainty*. Princeton University Press, Princeton, NJ; Traeger, C. P. (2014). On option values in environmental and resource economics. *Resource and Energy Economics*, *37*, 242-252.

In the discrete emission case, there are two overlapping types of option value: real option value and quasi-option value. Real option value is the full value of future flexibility of maintaining the option to mitigate, and mathematically equals the maximal value that can be derived from the option to [emit] now or later (incorporating learning) less the maximal value that can be derived from the possibility to [emit] now or never. Traeger, C. P. (2014). On option values in environmental and resource economics. *Resource and Energy Economics*, *37*, 242-252, equation 5. Quasi-option value is the value of future learning conditional on delaying the emission decision, which mathematically equals the value of mitigation to the decision maker who anticipates learning less the value of mitigation to the decision maker who anticipates only the ability to delay his/her decision, and not learning. *Id.* The two values are related, such that real option value can be decomposed into:

$$\mathrm{DPOV} = \mathbf{Max}\{QOV + SOV - \mathbf{Max}\{NPV, 0\}, 0\} = \mathbf{Max}\{QOV + SOV - \mathrm{SCC}, 0\}$$

where DPOV is the real option value, QOV is quasi-option value, SOV is simple option value (the value of the option to emit in the future condition on mitigating now), and NPV is the expected net present value of emitting the additional unit or the mean SCC in our case. *Id.*

[103] Even if society drastically reduced CO2 emissions, CO2 concentrations would continue to rise in the near future and many impacts would occur regardless due to lags in the climate system. Pindyck, R. S. (2007). Uncertainty in environmental economics. *Review of environmental economics and policy*, *1*(1), 45-65.

[104] Pindyck (2007).

Although there are stochastic dynamic optimization models that implicitly account for these two values, they analyze *optimal,* sequential decision making under climate uncertainty.[105] By nature of being optimization models (instead of policy models), these complex models focus on calculating the optimal tax and not the social cost of carbon, which differ in that the former is the present value of marginal damages on the optimal emissions path rather than on the BAU emissions path.[106] While society faces the irreversibility of emissions on the BAU emissions path when abatement is essentially near zero (i.e., far below the optimal level even in the deterministic problem),[107] the stochastic dynamic optimization model must also account for a potential counteracting abatement cost irreversibility – the sunk costs of investing in abatement technology if we learn that climate change is less severe than expected – by the nature of being on the optimal emissions path that balances the cost of emissions and abatement. In the optimal case, uncertainty and irreversibility of abatement *can theoretically* lead to a lower optimal emissions tax, unlike the social cost of carbon. The difference in the implication for the optimal tax and the SCC means that the stochastic dynamic modeling results are less applicable to the SCC.

What can we learn from new literature on stochastic dynamic programming models?

Bearing in mind the limitations of stochastic dynamic modeling, some new research provides valuable insights that are relevant to calculation of the social cost of greenhouse gases. The new and growing stochastic dynamic optimization literature implies that the IWG's SCC estimates are downward biased. The literature is made up of three models – real option, finite horizon, and infinite horizon models – of which the infinite time horizon (i.e., stochastic dynamic programming (SDP)) models are the most comprehensive for analyzing the impact of uncertainty on optimal sequential abatement policies.[108] Recent computational advancements in SDP are helping overcome the need for strong simplifying assumptions in this literature for purpose of tractability. Traditionally, these simplifications led to unrealistically fast rates of learning – leading to incorrect outcomes – and difficulty in comparing results across papers (due to differing uncertain parameters, models of learning, and model types). Even so, newer methods still only allow for a handful of uncertain parameters compared to the hundreds of uncertain parameters in FUND and PAGE. Despite these limitations, the literature supports the above finding that the SCC, if anything, increases under uncertainty.[109]

First, uncertainty increases the optimal emissions tax under realistic parameter values and modeling scenarios. While the impact of uncertainty on the optimal emissions tax (relative to the deterministic problem) depends on the uncertain parameters considered, the type of learning, and the model type

[105] Kann & Weyant, *supra*; Pindyck (2007), *supra*; Golub et al. (2014), *supra*.

[106] Nordhaus (2014) makes this difference clear when he clarifies that "With an optimized climate policy…the SCC will equal the carbon price…In the more realistic case where climate policy is not optimized, it is conventional to measure the SCC as the marginal damage of emissions along the actual path. There is some inconsistency in the literature on the definition of the path along which the SCC should be calculated. This paper will generally define the SCC as the marginal damages along the baseline path of emissions and output and not along the optimized emissions path." Nordhaus, W. (2014). Estimates of the social cost of carbon: concepts and results from the DICE-2013R model and alternative approaches. *Journal of the Association of Environmental and Resource Economists*, *1*(1/2), 273-312.

[107] On the BAU path, emissions far exceed their optimal level even without considering uncertainty. As a consequence, society is likely to regret an additional emission of CO2 in most future states of the world. Alternatively, society is unlikely to regret current abatement levels unless the extremely unlikely scenarios that there is little to no warming and/or damages from climate change.

[108] Kann and Weyant, 2000, *supra*; Pindyck, 2007, *supra*; Golub et al., 2014, *supra*.

[109] Kann and Weyant, 2000, *supra*; Pindyck, 2007, *supra*; Golub et al., 2014, *supra*; Lemoine and Rudik, 2017, supra. Comparing the optimal tax to the mean SCC is made further difficult by the frequent use of DICE as the base from which most stochastic dynamic optimization models are built. As a consequence, deterministic model runs are frequently the base of comparison for these models (Lemoine and Rudik, 2017).

(real option, finite horizon, and infinite horizon), the optimal tax clearly increases when tipping points or black swan events are included in stochastic optimization problems.[110] For SDP models, uncertainty tends to strengthen the optimal emissions path relative to the determinist case even without tipping points,[111] and these results are strengthened under realistic preference assumptions.[112] Given that there is no counter-balancing tipping abatement cost,[113] the complete modeling of climate uncertainty – which fully accounts for tipping points and fat tails – increases the optimal tax. Uncertainty leads to a stricter optimal emissions policy even if with irreversible mitigation costs, highlighting that the SCC would also increase when factoring in risk aversion and irreversibility given that abatement costs are very low on the BAU emissions path.

Second, given the importance of catastrophic impacts under uncertainty (as shown in the previous paragraph), the full and accurate modeling of tipping points and unknown knowns is critical when modeling climate change. The most sophisticated climate-economic models of tipping points – which include the possibility of multiple correlated tipping points in stochastic dynamic IAMs – find an increase in the optimal tax by 100%[114] to 800%[115] relative to the deterministic case without them. More realistic modeling of tipping points will also increase the SCC.

Finally, improved modeling of preferences will amplify the impact of uncertainty on the SCC. Adopting Epstein-Zin preferences that disentangle risk aversion and time preferences can significantly increase the SCC under uncertainty.[116] Recent research has shown that accurate estimation of decisions under uncertainty crucially depends on distinguishing between risk and time preferences.[117] By conflating risk and time preferences, current models substantially understate the degree of risk aversion exhibited by most individuals, artificially lowering the SCC. Similarly, adopting ambiguity aversion increase the SCC, but to a much lesser extent than risk aversion.[118] Finally, allowing for the price of non-market goods to increase with their relative scarcity can amplify the positive effect that even small tipping points have on

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[110] The real options literature tends to find an increase in the optimal emissions path under uncertainty relative to the deterministic case (Pindyck, 2007), though the opposite is true when modelers account for the possibility of large damages (i.e., tipping point or black swan events) even with a risk-neutral society (Pindyck, 2007; Golub et al., 2014). Solving finite horizon models employing non-recursive methods, modelers find that the results differ depending on the model of learning – the research demonstrates stricter emission paths under uncertainty without learning (with emission reductions up to 30% in some cases) and the impact under passive learning has a relatively small impact due the presence of sunken mitigation investment costs - except when tipping thresholds are included (Golub et al., 2014).

[111] Using SDP, modelers find that uncertainty over the equilibrium climate sensitivity parameter generally increases the optimal tax by a small amount, though the magnitude of this impact is unclear (Golub et al., 2014; Lemoine and Rudik, 2017). Similarly, non-catastrophic damages can have opposing effects dependent on the parameters changed, though emissions appear to decline overall when you consider their uncertainty jointly.

[112] Pindyck, 2007; Golub et al., 2017; Lemoine and Rudik, 2017

[113] Pindyck, 2007

[114] Lemoine, D., & Traeger, C. P. (2016b). Economics of tipping the climate dominoes. *Nature Climate Change*.

[115] Cai et al., 2016

[116] Cai et al., 2016; Lemoine and Rudik, 2017. The standard utility function adopted in IAMs with constant relative risk version implies that the elasticity of substitution equals the inversion of relative risk aversion. As a consequence, the society's preferences for the intra-generational distribution of consumption, the intergenerational distribution of consumption, and risk aversion hold a fixed relationship. For purposes of stochastic dynamic programming, this is problematic because this assumption conflates intertemporal consumption smoothing and risk aversion. Botzen, W. W., & van den Bergh, J. C. (2014). Specifications of social welfare in economic studies of climate policy: overview of criteria and related policy insights. *Environmental and Resource Economics*, *58*(1), 1-33. By adopting the Epstein-Zinn utility function which separates these two parameters, modelers can calibrate them according to empirical evidence. For example, Cai et al. (2016) replace the DICE risk aversion of 1.45 and elasticity parameter of 1/1.45 with values of 3.066 and 1.5, respectively.

[117] James Andreoni & Charles Sprenger, *Risk Preferences Are Not Time Preferences*, 102 AM. ECON. REV. 3357–3376 (2012).

[118] Lemoine, D., & Traeger, C. P. (2016b). Economics of tipping the climate dominoes. *Nature Climate Change*.; Lemoine and Rudik, 2017

the SCC if the tipping point impacts non-market services.[119] Including more realistic preference assumptions in IAMs would further increase the SCC under uncertainty.

Introducing stochastic dynamic modeling (which captures option value and risk premiums), updating the representation of tipping points, and including more realistic preference structures in traditional IAMs will—as in the optimal tax—further increase the SCC under uncertainty.

Conclusion: Uncertainty Raises the Social Cost of Greenhouse Gases

Overall, the message is clear: climate uncertainty is *never* a rationale for ignoring the SCC or shortening the time horizon of IAMs. Instead, our best estimates suggest that increased variability implies a higher SCC and a need for more stringent emission regulations.[120] Current omission of key features of the climate problem under uncertainty (the risk and climate premiums, option value, and fat tailed probability distributions) and incomplete modeling of tipping points imply that the SCC will further increase with the improved modeling of uncertainty in IAMs.

[119] Typically, IAMs assume constant relative prices of consumption goods. Gerlagh, R., and B.C.C. Van der Zwaan. 2002. “Long-term substitutability between environmental and man-made goods.” *Journal of Environmental Economics and Management 44*(2):329-345; Sterner, T., and U.M. Persson. 2008. “An Even Sterner Review: Introducing Relative Prices into the Discounting Debate.” *Review of Environmental Economics and Policy 2*(1):61-76. By replacing the standard isoelastic utility function in IAMs with a nested CES utility function following Sterner and Persson (2008), Cai et al. (2015) find that even a relatively small tipping point (i.e., a 5% loss) can substantially increase the SCC in the stochastic dynamic setting. Cai, Y., Judd, K. L., Lenton, T. M., Lontzek, T. S., & Narita, D. (2015). Environmental tipping points significantly affect the cost− benefit assessment of climate policies. *Proceedings of the National Academy of Sciences*, *112*(15), 4606-4611.

[120] Golub et al. (2014) states “The most important general policy implication from the literature is that despite a wide variety of analytical approaches addressing different types of climate change uncertainty, none of those studies supports the argument that no action against climate change should be taken until uncertainty is resolved. On the contrary, uncertainty despite its resolution in the future is often found to favor a stricter policy.”