Whitepaper on Valuing Methane Emissions Changes in Regulatory Benefit-Cost Analysis, Peer Review Charge Questions, and Responses

Table of Contents

Whitepaper: Valuing Methane Emissions Changes in Regulatory Benefit-Cost Analysis..............3

Peer Review Charge Questions..13

Review: Karen Fisher-Vanden..15

Review: John Reilly...19

Review: Steven Rose..23

EPA Summary and Response…………………………………………………………………………………………….28

Valuing Methane Emission Changes in Regulatory Benefit-Cost Analysis

1. Introduction

While CO_2 is the primary source of anthropogenic greenhouse gas (GHG) emissions contributing to climate change, other GHGs such as methane (CH_4) are also important contributors.[1] The Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC) concluded that in 2011 the increase in atmospheric CO_2 concentration since 1750 contributed 1.82 W m^{-2} to global mean radiative forcing, or 64% of the total radiative forcing from well mixed GHGs, and the direct effect of increased atmospheric CH_4 accounted for 0.48 W m^{-2}, or 17% of total radiative forcing from well mixed GHGs (Myhre et al. 2013). In addition, CH_4 emissions have indirect impacts on the climate due to their role as a precursor for tropospheric ozone and stratospheric water vapor, both of which are potent GHGs. Accounting for these indirect effects and the role that emissions of other substances like NOx and VOCs have on CH_4 atmospheric concentrations, AR5 estimated that historical anthropogenic emissions of CH_4 have contributed a total of 0.97 W m^{-2} to global mean radiative forcing, or almost a third of the radiative forcing resulting from emissions of well mixed GHGs. Therefore, CH_4 emissions are having, and will continue to have, a significant role on human well-being through their effect on the climate.

The United States Environmental Protection Agency (EPA) has promulgated several regulations that affect CH_4 emissions from a variety of sources. For example, the 2012 New Source Performance Standards and Amendments to the National Emissions Standards for Hazardous Air Pollutants for the Oil and Natural Gas Industry are expected to reduce CH_4 emissions by 900,000 metric tons annually.[2] Additionally, the 2017-2025 Light-duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards, promulgated jointly with the National Highway Traffic Safety Administration, is expected to reduce CH_4 emissions by over 100,000 metric tons in 2025 increasing to nearly 500,000 metric tons in 2050.[3] It is likely that future EPA rulemakings will also impact CH_4 emissions.

Consistent with Executive Order 12866, EPA conducts benefit-cost analysis to inform policy makers and the public about the economic efficiency of regulatory actions. The value of benefit-cost analysis will, in part, be determined by the ability to quantify and monetize the relevant outcomes of the regulatory action under investigation in a scientifically and economically defensible manner. EPA has promulgated regulations that result in changes in CH_4 emissions but has not yet quantified such impacts in its main benefit-cost analyses. In sensitivity analyses EPA has considered the benefits of CH_4 emissions reductions by using the global warming potential (GWP) metric to convert CH_4 emissions into carbon dioxide (CO_2) equivalents which are then valued using the U.S. Government's (USG) social cost of carbon (SC-CO_2)

[1] See EPA Endangerment Finding: Endangerment and Cause or Contribute Findings for Greenhouse Gases Under Section 202(a) of the Clean Air Act, 74 Fed. Reg. 66,496 (Dec. 15, 2009).
[2] http://www.gpo.gov/fdsys/pkg/FR-2012-08-16/pdf/2012-16806.pdf
[3] http://www.gpo.gov/fdsys/pkg/FR-2012-10-15/pdf/2012-21972.pdf

estimates.[4] To date, EPA has not included these indirect CH_4 benefit approximations in the main benefit-cost analyses due to the well-documented caveats associated with the approach (discussed in Section 2). While some direct estimates of CH_4 emissions mitigation benefits have been presented in the scientific literature, EPA has not used them in benefit-cost analyses because they are inconsistent with USG estimates of the SC-CO_2 (discussed in Section 3).[5]

While it is anticipated that the USG will continue to improve the models and data it uses to estimate the SC-CO_2 in accordance with evolving scientific and economic understanding, this paper illustrates how EPA could apply the social cost of CH_4 (SC-CH_4) estimates developed in Marten et al. (2014) to improve upon the current treatment of methane impacts in regulatory analysis so that they need not be implicitly assigned a value of zero in USG policy assessment. Marten et al. provide the first set of published SC-CH_4 estimates that are consistent with the modeling assumptions underlying the USG SC-CO_2. This paper begins by describing the GWP-based approach to valuing CH_4 mitigation benefits on the margin and its limitations. This discussion is followed by a description of the direct approach to estimating the benefits of marginal CH_4 emissions reductions, including a summary of Marten et al. and a comparison of direct estimates to the GWP-based approach.

2. Global Warming Potential Approximation Approach

The global warming potential (GWP) for CH_4 is a measure of the additional energy retained by the Earth's atmosphere as the result of a pulse of CH_4 emissions as compared to a pulse of CO_2 emissions. Specifically, the GWP is the time-integrated global mean radiative forcing from one kg of CH_4 emissions compared to one kg of CO_2 emissions over a given time horizon, such that

$$GWP_{CH_4,T} = \frac{\int_0^T Q_{CH_4}(t)dt}{\int_0^T Q_{CO_2}(t)dt} , \qquad (1)$$

where T is the time horizon and $Q_i(t)$ is the contribution to global mean radiative forcing at time t of a pulse of gas i at time zero. The time horizon is typically set to 100 years, but others have used alternative time horizons, such as 20 or 500 years, and the additional radiative forcing is estimated based on a constant background concentration for each gas.

The GWP was developed by the IPCC for their First Assessment Report (IPCC 1990) as a simple and purely physical metric to provide information about the potential impacts of each non-CO_2 GHG relative to CO_2 emissions. Under the Kyoto Protocol the GWP was designated for use in translating emissions of non-CO_2 GHGs into comparable CO_2 equivalents when estimating GHG sources and sinks.[6] Similarly the United

[4] The USG SC-CO_2 estimates are commonly referred to as the social cost of carbon but are consistent with a one metric ton change in CO_2 emissions.
[5] Page 49536 http://www.gpo.gov/fdsys/pkg/FR-2012-08-16/pdf/2012-16806.pdf
[6] Decision 2/CP.3 http://unfccc.int/resource/docs/cop3/07a01.pdf#page=31.

Nations Framework Convention on Climate Change (UNFCCC) requires the use of GWPs with a time horizon of 100 years when calculating national GHG inventories.[7]

The GWPs for CH_4 as estimated by the IPCC for both the Fourth Assessment Report (AR4) and AR5 are presented in Table 1. The estimates presented in AR4 include both direct and indirect effects taking into account the feedback of CH_4 emissions on its own lifetime and an estimated 40% increase in the radiative efficacy of CH_4 emissions due to their role as a precursor for tropospheric ozone and stratospheric water vapor. The CH_4 GWP estimates presented in AR5 also include the indirect effects of CH_4 emissions, but the increase in radiative efficacy due to these effects was increased to 55% due to new findings on the role of CH_4 in stratospheric ozone formation. A reassessment of the effect of CH_4 on its own lifetime led to an increase in the effective perturbation lifetime from 12 years in AR4 to 12.4 years in AR5.

Table 1: Global Warming Potential for CH_4

Time Horizon	AR4[9]	AR5[8]	
		No CC Feedback	With CC Feedback
20	72	84	86
100	25	28	34
500	7.6	--	--

Starting in AR4 the IPCC included climate-carbon (CC) feedbacks in the estimate of the radiative forcing projection from the CO_2 emissions pulse. This feedback accounted for the weakening of carbon sinks from increases in the temperature. However, these feedbacks were not accounted for when estimating the additional mean global radiative forcing due to a non-CO_2 emissions pulse, which would also have an effect on temperature, and in turn carbon sinks. Therefore, in AR5 the IPCC presented estimates both with and without the additional radiative forcing from the CC feedback associated with non-CO_2 emissions. Inclusion of CC feedbacks in calculating the GWP for CH_4 increases the estimate from 28 to 34 for a 100 year time horizon.

2.1 Application of GWP-Based Approach to Benefit-Cost Analysis

The SC-CO_2 is an estimate of the monetized damages associated with an incremental increase in CO_2 emissions in a given year. It is intended to include (but is not limited to) changes in net agricultural productivity, human health, property damages from increased flood risk, and the value of ecosystem services. As such, the SC-CO_2 is an estimate of the benefits of reducing CO_2 emissions at the margin. The USG first published SC-CO_2 estimates in 2010 following an interagency process that included EPA and other executive branch entities. The USG used three integrated assessment models (IAM) to develop SC-CO_2 estimates and selected four global values for use in regulatory analyses. The USG recently updated these estimates using new versions of each IAM and published them in 2013. The 2013 update did not

[7] http://unfccc.int/ghg_data/online_help/definitions/items/3817.php
[8] Source: Table 8.7 in Myhre et al. (2013).
[9] Source: Table 2.14 in Forster et al. (2007).

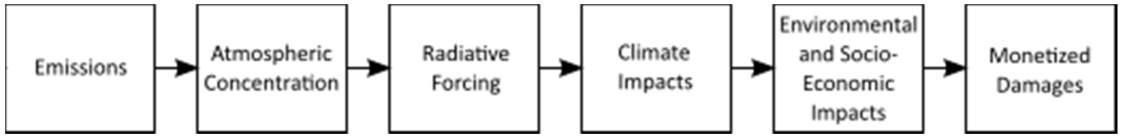
revisit the 2010 modeling decisions (e.g., discount rates, reference case socioeconomic and emission scenarios, or equilibrium climate sensitivity). Rather, updates were confined to those IAM modifications that were implemented by the model developers themselves and subsequently used in the peer-reviewed literature. The February 2010 Technical Support Document (TSD)[10] provides a complete discussion of the methods used to develop the USG SC-CO_2 estimates and the November 2013 TSD[11] presents and discusses the updated estimates.

The USG has not developed an estimate of the social cost of CH_4 emissions for use in regulatory analysis. As a result benefit-cost analyses informing U.S. federal rulemakings have not fully considered the benefits associated with CH_4 emissions mitigation. To understand the potential implication of these omissions, EPA has conducted sensitivity analysis in some of its regulatory analyses using the 100-year GWP to convert CH_4 emission reductions to CO_2-equivalents, which are then valued using the SC-CO_2. This approach approximates the social cost of methane (SC-CH_4) using the SC-CO2 and the GWP, such that

$$SC\text{-}CH_4 \approx GWP_{100} \times SC\text{-}CO_2 \quad . \qquad (2)$$

2.2 Limitations of the Global Warming Potential Approach for Valuing CH_4 Emissions Changes

The GWP is a simple, transparent, and well-established metric for assessing the relative impacts of non-CO_2 emissions compared to CO_2 on a purely physical basis. However, the GWP-based approximation of the SC-CH_4 in (2) has several well-documented limitations (e.g., Reilly and Richards 1993; Schmalensee 1993; Fankhauser 1994; Marten and Newbold 2012). Gas comparison metrics, such as the GWP, are designed to measure the impact of non-CO_2 GHG emissions relative to CO_2 at a specific point along the pathway from emissions to monetized damages (depicted in Figure 1), and this point may differ across measures. The GWP measures the cumulative radiative forcing from a perturbation of a non-CO_2 GHG relative to a perturbation of CO_2 over a fixed time horizon. The GWP and other gas comparison metrics are not ideally suited for use in benefit-cost analyses to approximate the social cost of non-CO_2 GHGs because they ignore important nonlinear relationships beyond radiative forcing in the chain between emissions and damages. These can become relevant because gases have different lifetimes. For example, the SC-CO_2 takes into account the fact that marginal damages from an increase in temperature are a function of existing temperature levels. Another limitation of gas comparison metrics for this purpose is that some environmental and socioeconomic impacts are not linked to all of the gases under consideration and will therefore be incorrectly allocated. For example, the economic impacts associated with increased agricultural productivity due to higher atmospheric CO_2 concentrations included in the SC-CO_2 would be incorrectly allocated to CH_4 emissions with the GWP-based valuation approach.



[10] http://www.whitehouse.gov/sites/default/files/omb/inforeg/for-agencies/Social-Cost-of-Carbon-for-RIA.pdf
[11] http://www.whitehouse.gov/sites/default/files/omb/assets/inforeg/technical-update-social-cost-of-carbon-for-regulator-impact-analysis.pdf

Figure 1: Path from GHG Emissions to Monetized Damages (Source: Marten et al. (2014))

Furthermore, the assumptions made in estimating the GWP are not consistent with the assumptions underlying SC-CO_2 estimates in general, including the USG SC-CO_2 estimates. For example the 100 year time horizon usually used in estimating the GWP is less than the 300 year horizon used in developing the USG SC-CO_2 estimates. The GWP-approach also treats all impacts within the time horizon equally, independent of the time at which they occur. This is inconsistent with the role of discounting in economic analysis, which accounts for a basic preference for earlier over later gains in utility, the small but positive probability of a large global catastrophe (e.g., large asteroid collision, super volcanic eruption, nuclear war), and expectations regarding future levels of economic growth. In the case of CH_4, which has a relatively short lifetime compared to CO_2, the temporal independence of the GWP could lead the approximation in (2) to underestimate the SC-CH_4 with a larger downward bias under higher discount rates (Marten and Newbold 2012).[12]

3. Direct Estimation

The SC-CH_4 can be directly estimated using an integrated assessment model (IAM) similar to the way in which the SC-CO_2 is estimated. IAMs couple simplified models of atmospheric gas cycles and climate systems with highly aggregated models of the global economy and human behavior to represent the impacts of GHG emissions on the climate and human welfare. Within IAMs, the equations that represent the influence of emissions on the climate are based on scientific assessments, while the equations that map climate impacts to human welfare are based on economic research that has studied the effects of climate on various market and non-market sectors. Estimating the social cost of emissions for a given GHG at the margin involves perturbing the emissions of that gas in a given year and forecasting the increase in monetized climate damages relative to the baseline. These incremental damages are then discounted back to the perturbation year to represent the marginal social cost of emissions of the specific GHG in that year.

Several researchers have directly estimated the social cost of CH_4 emissions using IAMs, though the number of such estimates is small compared to the large number of SC-CO_2 estimates available in the literature. Among these published direct estimates there is considerable variation in the models and input assumptions. These studies differ in the emission perturbation year, employ a wide range of constant and variable discount rate specifications, and consider a range of baseline socioeconomic and emissions scenarios that have been developed over the last 20 years. However, as discussed by Marten et al. (2014), none of the other published estimates of the SC-CH_4 are consistent with the USG SC-CO_2 estimates, and most are likely underestimates due to changes in the underlying science since their publication. Therefore, Marten et al. provide the first set of direct estimates of the SC-CH_4 that are consistent with the USG SC-CO_2 estimates.

[12] We note that the truncation of the time period in the GWP calculation could lead to an overestimate of SC-CH4 for near term perturbation years in cases where the SC-CO_2 is based on a sufficiently low or steeply declining discount rate.

The estimation approach of Marten et al. (2014) used the same set of three IAMs, five socioeconomic-emissions scenarios, equilibrium climate sensitivity distribution, and three constant discount rates used to develop the USG SC-CO_2 estimates. Marten et al. also used the same aggregation method as the USG SC-CO_2 to distill the 45 distribution of the SC-CH_4 produced for each emissions year into four estimates: the mean across all models and scenarios using a 2.5%, 3%, and 5% discount rate, and the 95th percentile of the pooled estimates from all models and scenarios using a 3% discount rate.

The primary modeling challenge addressed by Marten et al. (2014) is that two of the three IAMs as implemented by the USG are not "turn-key" ready to estimate the SC-CH_4 due to their lack of an atmospheric stock-flow model of CH_4 emissions and their influence on global mean radiative forcing. Instead, two of the three model implementations use exogenous projection of aggregate non-CO_2 radiative forcing, which prevents the direct perturbation of CH_4 emissions within the models. Therefore, to estimate the SC-CH_4 Marten et al. applied a simple model to estimate the path of additional radiative forcing from a CH_4 perturbation, which is then added to the exogenous non-CO_2 radiative forcing projection to estimate the incremental damages compared to the baseline.

The simple model applied by Marten et al. (2014) used an exponential decay function to project atmospheric CH_4 concentrations from the CH_4 emissions projections in the five socioeconomic-emissions scenarios. They set the average lifetime of CH_4 to 12 years following the findings of the IPCC in AR4. The direct radiative forcing associated with the atmospheric CH_4 concentration was estimated using the functional relationships presented in the IPCC's Third Assessment Report and used in AR4. To account for the indirect effects of CH_4 as a precursor for tropospheric ozone and stratospheric water vapor, Marten et al. followed the approach of the IPCC in AR4 of increasing the direct radiative forcing by 40%.

The USG SC-CO_2 modeling exercise assumed that overall radiative forcing from non-CO_2 sources remains constant past 2100 without specifying the projections for individual GHGs that were implicit in that assumption. This broad assumption was sufficient for the purposes of the USG in estimating the SC-CO_2; however, estimating the SC-CH_4 requires explicit projections of baseline CH_4 emissions to determine the atmospheric concentration and radiative forcing off of which to compare the perturbation. Marten et al. (2014) chose to interpret the USG SC-CO_2 assumption for non-CO_2 radiative forcing past 2100 as applying to each gas individually, such that the emissions of each gas fall to their respective rate of atmospheric decay. This has the effect of holding global mean radiative forcing due to atmospheric CH_4 constant past 2100. Marten et al. showed that, due to the relatively short lifetime of CH_4, alternative methods for extrapolating CH_4 emissions past 2100 have only a negligible effect (less than 0.5%) on the SC-CH_4.

The SC-CH_4 estimates developed by Marten et al. (2014) are presented in Table 2 along with the USG SC-CO_2 estimates. For more detailed results and a comparison to other published estimates we refer the reader to the discussion in Marten et al.

Table 2: $SC\text{-}CO_2$ and $SC\text{-}CH_4$ Estimates [2007$ per metric ton] (Source: Marten et al. (2014))

	$SC\text{-}CO_2$				$SC\text{-}CH_4$			
Year	5.0% Mean	3.0% Mean	2.5% Mean	3% 95th	5.0% Mean	3.0% Mean	2.5% Mean	3% 95th
2010	11	32	51	89	370	870	1,200	2,500
2015	11	37	57	109	460	1,100	1,400	2,900
2020	12	43	64	128	550	1,200	1,600	3,200
2025	14	47	69	143	660	1,400	1,800	3,800
2030	16	52	75	159	780	1,600	2,100	4,300
2035	19	56	80	175	920	1,900	2,300	5,000
2040	21	61	86	191	1,100	2,100	2,600	5,600
2045	24	66	92	206	1,200	2,300	2,900	6,300
2050	26	71	97	220	1,400	2,500	3,100	6,900

3.1 Application of Direct Estimates to Benefit-Cost Analysis

The application of direct estimates from Marten et al. (2014) to benefit-cost analysis of a regulatory action is analogous to the use of the $SC\text{-}CO_2$ estimates. Specifically, the direct estimates would be used to value decreases in CH_4 emissions anticipated from the rulemaking. Forecast reductions in CH_4 emissions in a given year resulting from the regulatory action are multiplied by the $SC\text{-}CH_4$ estimate based on a perturbation in that year. To obtain a present value estimate, the monetized stream of future CH_4 benefits are discounted back to the analysis year using the same discount rate used to estimate the $SC\text{-}CH_4$. Specifically, the present value of benefits from a regulatory action leading to reductions in CH_4 emissions ΔE_t , $t = 0,\ldots,H,$ is

$$\sum_{t=0}^{H} \Delta E_t \times \text{SC-CH}_{4,t} \times (1+r)^{-t} , \tag{3}$$

where r is the discount rate used to estimate the $SC\text{-}CH_4$. The $SC\text{-}CH_4$ estimates would be applied in the same way to calculate CH_4 dis-benefits of a rulemaking that leads to an increase in CH_4 emissions.

3.2 Comparison with the Global Warming Approach

The Marten et al. (2014) estimates are based on the conclusions presented in AR4, which was the latest assessment available when they conducted their modeling and analysis, and therefore GWP estimates based on the same assumptions would provide the most consistent comparison. As noted in Table 1, the AR4 100-year GWP for CH_4 is 25. However, based on the direct estimates in Table 2 the social cost of CH_4 emissions in 2020 are 25-46 times higher than for CO_2 depending on the discount rate. For emissions in 2050 the $SC\text{-}CH_4$ is 31-54 times higher than the $SC\text{-}CO_2$. Therefore the GWP-based approach to estimating the value of CH_4 emissions based on the SC-CO_2 will likely provide an underestimate particularly for higher discount rates and future emissions years in this application.

To illustrate the difference between the direct SC-CH_4 and GWP-based estimates, Table 3 recalculates the methane co-benefits of the EPA 2017-2025 Light-duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards[13] using both the Marten et al. (2014) SC-CH_4 estimates and the GWP-based approach. The GWP-based approach underestimates the climate co-benefits of the expected methane emission reductions by 14% to 50% depending on the discount rate assumption.

Table 3. Methane Co-benefits of 2017-2025 Light Duty Vehicle GHG Standards Using Alternative Valuation Methodologies [Billion 2007$][14]

USG Discount rate assumption	Using Marten et al. (2014) SC-CH_4	GWP-Based Approach (AR4 100 Year)	% Difference
5% Mean	2.5	1.2	- 50%
3% Mean	8.1	6.1	- 26%
2.5% Mean	11.6	9.7	- 16%
3% 95th percentile	21.9	18.8	- 14%

It should be noted that since the Marten et al. (2014) estimates are based on the IPCC AR4 conclusions, in some cases the GWP-based approach using AR5 100-year GWP estimates would yield higher benefits than the current Marten et al. estimates. This occurs for low discount rates and emissions years in the near term and is due to the higher CH_4 indirect effects and climate-carbon feedbacks included in the AR5 GWP estimates. As such, the estimates of Marten et al., by being based on AR4, may be considered conservative in these regards. The inclusion of new AR5 findings in the approach of Marten et al. is expected to increase the SC-CH_4 estimates, and the relative difference between those updated estimates and the GWP-based approach using the AR5 100-year GWP are expected to be similar to those discussed above.

4. Valuing Other Non-CO_2 GHG Emissions

While this white paper focuses on methane, the valuation of other non-CO_2 GHG emissions is relevant to EPA regulatory analyses and remains an ongoing area of research. At least one promulgated rulemaking to date, the 2017-2025 Light-duty Vehicle Greenhouse Gas Emission Standards, has been expected to reduce other non-CO_2 GHG emissions, specifically N_2O and HFC-134a. Marten et al. (2014) provides an analysis of the SC-N_2O parallel to their SC-CH_4 analysis. They use the same methodology described for SC-CH_4, replacing the simple CH_4 atmospheric gas cycle model with a simple N_2O atmospheric cycle, and found the directly modeled SC-N_2O estimates generally exceed those from the GWP-based approach.

[13] http://www.gpo.gov/fdsys/pkg/FR-2012-10-15/pdf/2012-21972.pdf

[14] NPV of climate benefits resulting from 2017-2050 CH_4 emission reductions, discounted back to 2012. See RIA, Table 7.1-4, http://www.epa.gov/otaq/climate/documents/420r12016.pdf.

Their estimates of the SC-N_2O are also consistent with the USG SC-CO_2 estimates and therefore, could also be used to improve the analysis of regulatory actions projected to influence N_2O emissions.

EPA currently does not have directly modeled estimates of the social cost of F-gases, which include a wide variety of gases spanning a broad range of atmospheric lifetimes and climate impacts. It is difficult to determine how directly modeled estimates of SC-F gases would compare to estimates from the GWP-based approach, given the limited number of published estimates at the moment and diversity of gases in this category.

5. Concluding Remarks

As directed by Executive Orders 12866 and 13563, EPA must use the best available scientific, technical, economic, and other information to quantify the costs and benefits of regulatory actions. Rigorous evaluation of costs and benefits has been a core tenet of the EPA rulemaking process for decades. Due to limitations of the GWP-based approach to value GHG emission impacts and the previous lack of peer-reviewed SC-CH_4 estimates consistent with the USG SC-CO_2 modeling assumptions, EPA has only monetized the benefits of CH_4 emissions mitigation in sensitivity analysis. However, Marten et al. (2014) now provides a set of published SC-CH_4 estimates consistent with the USG SC-CO_2 modeling exercise. As such, the Marten et al. estimates offer a method for improving the analyses of regulatory actions that are projected to influence CH_4 emissions without introducing inconsistency with the manner in which other CO_2 mitigation benefits are valued. These estimates can and should be updated if and when the modeling assumptions underlying the USG SC-CO_2 estimates are updated to reflect the conclusions of IPCC AR5 or other evolving scientific and economic knowledge.[15]

[15] The Office of Management and Budget (OMB) recently provided an opportunity for public comment on the updated November 2013 USG SC-CO_2 TSD, in addition to the public comment opportunities available through particular rulemakings. OMB is currently reviewing the comments received. Any revision to the underlying modeling assumptions will be addressed separately as the SC-CO_2 estimates are updated.

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Abstract and Charge Questions:

Consistent with Executive Order 12866, EPA conducts benefit-cost analysis to inform policy makers and the public about the potential economic implications of regulatory actions. EPA has promulgated regulations that result in changes in CH_4 emissions but has not yet quantified such impacts in its main benefit-cost analyses. Direct estimates of the benefits of mitigating CH_4 emissions have been presented in the scientific literature, but EPA has not used these estimates in benefit-cost analyses because they are inconsistent with U.S. Government (USG) estimates of the social cost of carbon dioxide (SC-CO_2).[16] A recently published paper (Marten et al. 2014) presents estimates of the social cost of CH_4 (SC-CH_4) that are consistent with USG estimates of the SC-CO_2. While it is anticipated that the USG will continue to improve the models and data it uses to estimate the SC-CO_2 in accordance with evolving scientific and economic understanding, the enclosed paper illustrates how EPA could apply the SC-CH_4 estimates from Marten et al. to improve upon the current treatment of methane impacts in regulatory impact analysis (RIA) so that they need not be implicitly assigned a value of zero in policy assessment. Consistent with EPA's peer review guidance, the Agency is seeking review of the application of these new benefit estimates to regulatory analysis before using them in an RIA. Specifically we seek guidance on the following questions:

1. Has EPA correctly interpreted the SC-CH_4 estimates provided in Marten et al. (2014) as designed to measure the monetized value of the climate impacts from marginal changes in CH_4 emissions in a way that is appropriate for use in benefit-cost analysis of regulatory actions projected to change CH_4 emissions?

2. Do you agree that the Marten et al. SC-CH_4 estimates are consistent with the USG SC-CO_2 estimates?

3. Do you agree with EPA's characterization of the limitations of using the global warming potential (GWP) to approximate the SC-CH_4 (and other non-CO_2 GHGs)?

4. Do you agree with EPA's assessment that direct estimates of the SC-CH_4, as developed by Marten et al., are more appropriate for monetizing changes in CH_4 emissions than using the GWP to scale the USG SC-CO_2?

[16] See the February 2010 Technical Support Document (TSD) and November 2013 TSD Update for a complete discussion of the methods used to develop the USG SC-CO_2 estimates: http://www.whitehouse.gov/sites/default/files/omb/inforeg/for-agencies/Social-Cost-of-Carbon-for-RIA.pdf, http://www.whitehouse.gov/sites/default/files/omb/assets/inforeg/technical-update-social-cost-of-carbon-for-regulator-impact-analysis.pdf.

5. Are there other existing approaches for monetizing the benefits (or dis-benefits) to society from reductions (increases) in CH_4 emissions that should be considered in regulatory analysis?

6. Although the focus of this review is on the application of estimates of the social cost of CH_4 to benefit-cost analysis for regulations, do your answers for the questions above hold for the application of the social cost of N_2O estimates provided in Marten et al.?

7. Are there implementation issues not addressed in the paper that EPA should consider before applying the Marten et al. estimates in regulatory analysis?

Document Title: Valuing Methane Emission Changes in Regulatory Benefit-Cost Analysis

Approximate Length: 10 pages

Supporting Materials: Marten et al. (2014) (36 pages excluding Appendices)

Abstract and Charge Questions:

Consistent with Executive Order 12866, EPA conducts benefit-cost analysis to inform policy makers and the public about the potential economic implications of regulatory actions. EPA has promulgated regulations that result in changes in CH_4 emissions but has not yet quantified such impacts in its main benefit-cost analyses. Direct estimates of the benefits of mitigating CH_4 emissions have been presented in the scientific literature, but EPA has not used these estimates in benefit-cost analyses because they are inconsistent with U.S. Government (USG) estimates of the social cost of carbon dioxide (SC-CO_2).[1] A recently published paper (Marten et al. 2014) presents estimates of the social cost of CH_4 (SC-CH_4) that are consistent with USG estimates of the SC-CO_2. While it is anticipated that the USG will continue to improve the models and data it uses to estimate the SC-CO_2 in accordance with evolving scientific and economic understanding, the enclosed paper illustrates how EPA could apply the SC-CH_4 estimates from Marten et al. to improve upon the current treatment of methane impacts in regulatory impact analysis (RIA) so that they need not be implicitly assigned a value of zero in policy assessment. Consistent with EPA's peer review guidance, the Agency is seeking review of the application of these new benefit estimates to regulatory analysis before using them in an RIA. Specifically we seek guidance on the following questions:

1. Has EPA correctly interpreted the SC-CH_4 estimates provided in Marten et al. (2014) as designed to measure the monetized value of the climate impacts from marginal changes in CH_4 emissions in a way that is appropriate for use in benefit-cost analysis of regulatory actions projected to change CH_4 emissions?

   I have read both Marten et al. (2014) and the review document and feel that the review document provides an accurate summary of the issues and methodologies discussed in Marten et al. (2014). I feel that Table 3 of the review document provides a nice example of how the SC-CH_4 estimates from Marten et al. (2014) could be used in BCAs of proposed regulations and underscores the bias that arises if a GWP-based approach is used rather than the direct approach proposed by Marten et al. (2014).

   There, of course, is a whole host of issues that arise when applying any social cost measure to regulatory analyses, which have been extensively discussed in the literature

[1] See the February 2010 Technical Support Document (TSD) and November 2013 TSD Update for a complete discussion of the methods used to develop the USG SC-CO_2 estimates: http://www.whitehouse.gov/sites/default/files/omb/inforeg/for-agencies/Social-Cost-of-Carbon-for-RIA.pdf, http://www.whitehouse.gov/sites/default/files/omb/assets/inforeg/technical-update-social-cost-of-carbon-for-regulator-impact-analysis.pdf.

and which I expand on in my responses below. A key issue that I would like to raise here is that these measures are only appropriate for marginal changes in CH_4. These measures are not designed to be used to evaluate non-marginal changes in methane emissions (or any other gas, for that matter). Therefore, caution must be used when applying social cost measures like this.

2. Do you agree that the Marten et al. SC-CH_4 estimates are consistent with the USG SC-CO_2 estimates?

   "Consistent" can have many interpretations. I will say that the Marten et al. SC-CH_4 estimates are computed in a similar way as the SC-CO_2 estimates, so in this regard, the two estimates are "consistent." However, CO_2 is more explicitly modeled in the three models than CH_4 so in this regard they are not "consistent." However, this inconsistency is due to limitations of the models and I feel that Marten et al. have taken appropriate steps to address these limitations the best way possible. However, gaps still remain and should be recognized.

3. Do you agree with EPA's characterization of the limitations of using the global warming potential (GWP) to approximate the SC-CH_4 (and other non-CO_2 GHGs)?

   The review document (and Marten et al) discusses a number of problems that arise when GWP is used to approximate SC-CH_4: (1) in the introduction and in section 2, the authors point out that the indirect effects of CH_4, as a precursor to tropospheric ozone and stratospheric water vapor, can amplify radiative forcing significantly (which would not be captured in the GWP); (2) GWP ignores important nonlinear relationships beyond radiative forcing in the chain between emissions and damages—e.g., increased agricultural productivity due to CO_2 fertilization would be incorrectly attributed to CH_4 if the GWP was used; (3) GWP does not account for differences in time horizons between gases—e.g., since CH_4 has a shorter lifetime than CO_2, the GWP approach would underestimate the SC-CH_4.

   Although all three are technically correct, I feel that (1) and (2) could be addressed to a certain extent (although not perfectly) by adjusting the GWP to account for these biases. However, the temporal issue raised in (3) seems more difficult to address through simple adjustments to the GWP.

   In sum, I agree with the authors that problems exist and that the direct approach in theory is the best way to avoid these issues.

4. Do you agree with EPA's assessment that direct estimates of the SC-CH_4, as developed by Marten et al., are more appropriate for monetizing changes in CH_4 emissions than using the GWP to scale the USG SC-CO_2?

As discussed in my response to question 3 above, I agree that the direct approach is likely a superior approach to the indirect GWP approach. However, it should be noted that the direct approach has issues as well. Namely, as discussed in section 3, most models do not include an atmospheric stock-flow model of CH_4; thus, the authors were forced to develop a separate model to project the path of radiative forcing from a CH_4 perturbation, and then incorporate this path into the IAM exogenously. As a result, indirect or feedback effects are missed. For instance, climate change impacts on agriculture will affect methane emissions.

In sum, no approach is perfect but in my opinion, the "direct" approach used by Marten et al is preferred to the indirect GWP approach for the reasons outlined in the review document. However, the EPA should continue to seek improvements to the direct approach put forth by Marten et al.

5. Are there other existing approaches for monetizing the benefits (or dis-benefits) to society from reductions (increases) in CH_4 emissions that should be considered in regulatory analysis?

   My complaint with past SC measures is the use of highly aggregated and stylized models to monetize the benefits of reductions. By using models that represent the global economy as one aggregate sector, we are missing important subsector interactions and distributional effects that can only be captured with a more disaggregated model, such as a computable general equilibrium model. My sense would be that these SC would be much higher if a more disaggregated model was used. Modeling the economy as one monolithic sector implies, for instance, perfect substitutability across subsectors which will underestimate the cost of damages. It also assumes perfect trade which can also underestimate the cost of damages. (See Chapter 6 of the IPCC WGIII Fifth Assessment Report which highlights some of these biases that arise with alternative model characteristics).

   The use of these simplified models for SC estimates, I believe, is a large source of the criticisms we've seen with respect to the SCC reports. The use of more sophisticated economic models (like those used in the IPCC) is needed, in my opinion.

6. Although the focus of this review is on the application of estimates of the social cost of CH_4 to benefit-cost analysis for regulations, do your answers for the questions above hold for the application of the social cost of N_2O estimates provided in Marten et al.?

   Yes.

7. Are there implementation issues not addressed in the paper that EPA should consider before applying the Marten et al. estimates in regulatory analysis?

I am not sure I would characterize these as "implementation" issues, but I do want to take this opportunity to stress the importance of being forthcoming with the shortcomings of these SC estimates. These shortcoming are not specific to any gas.

(1) As discussed in my response to question 1, these estimates are not appropriate for evaluating large (non-marginal) changes in emissions of any of these gases.

(2) As discussed in my response to question 5, the SC values will be underestimated due to the use of highly aggregated models.

(3) These estimates do not take into account extreme or threshold events, which could amplify the estimates significantly.

(4) These estimates will be biased downward due to the omissions of nonmarket values and omitted impacts, and will be biased upward due to the lack of adaptation responses (although FUND does account for some of this).

John Reilly, MIT December 28, 2014

This report is a response to a request from Katherine Kiel (Dec. 10, 2014) to review a draft EPA (no date) paper, "Valuing Methane Emission Changes in Regulatory Benefit-Cost Analysis." As part of the request I was provided with the 7 charge questions repeated below in italics, the EPA paper, and the paper: Alex L. Marten, Elizabeth A. Kopits, Charles W. Griffiths, Stephen C. Newbold, and Ann Wolverton, 2014 (on line) Incremental C_4H and N_2O mitigation benefits consistent with the US Government's SC-CO_2 Estimates, *Climate Policy*, which forms the basis for estimates provided in the draft EPA paper.

The basic objective of the EPA paper was to outline a process for establishing a social cost of methane (and possibly N_2O) that is consistent with the established basis for estimating a social cost of carbon previously developed by EPA.

1. *Has EPA correctly interpreted the SC-CH_4 estimates provided in Marten et al. (2014) as designed to measure the monetized value of the climate impacts from marginal changes in CH_4 emissions in a way that is appropriate for use in benefit-cost analysis of regulatory actions projected to change CH_4 emissions?*

   The Marten et al. (2014) paper follows closely the original social cost of carbon approach developed by the EPA, using the same 3 IA models, expanding them to include methane and nitrous oxide. EPA's interpretation of the paper appears to be correct. The main addition was an explicit treatment of the lifetime of methane (and nitrous oxide). The formulation used is obviously a simplification of complex atmospheric chemistry but has been used in earlier publications and likely approximates a more complex representation. The *ad hoc* increase in radiative forcing to account for indirect effects is another simplification, and obviously has substantial impacts on the estimates. It is justified by the IPCC indirect estimates. It is not clear that the method includes the fact that abiogenic methane decays into CO_2 and hence may represent an additional impact of methane release. (Biogenic methane also decays into CO_2 but if that methane is derived from plant material that regrows it would then not represent an addition of CO_2 to the atmosphere.)

2. *Do you agree that the Marten et al. SC-CH_4 estimates are consistent with the USG SC-CO_2 estimates?*

   While there is considerable controversy about how to estimate a Social Cost of Carbon from a theoretical standpoint as well as the empirical foundation for such an estimate, the method put forward by Marten et al. (2014) is theoretically and empirically consistent with the original Social Cost of Carbon estimates developed by EPA.

3. *Do you agree with EPA's characterization of the limitations of using the global warming potential (GWP) to approximate the SC-CH_4 (and other non-CO_2 GHGs)?*

I agree that using GWP's to scale the social cost of carbon would be theoretically inconsistent. As the EPA (no date) paper discusses, the Social Cost of Carbon method appropriately uses a discount rate to weight damages at different points in time, whereas the GWP approach stops at radiative forcing and then uses an arbitrary time horizon to truncate the effects, weighting effects in each year equally. This leads to the controversy about which GWP time horizon to use. Of course this controversy is not completely avoided as it resurfaces as a controversy about the appropriate discount rate. It appears to turn out that given the time path of damages the 100-year GWP of methane is very similar to the Social Cost of Methane relative to the Social Cost of Carbon as estimated in the Marten et al (2014) paper. (This was a conclusion Reilly and Richards (1993) reached.) With a very different path of damages this result may not hold. For that reason as EPA imagines updating these estimates, and for theoretical consistency, using the Marten et al. (2014) method for arriving at a Social Cost of methane (or nitrous oxide) appears much more defensible.

While it does not affect the basic conclusions, I have some issues with the paragraph in EPA (no date) repeated below in italics, especially the sentences highlighted here in bold.

> *Furthermore, the assumptions made in estimating the GWP are not consistent with the assumptions underlying SC-CO_2 estimates in general, including the USG SC-CO_2 estimates.* ***For example the 100 year time horizon usually used in estimating the GWP is less than the 300 year horizon used in developing the USG SC-CO_2 estimates.*** *The GWP-approach also treats all impacts within the time horizon equally, independent of the time at which they occur.* ***This is inconsistent with the role of discounting in economic analysis, which accounts for a basic preference for earlier over later gains in utility, the small but positive probability of a large global catastrophe (e.g., large asteroid collision, super volcanic eruption, nuclear war), and expectations regarding future levels of economic growth.*** *In the case of CH_4, which has a relatively short lifetime compared to CO_2, the temporal independence of the* ***GWP could lead the approximation in (2) to underestimate the SC-CH_4 with a larger downward bias under higher discount rates (Marten and Newbold 2012).[1]***

[1] We note that the truncation of the time period in the GWP calculation could lead to an overestimate of SC-CH4 for near term perturbation years in cases where the SC-CO_2 is based on a sufficiently low or steeply declining discount rate.

Regarding the inconsistency of the 100- and 300-year horizons: Yes, I suppose this is true but there really is no direct comparison. In the economic analysis one hopefully has a far enough time horizon so that with discounting it is irrelevant. In some sense choice of discount rate is a substitute for the choice of time horizon—the higher the discount rate the shorter the time horizon. In a final version of this paper I might rephrase this as something like. *In the USG SC-CO_2 estimates a 300-year time horizon was used, long enough to minimize its effects on estimates given the discount rates used. In contrast the GWP approach is to truncate estimates at different time horizons (20-, 100-, 500-years), treating all impacts within the time horizon equally, independent of the time at which they occur.* I think this gets across the point you want to make without directly suggesting that the 100-year and 300-year horizons are inconsistent (when in fact that is not even comparable.)

Then the second emboldened sentence raising a huge set of issues and controversies. I think the sentence would be best deleted. The discount rate should not theoretically include the risk of catastrophe. Risks should be separately evaluated with a risk-free discount rate to arrive at an "expected" social cost of carbon, perhaps with a utility function that more heavily weights bad outcomes. While an observed rate of return can include a risk premium based on a specific assessment of the risk (and time profile of the risk) it is inappropriate to apply a risk premium to a discount rate and then apply that risk-adjusted rate to many different investment profiles. Here, different characterizations of when catastrophes may occur. Embedding risk into the discount rate in this manner is little different than using GWP's with truncated time horizons to implicitly give different weights (1 or 0) to damages occurring at different times. And while in a Ramsey model the discount rate is approximately the sum of the pure rate of time preference plus the growth rate that again is calculation under certainty so using "expected growth" is inconsistent. Then you have the Weitzman argument that with uncertainty in the appropriate discount rate, one should use a declining rate. And bringing up things like asteroid collisions and such just seems distracting here.

Finally, I guess the last emboldened statement is true but it took me a long time to figure it out. A higher discount rate, as compared to a lower rate, will lead to a lower social cost of carbon (or methane). So concluding that it will underestimate the Social Cost of Methane seemed initially backward. Further a higher discount rate, while lowering the social cost of both gases, will tend to raise the Social Cost of Methane relative to that of carbon. But I guess if I fully parse this sentence, you are saying that taking a specific GWP-horizon (e.g 100 years) and deriving a SC of methane by applying it to your existing SC of carbon, then if you were to do this the right way with a high discount rate—that SC of methane would be higher then that derived using the shorthand method. Maybe there is a clearer way to say this…but then I'm not sure why this is important. There seems to be a concern about underestimating the methane value. You could just as easily say, that methane would be overvalued for low discount rates. I'd think you just want the CS of carbon and methane to be consistent and unbiased in either direction.

4. *Do you agree with EPA's assessment that direct estimates of the SC-CH_4, as developed by Marten et al., are more appropriate for monetizing changes in CH_4 emissions than using the GWP to scale the USG SC-CO_2?*

   Yes, see above.

5. *Are there other existing approaches for monetizing the benefits (or dis-benefits) to society from reductions (increases) in CH_4 emissions that should be considered in regulatory analysis?*

   Not of which I am aware. As the Reilly and Richards (1993) paper referred to in the Marten et al. (2014) paper the multiple impacts of these different gases, beyond climate change, could in principle be incorporated into the analysis but that raises further complications. E.g. CO_2 has some benefit to crop growth (disputed) but ozone (of which methane is a precursor) has not only climate implications but also damages to crops and health. However, with all the recognized limitations to the empirical foundation for the SC estimates, the chosen approach is theoretically sound.

6. *Although the focus of this review is on the application of estimates of the social cost of CH_4 to benefit-cost analysis for regulations, do your answers for the questions above hold for the application of the social cost of N_2O estimates provided in Marten et al.?*

   Yes, the method is equally applicable to N2O.

7. Are there implementation issues not addressed in the paper that EPA should consider before applying the Marten et al. estimates in regulatory analysis?

   As the paper itself points out, the current approach of using a social cost of 0 is clearly not right and so whatever the limitations of existing methods its seems better to use something rather than nothing. Of course one could use a value that is so high that zero would be preferable, but I don't see that error here. More to the point: Accepting the Social Cost of Carbon estimates, this approach consistently applies the concept to methane (and potentially other GHGs).

   John Reilly
   MIT

Peer Review of EPA Proposed Methodology "Valuing Methane Emission Changes in Regulatory Benefit-Cost Analysis"

Steven Rose, Ph.D., Energy and Environmental Analysis Research Group, EPRI

January 15, 2015

This is an extremely challenging research area due to the breadth of physical and social sciences represented and the vast uncertainty inherent in modeling global biophysical and economic systems for centuries to come. EPA should be commended for seeking peer review feedback. Peer review is important for producing scientifically defensible results and instilling public confidence. However, given the regulatory importance of the social cost of greenhouse gas estimates, a different peer review process should be pursued going forward that will increase public confidence in the ultimate outcome (see suggestion at the end of my comments).

For this review activity, EPA requested peer review feedback on seven charge questions. Below I have responded to each. Overall, I am concerned about moving forward with direct non-CO_2 social cost estimates based on the USG SC-CO_2 methodology before having a peer reviewed SC-CO_2 methodology.

Responses to EPA Charge Questions

1. *Has EPA correctly interpreted the SC-CH_4 estimates provided in Marten et al. (2014) as designed to measure the monetized value of the climate impacts from marginal changes in CH_4 emissions in a way that is appropriate for use in benefit-cost analysis of regulatory actions projected to change CH_4 emissions?*

   Yes, the Marten et al. SC-CH_4 estimates are derived with marginal global methane pulses and as such would be conceptually appropriate for valuing incremental changes in global methane emissions such as those likely to result from U.S. regulatory actions. However, as discussed below, there are computational issues with the specific Marten et al. SC-CH_4 estimates that need to be considered; and, implementation issues associated with using the SC-CH_4 estimates to value regulatory action methane changes.

2. *Do you agree that the Marten et al. SC-CH_4 estimates are consistent with the USG SC-CO_2 estimates?*

   The Marten et al. estimates are mostly consistent with the USG SC-CO_2 estimates. They are consistent in a variety of ways with the USG SC-CO_2 estimates due to the common experimental design (e.g., same three integrated assessment (IA) models, uncertainty specification, scenario runs, and results aggregation procedure). However, they do not appear to be entirely consistent, and the implications are not clear to me. For instance, the simple model used to compute CH_4 concentrations and radiative forcing is different from the modeling used to construct non-CO_2 forcing for the PAGE and DICE model's USG SC-CO_2 reference and pulse scenarios. It is not clear to me whether this is a big deal. One would want to compare reference <u>**and**</u> incremental perturbation responses for all the EMF-22 emissions scenarios. Marten et al. makes some comparison to MAGICC 5.3, but doesn't comment on reference scenario differences (that could impact SC-CO_2 estimates) or on the differences for higher and lower emissions scenarios. Another inconsistency is the implementation of the CH_4 and CO_2 perturbations. The CO_2 perturbations in the USG SC-CO_2 calculations vary by model, differing in temporal implementation and magnitude (see Section 5 in *Understanding the Social Cost of Carbon: A Technical Assessment*, http://epri.co/3002004657). In DICE, a 1 GtC shock was added over the decade which straddles year *t*, in FUND, a 1 million metric ton carbon (1 MtC) shock was added to every year within a decade from year *t* forward, and in PAGE, 100 billion metric tons of CO_2 (100 GtCO_2, 27 GtC) was distributed evenly over the decades preceding and subsequent to year *t*.[1] In Marten et al. however, the CH_4 perturbation was a 1 MtCH_4 pulse in a single year *t*.

More importantly, while consistency is the driving motivation for the Marten et al. paper, it creates a serious problem. The Marten et al. SC-CH_4 estimates inherit all the issues associated with the USG SC-CO_2 estimates. Overall, consistency with the USG SC-CO_2 methodology is a scientifically pragmatic and laudable objective for SC-CH_4 calculations. However, it requires that the SC-CO_2 methodology be scientifically sound. However, the USG SC-CO_2 methodology, and the IA models themselves, have not undergone peer review; and, a number of fundamental issues have been identified that could merit and motivate revisions to the USG SC-CO_2 methodology (and resulting SC-CO_2 & SC-CH_4 estimates). Scientifically, it would be inappropriate at this stage to propagate issues with the SC-CO_2 methodology by moving forward with the proposed Marten et al. (2014) SC-CH_4 (and SC-N_2O) estimates. Unfortunately, consistency alone is not adequate justification for using the Marten et al. estimates. A peer reviewed SC-CO_2 methodology is needed before creating consistent SC-X estimates for non-CO_2 gases. See reply below to Charge Question #4 for some of the important issues that need to be considered.

3. *Do you agree with EPA's characterization of the limitations of using the global warming potential (GWP) to approximate the SC-CH_4 (and other non-CO_2 GHGs)?*

   Yes, conceptually, I agree with the limitations noted. However, practically, there are methodological issues that should be re-considered, and potentially revised, before one can legitimately begin to claim that the SC-CH_4 estimates are improvements over GWP application. See reply to Charge Question 4.

4. *Do you agree with EPA's assessment that direct estimates of the SC-CH_4, as developed by Marten et al., are more appropriate for monetizing changes in CH_4 emissions than using the GWP to scale the USG SC-CO_2?*

   Conceptually, direct estimates of SC-CH_4 are more appropriate than using GWPs to value CH_4 emissions changes associated with US regulatory actions. Practically, however, is another issue. It depends on the scientific soundness of the SC-CH_4 estimation methodology. Unfortunately, the current USG SC-CO_2 methodology, and therefore the proposed SC-CH_4 methodology, has not been peer reviewed to establish scientific soundness, and as noted, fundamental issues with the current methodology have been identified. For instance, we recently completed and published a very extensive technical assessment of the USG SC-CO_2 modeling that coded up individual

[1] Note that with PAGE, the emissions pulse is initially introduced as a uniform increase in average annual CO_2 emissions over the given period associated with year *t*. However, within PAGE's climate model, emissions for years *t-1* and *t* are averaged. Thus, the emissions pulse enters PAGE's carbon cycle as uniform (but half-sized) increases in average annual emissions in both the decades preceding and following year *t*.

components of the models and ran diagnostic scenarios (*Understanding the Social Cost of Carbon: A Technical Assessment*, http://epri.co/3002004657). From the analyses, we identified a number of fundamental issues with the USG SC-CO_2 approach that should be considered:

a. Significant structural & response differences across models that need to be evaluated to determine whether they are providing useful information or are differences to reconcile or address explicitly as an uncertainty. For instance, the models do not consider the same sets of emissions and radiative forcing categories—the drivers for projected temperature. The models also have stark differences in key pieces of the climate modeling (e.g., the carbon cycle, climate sensitivity, climate feedbacks, and projected climate change uncertainty), with some elements excluded entirely from some models. Furthermore, unique model specific factors dominate results in the damage components and therefore raise questions about their representation within each model and across models—e.g., agricultural CO_2 fertilization, cooling energy demand, global damages dominated by China, regional scaling of damages, rapidly growing global non-economic damages, potential discontinuity damages, and damages that increase quadratically with temperature. Finally, the study also finds dramatic differences in estimated damages across models for comparable regions and sectors that are not explored or explained.

b. Reasonable alternative specifications, additional uncertainties, and some variation that is artificial due to, for instance, difference in model implementation. Together, these findings suggest the need to revisit the representation of uncertainty in the experimental design.

c. Inconsistencies across modeling, as well as inter-model dependency, that raises an issue about the statistical comparability of results produced by the three different models. Statistical comparability and independence is required for USG SC-CO_2 approach which combines 150,000 results from the three IA models into a distribution in order to derive a single USG SC-CO_2 for a given year and discount rate.

d. The current USG SC-CO_2 estimates may not be robust (i.e., insensitive to alternative assumptions) given that (i) the study finds the underlying climate and damage results from the models (e.g., concentrations, radiative forcing, temperature, and sector and regional specific damages over time) to be very sensitive to alternative assumptions, and (ii) the study finds reasonable alternatives to the assumptions and modeling used in the USG SC-CO_2 experiment.

e. Issues with the overall experimental design, in particular the use of multiple models, which creates the consistency and comparability challenges and issues noted previously.

Based on these findings, the study makes a number of recommendations that could help increase scientific and public confidence in the SC-CO_2 results:

a. Internally review the modeling to evaluate differences, improve comparability and uncertainty representation, and enhance robustness.

b. Revisit the experimental design, especially given the challenges with the multi-model approach.

c. Evaluate robustness to reasonable alternative assumptions and modeling to insure that the results are stable.

d. Peer review the approach and the models used. The USG SC-CO_2 approach is novel and peer review would be valuable and practical. Model review would also be practical given the regulatory use of the models.

e. Additional documentation and justification for methodological choices to facilitate communications & interpretation, and increase public confidence.

f. Application guidance to insure proper application of USG SC-CO_2 estimates.

Other researchers, of course, have also identified issues with the current USG SC-CO_2 approach. Marten et al. cite a number of studies (Arrow et al., 2013; Kopp & Mignone 2012; Marten, 2011; O'Neil, 2010; Warren, Mastrandrea, Hope, & Hof, 2010). And recently, the scientific community has called for a more scientific process with greater scientific community engagement and formal peer review (Pizer et al., 2015).

5. *Are there other existing approaches for monetizing the benefits (or dis-benefits) to society from reductions (increases) in CH_4 emissions that should be considered in regulatory analysis?*

   Global temperature potentials could be considered, but they would have similar time period issues as GWPs.

6. *Although the focus of this review is on the application of estimates of the social cost of CH_4 to benefit-cost analysis for regulations, do your answers for the questions above hold for the application of the social cost of N_2O estimates provided in Marten et al.?*

   Yes, I have similar concerns about the Marten et al. SC-N_2O estimates and would be reluctant to move forward with the Marten et al. SC-N_2O and SC-CH_4 estimates.

7. *Are there implementation issues not addressed in the paper that EPA should consider before applying the Marten et al. estimates in regulatory analysis?*

   Yes, in addition to the issues raised in my comments above regarding the Marten et al. SC-CH_4 (and SC-N_2O) estimates, there are a few issues regarding use of SC-CH_4 and SC-N_2O values. First, in regulatory applications, it will be essential to estimate net global changes in emissions due to proposed rules in order to appropriately utilize SC-CH_4 and SC-N_2O estimates, which reflect the marginal value of **net global** changes in methane and nitrous oxide respectively. Second, it will be important to think about consistency in the underlying assumptions in benefit and cost calculations, e.g., those used for computing social costs of GHGs, GHG emissions reductions, and compliance costs. Third, current USG guidance to use all SC-CO_2 estimates will presumably be the same for SC-CH_4 and SC-N_2O estimates. As such, the guidance needs to be expanded to provide direction on how agencies should use the multiple resulting CO_2 (CH_4, or N_2O) benefit estimates in benefit-cost analyses and regulation proposal decisions.

Additional comment

Given the regulatory importance of the social cost of greenhouse gas estimates, a more extensive and public peer review process should be pursued going forward that will give the public greater confidence in the ultimate values. Specifically, peer review of the USG SC-CO_2 methodology (and the subsequent non-CO_2 social cost methodologies) should be a public process with a scientific review panel (created through a public selection process) that produces a single report reflecting the panel's critique and recommendations. This sort of review process is typical for important regulatory metrics and methodologies, and a key function of groups like EPA's Science Advisory Board. The peer review I'm participating in here is a useful means of soliciting scientific feedback, but not a substitute for the review process needed (and described above).

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EPA Summary and Response

EPA recently conducted a peer review of the application of the Marten et al. (2014) non-CO_2 social cost estimates in regulatory impact analysis (RIA). Three reviewers considered seven charge questions that covered issues related to the EPA's interpretation of the estimates, the consistency of the estimates with the SC-CO_2 estimates used in RIAs, EPA's characterization of the limits of the alternative GWP-approach to approximate the social cost of non-CO_2 GHGs, and the appropriateness of using the Marten et al. estimates in RIAs. The reviewers agreed with EPA's interpretation of Marten et al.'s estimates; generally found the estimates to be consistent with the SC-CO_2 estimates; and concurred with the limitations of the GWP approach, finding directly modeled estimates to be more appropriate.

While outside of the scope of the review, the reviewers briefly considered potential areas of improvement for the methodology used by the U.S. federal government to estimate the SC-CO_2. They noted that because the SC-CO_2 and SC-CH_4 methodologies are similar, the potential improvements may also apply to the SC-CH_4 estimates. Two of the reviewers concluded that use of the SC-CH_4 estimates developed by Marten et al. and published in the peer-reviewed literature in RIAs is appropriate, provided that the Agency discuss the limitations, similar to the discussion provided for SC-CO_2 estimates and other economic analyses. All three reviewers encouraged continued improvements in the SC-CO_2 estimates and suggested that as those improvements are realized they should also be reflected in the SC-CH_4 estimates, with one reviewer suggesting that application of the SC-CH_4 estimates lag this process.

EPA supports continued improvement in the SC-CO_2 estimates developed by the U.S. federal government and agrees that improvements in the SC-CO_2 estimates should also be reflected in SC-CH_4 estimates applied in RIAs. Through this and other forums, EPA and other members of the interagency working group on the SC-CO_2 have received many thoughtful suggestions for areas of potential improvements for the SC-CO_2 estimates. In response, the interagency working group is seeking independent advice from the National Academies of Science, Engineering, and Medicine on how to approach future updates to the SC-CO_2 estimates.[1] In the meantime, the interagency working group and OMB continues to recommend the use of the current SC-CO_2 estimates in RIAs. The fact that the reviewers agree that the SC-CH_4 estimates are generally consistent with the SC-CO_2 estimates, which continue to be recommended by OMB's guidance on valuing CO_2 emissions reductions, leads EPA to conclude that use of the SC-CH_4 estimates is an analytical improvement over excluding changes in methane emissions from the monetized portion of the benefit-cost analysis.

In light of the favorable peer review and past comments urging EPA to value non-CO_2 GHG impacts in rulemakings, the Agency is using the Marten et al. (2014) SC-CH_4 estimates to value methane climate impacts in the main benefits analysis in proposed rulemakings.[2] Consistent with Agency practice, EPA is

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[1] Information about the status of the National Academies' review is available on the Academies' website at: http://sites.nationalacademies.org/DBASSE/BECS/CurrentProjects/DBASSE_167526.

[2] Specifically, EPA has used these new estimates to value methane impacts in the benefit-cost analysis for the *Proposed Revisions to the Emission Guidelines and New Source Performance Standards in the Municipal Solid Waste Landfills Sector and the Proposed Emission Standards for New and Modified Sources in the Oil and Natural Gas Sector*. The estimates were also presented in sensitivity analysis supporting the *Proposed Phase 2 Greenhouse Gas Emissions Standards and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles*, which was completed while the Marten et al. (2014) peer review was still underway.

taking public comment on the application of the new estimates in the proposed rules, and will consider the comments before finalizing the analyses.