June 21, 2021

Office of Management and Budget Notice of Availability and Request for Comment on "Technical Support Document: Social Cost of Carbon, Methane, and Nitrous Oxide Interim Estimates under Executive Order 13990," 86 FR 24669 (May 7, 2021)

Comments submitted by Patrick J. Michaels, Kevin D. Dayaratna, and Marlo Lewis.[1]

Thank you for the opportunity to comment on the Interagency Working Group's (IWG) Technical Support Document: Social Cost of Carbon, Methane, and Nitrous Oxide Interim Estimates under Executive Order 13990.[1] The authors and undersigned organizations strongly oppose the use of social cost of carbon (SCC) analysis as a basis, framework, or tool for making or informing federal agency regulatory, permitting, or procurement decisions. SCC analysis is too dependent on non-validated assumptions and inputs to be fit for such purposes.

Worse, as in the IWG's 2010, 2013, and 2016 technical support documents (TSDs), the IWG's 2021 interim TSD utilizes highly-questionable and cherry-picked assumptions and inputs to

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support the climate crisis narrative and promote climate policies whose very real costs would hugely exceed the undetectably small hypothetical benefits.

Our comments are organized as follows.

Section 1 provides an overview of SCC analysis basics. It explains why the integrated assessment models (IAMs) used to estimate SCC values are not an appropriate tool to guide policymaking. We also outline specific flaws in the IWG's methodology. The IWG uses outdated climate sensitivity assumptions, below-market discount rates, an analysis period extending far beyond the limits of informed speculation, and implausible ("return to coal") emission baselines. Two of its IAMs unscientifically depreciate carbon dioxide fertilization benefits, and one unreasonably depreciates human adaptative capability.

Section 2 discusses the IWG's reliance on climate sensitivity estimates from models that substantially overestimate observed tropical tropospheric warming during the past 40 years. We caution that the IWG's SCC estimates will become even more unrealistic if IAM sensitivity assumptions are derived from the CMIP6 models that will be used in the forthcoming Sixth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). The social cost of carbon is too speculative and assumption-driven for any government to adopt official SCC estimates. However, if the IWG insists on doing so, it should use only the climate sensitivity estimates similar to those of the Russian Institute of Numerical Mathematics (INM) suite of general circulation models (GCMs)—the only models to accurately track observed tropical tropospheric warming since 1979.

Section 3 sets the stage for the next sections that show in detail how IAM assumptions and inputs can easily be manipulated for political purposes. Sections 3-8 draw upon Kevin Dayaratna's 2020 Congressional Testimony.[2]

Section 4 shows how discount rates affect SCC estimates. We make a case for using a 7 percent discount rate, which would allow the public to compare the productivity of climate policy investments to market-driven investments. Using a 7 percent rate would dramatically reduce the IWG's SCC estimates. If the IWG continues to produce SCC estimates, it should include a 7 percent discount rate. It should not use below-market (1-2 percent) discount rates, which are useful only for propaganda purposes such as making fossil fuels look unaffordable no matter how cheap, and renewables look like a bargain at any price.

Section 5 discusses how the time horizon affects SCC estimates. The IWG estimates cumulative climate damages out to the year 2300—well beyond the limits of informed speculation. Even if the IWG gets climate sensitivity right, it is in no position to make official pronouncements about the economic and technological evolution of the 22nd and 23rd centuries. If the IWG continues to produce SCC estimates, it should limit the analytic horizon to 2150, which could reduce SCC estimates by more than 25 percent.

Section 6 explains that the IWG relies on an outmoded climate sensitivity probability distribution that inflates SCC estimates. If the IWG continues to produce SCC estimates, it should use sensitivity estimates from recent empirically-constrained studies. Doing so would dramatically reduce the IWG's SCC estimates.

Section 7 shows that running the FUND model with updated empirical information regarding climate sensitivity produces significant probabilities of negative SCC estimates through at least the mid-21st century. That means there is a significant probability that the agricultural benefits of CO_2 emissions will outweigh any climate change-related damages beyond the next 30 years. If the IWG continues to produce SCC estimates, it should clearly present the probabilities of negative SCC values.

Section 8 documents the immense agricultural benefits of CO_2 fertilization. DICE and PAGE—two of the three IAMs used by the IWG—effectively assign a value of zero dollars to those benefits. The FUND model estimates CO_2 fertilization benefits on the basis of studies from the 1990s. If the IWG continues to produce SCC estimates, it should not use models that ignore CO_2 fertilization benefits, and it should utilize the best available science to estimate such benefits.

Section 9 provides an assessment of human adaptive capabilities based on various long-term trends such as the 99 percent reduction globally since the 1920s in the average person's risk dying from extreme weather events. If the IWG continues to produce SCC estimates, it should eschew models that assume adaptation is futile beyond 2°C of warming and 10 inches of sea-level rise.

Section 10 discusses the implausibility of the baseline emission scenarios used by the IWG to estimate the incremental impact of an additional ton of CO_2 emissions. Four of the IWG's five baseline emission scenarios implausibly assume that, absent specific climate policies, the world returns to a coal-based energy system, not just for the remainder of the 21st century, but through the entire analysis period ending in 2300. This assumption dramatically inflates SCC estimates. Replacing it with more realistic emission baselines would just as dramatically reduce those estimates. If the IWG continues to produce SCC estimates, it should replace its outmoded emission baselines with new baselines reflecting recent energy market and emission trends.

Section 11 presents our conclusions.

Please direct any questions about these comments to Patrick J. Michaels (pat.michaels@cei.org), Kevin D. Dayaratna (kevin.dayaratna@heritage.org), and Marlo Lewis (marlo.lewis@cei.org).

Section 1: Social Cost of Carbon Basics

The SCC is an estimate in dollars of the cumulative long-term damage caused by one ton of carbon dioxide (CO_2) emitted in a specific year. That number also represents an estimate of the benefit of avoiding or reducing one ton of CO_2 emissions.

The computer programs used to project SCC values are called integrated assessment models (IAMs) because they combine a climate model, which estimates the physical impacts of CO_2 emissions, with an economic model, which estimates the dollar value of climate change effects on agricultural productivity, property values, and other economic variables. The IWG uses three IAMs—abbreviated DICE, FUND, and PAGE—to estimate SCC values.

In federal agency analyses, the cumulative damage of an incremental ton of CO_2 emissions is estimated from the year of the emission's release until 2300. SCC estimates are highly sensitive to:

- The climate sensitivity assumptions chosen to estimate the warming impact of projected increases in atmospheric greenhouse gas (GHG) concentration.
- The discount rates chosen to calculate the present value of future emissions and reductions.
- The timespan chosen to estimate cumulative damages from rising GHG concentration.
- The extent to which the SCC reflects empirical information about the agricultural and ecological benefits of carbon dioxide fertilization.
- The assumptions chosen regarding the potential for adaptation to decrease the cost of future climate change impacts.
- The choice of socioeconomic pathways used to project future GHG emissions and concentrations.

What this means is that, if a modeler intends to make climate change look economically catastrophic and make greenhouse gas regulations appear essential, the modeler:

- Uses IAMs that assume high climate sensitivity.
- Runs the IAMs with below-market discount rates.
- Calculates cumulative damages over a 300-year period—i.e., well beyond the limits of informed speculation about how the global economy will evolve and how adaptative technologies will develop.
- Ignores or minimizes CO_2 fertilization benefits in the modeling.[3]
- Includes at least one IAM that assumes adaptation cannot mitigate the cost of climate change impacts once global warming and sea-level rise exceed 2°C and 0.25 meters, respectively.[4]
- Runs the models with emission scenarios that assume the world "returns to coal" absent new climate policies.

In other words, the modeler would do exactly what the Obama IWG did in its 2010, 2013, and 2016 TSDs, and what the Biden IWG proposes to do in its 2021 interim TSD.

Section 2: Climate Models Versus Observations

The key climate variable in SCC estimates is equilibrium climate sensitivity (ECS), which is typically defined as the increase in global mean surface temperature after the climate system fully adjusts to a doubling of CO_2-equivalent greenhouse gas concentration. IAMs do not estimate climate sensitivity. Rather, IAMs use the sensitivity estimates from general circulation models (GCMs) as inputs. In this section of the comments, we show that so-called state-of-the-art GCMs significantly overestimate observed warming—a clear indication that the models overestimate climate sensitivity.

We begin with the first two lines of the TSD's Executive Summary, which imply that the SCC estimates later presented are "robust and scientifically founded":

> A robust and scientifically founded assessment of the positive and negative impacts that an action can be expected to have on society provides important insights in the policy-making process.[5]

"Robust" means an analysis that stands up to new data or further analyses. It is easy to demonstrate that the TSD's proposed SCC estimates are anything but robust.

In its Fifth Assessment Report (AR5), the IPCC used the Coupled Model Intercomparison Project Phase 5 (CMIP5) models to project future warming and the associated climate impacts.[6] The figure below compares predicted and observed average tropospheric temperature over the tropics.[7] The observations come from satellites, weather balloons, and reanalyses.[8]

A careful look at the figure reveals that only one of the 102 model runs correctly simulates what has been observed. This is the Russian climate model INM-CM4, which also has the least prospective warming of all of them, with an ECS of 2.05°C, compared to the CMIP5 average of 3.4°C.

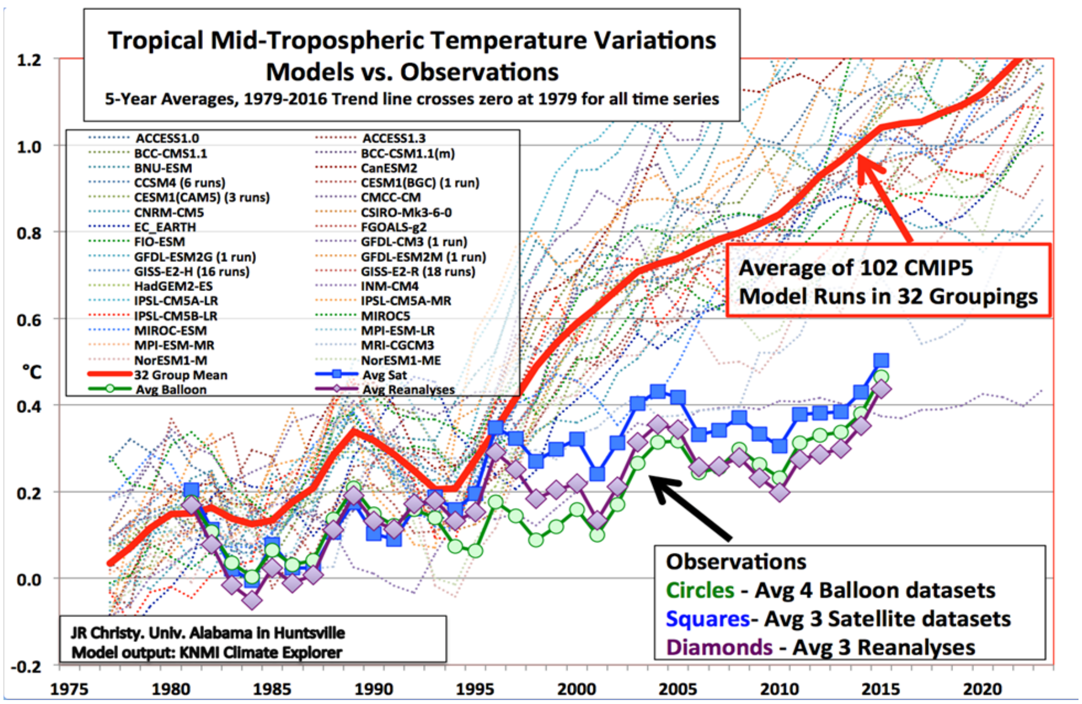


Figure 1. Solid red line—average of all the CMIP-5 climate models; Thin colored lines—individual CMIP-5 models; solid figures—weather balloon, satellite, and reanalysis data for the tropical troposphere. [9]

Best scientific practice uses models that work and does not seriously consider those that do not. This is standard when formulating the daily weather forecast, and should be standard with regard to climate forecasts.

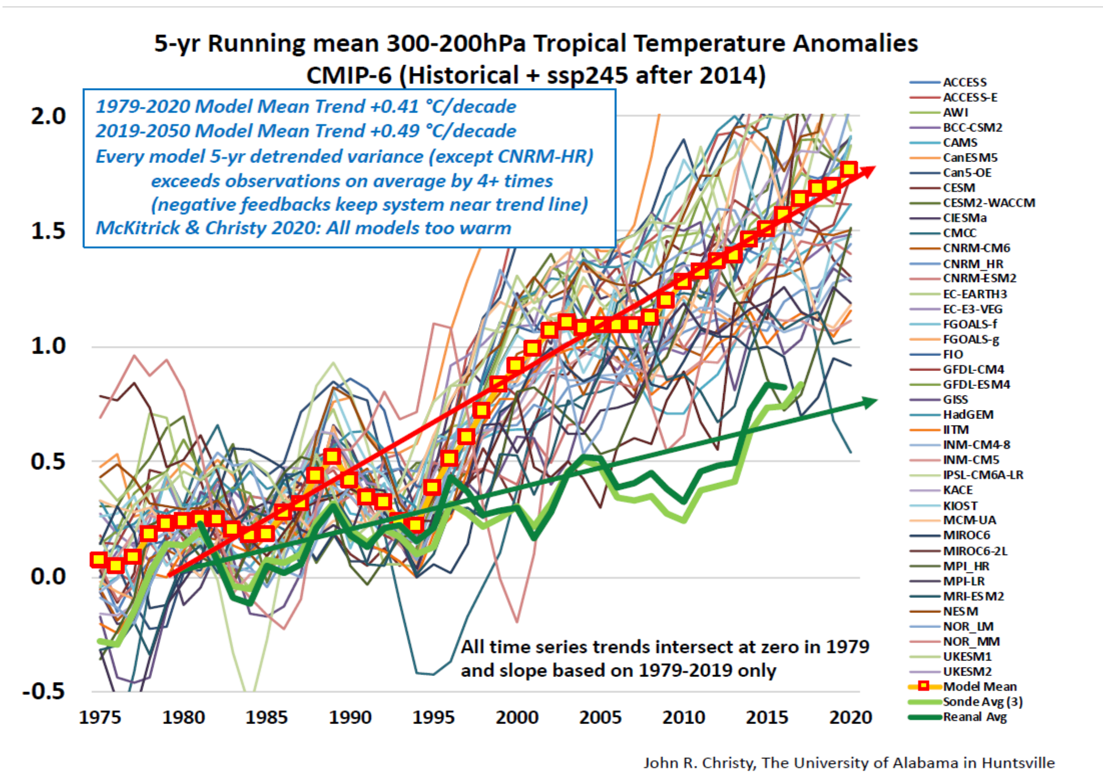
There's another problem with the CMIP5 suite that popped up in 2016 and continues to appear: *The models are fudged.* That's plain English for "selective parameterization." In the words of Frédéric Hourdin, the chief of the French climate modelling effort:

> One can imagine changing a parameter that is known to affect the sensitivity, keeping both this parameter and the ECS in the anticipated acceptable range… [emphasis added].[10]

In an article related to Hourdin's paper, Paul Voosen noted that all models are treated this way. Isaac Held, from NOAA's GFDL in Princeton, told Voosen that all models are tuned to mimic the 20th century.[11] Clearly, the CMIP5 models themselves are manipulated. Again, IAM climate sensitivity assumptions derive from GCM sensitivity estimates.

The IPCC is nearing completion of an upcoming (2022) Sixth Assessment Report, and a new suite of models, designated CMIP6, is being released. Will those be an improvement?

No. As shown by McKitrick and Christy (2020), the CMIP6 models are even worse.[12] Of the two models that work, the Russian INM-CM4.8 has even less warming than its predecessor, with an ECS of 1.8°C, compared to the CMIP6 community value of around four degrees.[13] The other one is also a very low ECS model from the same group, INM-CM5. The model mean warming rate exceeds observation by more than four times at altitude in the tropics.



Quoting from McKitrick and Christy's conclusion:

> The literature drawing attention to an upward bias in climate model warming responses in the tropical troposphere extends back at least 15 years now (Karl et al., 2006). Rather than being resolved, the problem has become worse, since now every member of the CMIP6 generation of climate models exhibits an upward bias in the entire global troposphere as well as in the tropics.

Zeke Hausfather, hardly a climate skeptic, has noted that while the CMIP6 models are warmer than the previous generation, the warmer they are, the more they over-forecast warming in recent decades, confirming what McKitrick and Christy found.[14]

Zhu, Poulsen, and Otto-Bliesner (2020) used a CMIP6 model called CESM2 to project warming from an emission scenario that reaches 855 parts per million by 2100—roughly three times the pre-industrial concentration. Despite being tuned to match the behavior of 20th century climate, the model produced a global mean temperature "5.5°C greater than the upper end of proxy temperature estimates for the Early Eocene Climate Optimum." That was a period when CO_2 concentrations of about 1,000 ppm persisted for millions of years.[15] Moreover, the modeled tropical land temperature exceeded 55°C, "which is much higher than the temperature tolerance of plant photosynthesis and is inconsistent with fossil evidence of an Eocene Neotropical rainforest."[16]

All of this emphasizes that the IWG's current SCC estimates grossly overestimate climate damages, and will become more inaccurate if updated with CMIP6.

There is the obvious alternative of relying on the INM (Russian) model suites, which should have been done. Absent that, why does the IWG neglect the reality-based (and low) ECS calculations of Christy and McNider (2017) and Lewis and Curry (2018)?[17] Dayaratna et al. (2020) used this approach (in combination with updated empirical data on carbon dioxide fertilization) and found the SCC may very well be negative up to and beyond 2050 at all discount rates used.[18] A negative SCC is another way of saying that each incremental ton of CO_2 produces a net benefit.

Section 3: The IWG's IAMs Are Not Legitimate Tools for Guiding Policy Decisions

The Obama administration IWG used three IAMs—DICE, FUND, and PAGE—to estimate SCC values.[19] The Biden administration's reconstituted IWG relies on the same models. Over the past several years, Dayaratna and colleagues at the Heritage Foundation have run the DICE and FUND models, testing their sensitivity to a variety of important assumptions. That body of research, published in the peer-reviewed literature, think tank reports, and congressional testimony, repeatedly demonstrates that although the IAMs might be interesting academic exercises, they are extremely sensitive to very reasonable changes to assumptions.[20] Far from being robust, the models can easily be manipulated by user-selected assumptions. Consequently, they are not legitimate tools for guiding federal agency regulatory, permitting, or procurement decisions.

All the IAMs have serious shortcomings. In particular, the models' loss functions projecting economic damages from changes in global mean average temperatures are often arbitrarily chosen, and we have yet to see any legitimate justification of these functions themselves. MIT professor Robert Pindyck explained the problem as follows:

> When assessing climate sensitivity, we at least have scientific results to rely on, and can argue coherently about the probability distribution that is most consistent with those results. When it comes to the damage function, however, we know almost nothing, so

> developers of IAMs can do little more than make up functional forms and corresponding parameter values. And that is pretty much what they have done.[21]

The highly speculative character of loss functions is discrediting, because different loss functions will almost surely yield different SCC estimates.

Climate damages are estimated by Monte Carlo simulation. The general idea behind Monte Carlo simulation is that since some aspects of the models are random, the models are run repeatedly to generate a spectrum of probable outcomes. As a result of principles in probability theory, repeated estimation for a sufficient amount of time supposedly provides a reasonable characterization of the SCC's distributional properties.

Not so. As with any statistical model, the IAMs are grounded by assumptions. The Heritage Foundation studies rigorously examined three important assumptions: the choice of a discount rate, a time horizon, and the specification of an equilibrium climate sensitivity (ECS) distribution.

Section 4: How the Discount Rate Affects the SCC

Models used to estimate the SCC rely on the specification of a discount rate. The concept of discount rates is best viewed by considering an expenditure today as a benefit in the future via an investment. Discounting the future benefits of averted climate damage compares the rate of return from CO_2 reduction to the rate of return expected from other investments.

In principle, discounting runs the compound rate of return exercise backwards, calculating how much would need to be invested at a reasonably expected interest rate today to result in the value of the averted future climate damage. Contrary to the IWG's argument,[22] it is reasonable to include a 7 percent discount rate, as 7 percent is the rate of return of the New York Stock Exchange over the last hundred years.[23]

The IWG ran the models using 2.5 percent, 3.0 percent, and 5.0 percent discount rates despite the fact that Office of Management and Budget (OMB) guidance in Circular A-4 specifically stipulates that a 7.0 percent discount rate be used as well.[24] At the Heritage Foundation, Dayaratna and colleagues ran DICE and FUND using a 7.0 percent discount rate. Below are the Heritage analysts' results published in the peer-reviewed journal *Climate Change Economics*:

	DICE Model Average SCC – Baseline, End Year 2300			
Year	**Discount Rate - 2.5%**	**Discount Rate – 3.0%**	**Discount Rate – 5.0%**	**Discount Rate – 7.0%**
2020	$56.92	$37.79	$12.10	$5.87
2030	$66.53	$45.15	$15.33	$7.70
2040	$76.96	$53.26	$19.02	$9.85
2050	$87.70	$61.72	$23.06	$12.25

	FUND Model Average SCC – Baseline, End Year 2300			
Year	**Discount Rate - 2.5%**	**Discount Rate – 3.0%**	**Discount Rate – 5.0%**	**Discount Rate – 7.0%**
2020	$32.90	$19.33	$2.54	–$0.37
2030	$36.16	$21.78	$3.31	–$0.13
2040	$39.53	$24.36	$4.21	$0.19
2050	$42.98	$27.06	$5.25	$0.63

As the above tables illustrate, the SCC estimates are drastically reduced when the models are run with a 7.0 percent discount rate. In fact, under the FUND model, the estimates are negative through 2030 and very low through 2050. Using a 7.0 percent discount rate can cause the SCC to drop by as much as 80 percent or more. We will discuss negative SCC values in Section 7.

The IWG now proposes to lower the central estimate discount rate below 3 percent and may use low-end rates as low as 1 percent.[25] What that would mean in the policy arena may be inferred from a 2013 study co-authored by Chris Hope, architect of the PAGE model.

Selecting a 1 percent discount rate, Hope and his colleagues estimated that in 2010, the SCC was already $266 per ton—about ten times larger than Obama administration's central SCC estimate. The authors concluded that new renewable generation is more "economically efficient" than either new gas or existing coal generation.[26] By tweaking just one variable, SCC modelers can make fossil fuels look unaffordable no matter how cheap and renewable energy look like a bargain at any price. Speaking candidly, isn't that the political purpose of the exercise?

If the IWG continues to estimate SCC values, it should include estimates discounted at 7 percent. Only on that basis can the public compare climate policy "investments" to other capital investments. And only through such comparisons can policymakers reasonably assess which investments will best position future generations to inherit the most productive capital stock.

Section 5: How the Time Horizon Affects the SCC

The IWG bases its SCC estimates on projections of climate change damages over a 300-year period (2000-2300). That in itself raises questions about the legitimacy of those estimates. No colonial bureaucrat in 1721 could forecast that in the 2000s people would fly in aluminum tubes at 600 mph and communicate instantly with tiny boxes capable of accessing virtually all the information available in the world. The IWG is no better qualified to forecast the economic and technological evolution of the 22^{nd} and 23^{rd} centuries.

Human beings use technology to adapt to environmental conditions. Consequently, the loss functions in IAMs depend on assumptions about how adaptive technologies will be developed and deployed as the world warms. It is essentially impossible to forecast technological change decades, let alone centuries, into the future.

To test the sensitivity of SCC estimates to the time horizon chosen, Dayaratna and his former Heritage Foundation colleague David Kreutzer ran the DICE model with a significantly shorter, albeit still unrealistic, analytic horizon of 150 years.[27]

Here are the DICE-estimated SCC values with a baseline ending in 2300[28]:

TABLE 1

Average SCC Baseline, End Year 2300

Year	Discount Rate: 2.5%	Discount Rate: 3%	Discount Rate: 5%	Discount Rate: 7%
2010	$46.57	$30.04	$8.81	$4.02
2015	$52.35	$34.32	$10.61	$5.03
2020	$56.92	$37.79	$12.10	$5.87
2025	$61.48	$41.26	$13.60	$6.70
2030	$66.52	$45.14	$15.33	$7.70
2035	$71.57	$49.03	$17.06	$8.70
2040	$76.95	$53.25	$19.02	$9.85
2045	$82.34	$57.48	$20.97	$11.00
2050	$87.69	$61.72	$23.06	$12.25

Source: Calculations based on Heritage Foundation Monte Carlo simulation results using the DICE model. B 2860 heritage.org

Here are the results with a baseline ending in 2150:

TABLE 3

Average SCC, End Year 2150

Year	Discount Rate: 2.5%	Discount Rate: 3%	Discount Rate: 5%	Discount Rate: 7%
2010	$36.78	$26.01	$8.66	$4.01
2015	$41.24	$29.65	$10.42	$5.02
2020	$44.41	$32.38	$11.85	$5.85
2025	$47.57	$35.11	$13.28	$6.68
2030	$50.82	$38.00	$14.92	$7.67
2035	$54.07	$40.89	$16.56	$8.66
2040	$57.17	$43.79	$18.36	$9.79
2045	$60.27	$46.68	$20.16	$10.92
2050	$62.81	$49.20	$22.00	$12.13

Source: Calculations based on Heritage Foundation Monte Carlo simulation results using the DICE model. B 2860 heritage.org

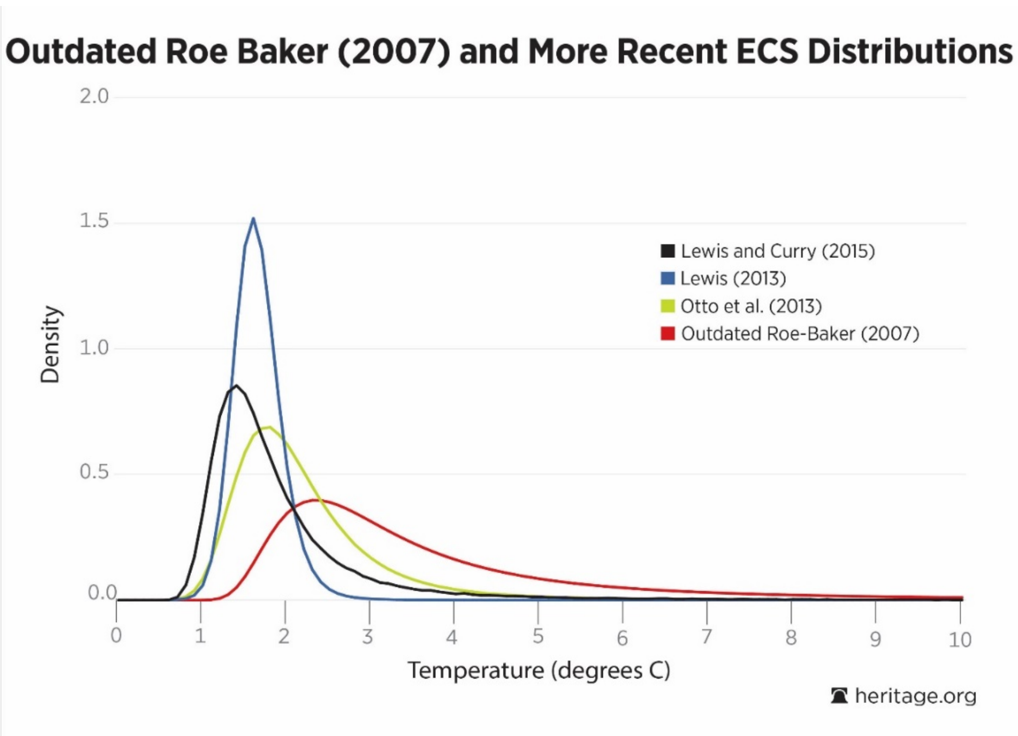
The SCC estimates drop substantially—in some cases by more than 25 percent—as a result of ending the SCC analysis period in 2150.

If the federal government is going to use the SCC in policymaking, the accompanying analyses should limit the time horizon at most to 150 years, and include much stronger caveats about the inutility of long-term economic and technology forecasting.

Section 6: How the Equilibrium Climate Sensitivity (ECS) Distribution Affects the SCC

The key climate specification used in estimating the SCC, as indicated in the discussion of general circulation models in Section 2, is the ECS distribution. These distributions probabilistically quantify the earth's temperature response to a doubling of CO_2 concentrations. The ECS distribution used by the IWG is based on a paper published in the journal *Science* fourteen years ago by Gerard Roe and Marcia Baker.[29] This non-empirical distribution, calibrated by the IWG based on assumptions it selected in conjunction with IPCC recommendations, is no longer scientifically defensible.[30]

Since 2011, a variety of newer and empirically-constrained distributions have been published in the peer-reviewed literature. Many of those distributions suggest lower probabilities of extreme global warming in response to CO_2 concentrations. Below are a few such distributions:[31]



The areas under the curves between two temperature points represent the probability that the earth's temperature will increase between those amounts in response to a doubling of CO_2 concentration. For example, the area under the curve from 4°C onwards (known as right-hand "tail probability") represents the probability that the Earth's temperature will warm by more than 4°C in response to a doubling of CO_2 concentrations. Note that the more up-to-date ECS distributions (Otto et al., 2013; Lewis, 2013; Lewis and Curry, 2015) have significantly lower tail probabilities than the outdated Roe-Baker (2007) distribution used by the IWG.

Here is the IWG's 2016 SCC estimates for 2020-2050:

Table ES-1: Social Cost of CO_2, 2010 – 2050 (in 2007 dollars per metric ton of CO_2)

Year	5% Average	**3% Average**	2.5% Average	High Impact (95th Pct at 3%)
2010	10	**31**	50	86
2015	11	**36**	56	105
2020	12	**42**	62	123
2025	14	**46**	68	138
2030	16	**50**	73	152
2035	18	**55**	78	168
2040	21	**60**	84	183
2045	23	**64**	89	197
2050	26	**69**	95	212

In *Climate Change Economics*, Dayaratna and colleagues re-estimated the SCC in DICE and FUND using the more up-to-date ECS distributions and obtained the following results:[32]

	DICE Model Average SCC – ECS Distribution Updated in Accordance with Lewis and Curry (2015), End Year 2300			
Year	**Discount Rate - 2.5%**	**Discount Rate – 3.0%**	**Discount Rate – 5.0%**	**Discount Rate – 7.0%**
2020	$28.92	$19.66	$6.86	$3.57
2030	$33.95	$23.56	$8.67	$4.65
2040	$39.47	$27.88	$10.74	$5.91
2050	$45.34	$32.51	$13.03	$7.32

	FUND Model Average SCC – ECS Distribution Updated in Accordance with Lewis and Curry (2015), End Year 2300			
Year	**Discount Rate - 2.5%**	**Discount Rate – 3.0%**	**Discount Rate – 5.0%**	**Discount Rate – 7.0%**
2020	$5.86	$3.33	–$0.47	–$1.10
2030	$6.45	$3.90	–$0.19	–$1.01
2040	$7.02	$4.49	–$0.18	–$0.82
2050	$7.53	$5.09	$0.64	–$0.53

Using the more up-to-date ECS distributions dramatically lowers SCC estimates. The IWG's outdated assumptions overstate the probabilities of extreme global warming, which artificially inflates their SCC estimates. We advise policymakers not to use SCC estimation for policymaking, as it is highly susceptible to user manipulation. However, if it must be used, modelers should utilize realistic estimates of climate sensitivity.

Section 7: Negative SCC Values

Policymakers and the media often assume carbon dioxide emissions have only harmful impacts on society. However, CO_2 emissions have enormous direct agricultural[33] and ecological benefits,[34] global warming lengthens growing seasons,[35] and warming potentially alleviates cold-related mortality, which exceeds heat-related mortality by 20 to 1.[36]

Of the three IAMs used by the IWG, only the FUND model estimates CO_2 fertilization benefits. Dayaratna and colleagues investigated whether a model with CO_2 fertilization benefits could produce negative SCC estimates. They computed the probability of a negative SCC under a variety of assumptions. Below are some of the results published both at the Heritage Foundation as well as in the peer-reviewed journal *Climate Change Economics*:[37]

	FUND Model Probability of Negative SCC – ECS Distribution Based on Outdated Roe–Baker (2007) Distribution, End Year 2300			
Year	**Discount Rate - 2.5%**	**Discount Rate – 3.0%**	**Discount Rate – 5.0%**	**Discount Rate – 7.0%**
2020	0.084	0.115	0.344	0.601
2030	0.080	0.108	0.312	0.555
2040	0.075	0.101	0.282	0.507
2050	0.071	0.093	0.251	0.455

	FUND Model Probability of Negative SCC – ECS Distribution Updated in Accordance with Otto et al. (2013), End Year 2300			
Year	**Discount Rate - 2.5%**	**Discount Rate – 3.0%**	**Discount Rate – 5.0%**	**Discount Rate – 7.0%**
2020	0.268	0.306	0.496	0.661
2030	0.255	0.291	0.461	0.619
2040	0.244	0.274	0.425	0.571
2050	0.228	0.256	0.386	0.517

	FUND Model Probability of Negative SCC – ECS Distribution Updated in Accordance with Lewis (2013), End Year 2300			
Year	**Discount Rate - 2.5%**	**Discount Rate – 3.0%**	**Discount Rate – 5.0%**	**Discount Rate – 7.0%**
2020	0.375	0.411	0.565	0.685
2030	0.361	0.392	0.530	0.645
2040	0.344	0.371	0.491	0.598
2050	0.326	0.349	0.449	0.545

	FUND Model Probability of Negative SCC – ECS Distribution Updated in Accordance with Lewis and Curry (2015), End Year 2300			
Year	**Discount Rate - 2.5%**	**Discount Rate – 3.0%**	**Discount Rate – 5.0%**	**Discount Rate – 7.0%**
2020	0.402	0.432	0.570	0.690
2030	0.388	0.414	0.536	0.646
2040	0.371	0.394	0.496	0.597
2050	0.354	0.372	0.456	0.542

As the above statistics illustrate, under a very reasonable set of assumptions, the SCC is overwhelmingly likely to be negative, which implies—if one adopts the perspective of a central planner—that the government should *subsidize* (not limit) CO_2 emissions. We, of course, oppose such interventionism. Our purpose here is to illustrate the extreme sensitivity of these models to reasonable changes in assumptions. Although we recommend the SCC not be used by policymakers, if it must be used, the final TSD and other official reports should present the probabilities of negative SCC values—i.e., the chance that the direct benefits of CO_2 emissions will exceed climate-related damages.

Section 8: Agricultural Benefits and Benefit-Cost Analysis

It is a well-established fact that increases in CO_2 concentration enhance plant growth by increasing their internal water use efficiency as well as raising the rate of net photosynthesis.[38] The FUND model attempts to incorporate those benefits; however, this aspect of the model is grounded on research that is one to two decades old.

As discussed in Section 7, Dayaratna et al. (2017) found substantial probabilities of negative SCC using those outdated assumptions in FUND. In the peer-reviewed journal *Environmental Economics and Policy Studies*, Dayaratna et al. (2020) summarized more recent CO_2 fertilization research and updated the FUND model with the new empirical information.[39] To facilitate the IWG's review of that research, we excerpt several paragraphs from Dayaratna et al. (2020):

> Three forms of evidence gained since then indicates that the CO_2 fertilization effects in FUND may be too low. First, rice yields have been shown to exhibit strong positive responses to enhanced ambient CO_2 levels. Kimball (2016) surveyed results from Free-Air CO_2 Enrichment (FACE) experiments, and drew particular attention to the large yield responses (about 34 percent) of hybrid rice in CO_2 doubling experiments, describing these as "the most exciting and important advances" in the field. FACE experiments in both Japan and China showed that available cultivars respond very favorably to elevated ambient CO_2. Furthermore, Challinor et al. (2014), Zhu et al. (2015) and Wu et al. (2018) all report evidence that hybrid rice varietals exist that are more heat-tolerant and therefore able to take advantage of CO_2 enrichment even under warming conditions (2013). Collectively, this research thus indicates that the rice parameterization in FUND is overly pessimistic.
>
> Second, satellite-based studies have yielded compelling evidence of stronger general growth effects than were anticipated in the 1990s. Zhu et al (2016) published a comprehensive study on greening and human activity from 1982 to 2009. The ratio of land areas that became greener, as opposed to browner, was approximately 9 to 1. The increase in atmospheric CO_2 was just under 15 percent over the interval but was found to be responsible for approximately 70 percent of the observed greening, followed by the deposition of airborne nitrogen compounds (9 percent) from the combustion of coal and deflation of nitrate-containing agricultural fertilizers, lengthening growing seasons (8 percent) and land cover changes (4 percent), mainly reforestation of regions such as southeastern North America …
>
> Munier et al. (2018) likewise found a remarkable increase in the yield of grasslands. In a 17-year (1999-2015) analysis of satellite-sensed LAI [leaf area index], during which time the atmospheric CO_2 level rose by about 10 percent, there was an average LAI increase of 85 percent. A full 31 percent of earth's continental land outside of Antarctica is covered by grassland, the largest of the three agricultural land types they classified. Also, for summer crops, such as maize (corn) and soybeans, greening increased an average of 52 percent, while for winter crops, whose area is relatively small compared to those for summer, the increase was 31 percent. If 70 percent of the yield gain is attributable to increased CO_2, the results from Zhu et al (2016) imply gains of 60 percent, 36 percent and 22 percent over the 17-year period for, respectively, grasslands, summer crops and winter crops, associated with only a 10 percent increase in CO_2, compared to parameterized yield gains in the range of 20 to 30 percent for CO_2 doubling in FUND.

> Third, there has been an extensive amount of research since Tsingas et al. (1997) on adaptive agricultural practices under simultaneous warming and CO_2 enrichment. Challinor et al. (2014) surveyed a large number of studies that examined responses to combinations of increased temperature, CO_2 and precipitation, with and without adaptation. In their metanalysis, average yield gains increased 0.06 percent per ppm increase in CO_2 and 0.5 percent per percentage point increase in precipitation, and adaptation added a further 7.2 percent yield gain, but warming decreased it by 4.9 percent per degree C. In FUND, 3°C warming negates the yield gains due to CO_2 enrichment. However, based on Challinor et al.'s (2014) regression analysis, doubling CO_2 from 400 to 800 pm, while allowing temperatures to rise by 3°C and precipitation to increase by 2 percent, would imply an average percent yield increase ranging from 2.1 to 12.1 percent increase, indicating the productivity increase in FUND is likely too small.

Based on that literature, Dayaratna et al. (2020) updated the FUND model's coefficients to increase its agricultural benefits by 15 percent and 30 percent. In addition, the researchers used an updated ECS distribution—that of Lewis and Curry (2018).[40] In the charts below, the last three columns show the updated mean SCC as well as the associated probability of negative SCC values.

	FUND Model Average SCC, agricultural component updated - Discount Rate – 2.5%			
	Roe Baker (2007)	**Lewis and Curry (2018)**	**Lewis and Curry (2018) + 15%**	**Lewis and Curry (2018) + 30%**
2020	$32.90	$3.78 / 0.46	$0.62 / 0.53	-$1.53 / 0.59
2030	$36.16	$4.69 / 0.44	$1.25 / 0.51	-$1.02 / 0.57
2040	$39.53	$5.76 / 0.42	$2.03 / 0.48	-$0.33 / 0.54
2050	$42.98	$6.98 / 0.39	$2.96 / 0.46	-$0.55 / 0.51

	FUND Model Average SCC, agricultural component updated - Discount Rate – 3%			
	Roe Baker (2007)	**Lewis and Curry (2018)**	**Lewis and Curry (2018) + 15%**	**Lewis and Curry (2018) + 30%**
2020	$19.33	$1.61 / 0.49	-$0.82 / 0.57	-$2.74 / 0.63

2030	$21.78	$2.32 / 0.47	-$0.35 / 0.54	-$2.39 / 0.61
2040	$24.36	$3.18 / 0.44	$0.28 / 0.51	-$1.85 / 0.57
2050	$27.06	$4.21 / 0.42	$1.08 / 0.48	-$1.12 / 0.54

	FUND Model Average SCC, agricultural component updated - Discount Rate – 5%			
	Roe Baker (2007)	**Lewis and Curry (2018)**	**Lewis and Curry (2018) + 15%**	**Lewis and Curry (2018) + 30%**
2020	$2.54	-$1.02 / 0.62	-$2.25 / 0.71	-$3.41 / 0.78
2030	$3.31	-$0.77 / 0.58	-$2.14 / 0.67	-$3.41 / 0.74
2040	$4.21	-$0.39 / 0.54	-$1.89 / 0.63	-$3.24 / 0.70
2050	$5.25	$0.15 / 0.49	-$1.47 / 0.58	-$2.87 / 0.65

	FUND Model Average SCC, agricultural component updated - Discount Rate – 7%			
	Roe Baker (2007)	**Lewis and Curry (2018)**	**Lewis and Curry (2018) + 15%**	**Lewis and Curry (2018) + 30%**
2020	-$0.37	-$1.25 / 0.71	-$2.06 / 0.80	-$2.84 / 0.85
2030	-$0.13	-$1.18 / 0.67	-$2.08 / 0.76	-$2.94 / 0.82
2040	$0.19	-$0.98 / 0.62	-$1.98 / 0.71	-$2.91 / 0.77
2050	$0.63	-$0.66 / 0.56	-$1.74 / 0.65	-$2.71 / 0.72

As these results illustrate, under more realistic assumptions regarding agricultural productivity and climate sensitivity, the mean SCC essentially drops to zero and in many cases has a substantial probability of being negative. These results further demonstrate that the SCC is highly sensitive to very reasonable changes to assumptions and is thus readily prone to user manipulation.

Indeed, we could not help noticing that the concepts of CO_2 fertilization and global greening do not occur in the IWG's interim TSD. Similarly, although Dayaratna et al. (2020) was published in January 2020, it is not included among the TSD's 115 references.

Section 9: Unreasonable Pessimism Regarding Human Adaptive Capabilities

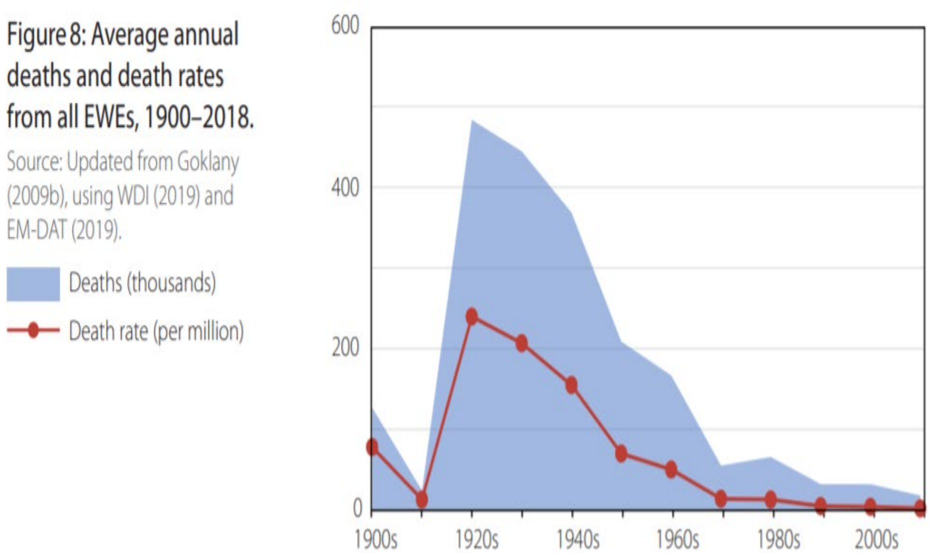
Other things being equal, the more pessimistic an IAM's view of human adaptive capabilities, the higher the SCC estimates it will produce. Climate impact assessments often ignore, assume away, or depreciate mankind's remarkable capacity for adaptation.[41] For example, the Fourth National Climate Assessment's estimates of U.S. climate damages in the 2090s "only capture adaptation to the extent that populations employed them in the historical period," i.e., during 1980-2010. Similarly, the Assessment's $505 billion estimate of annual RCP8.5 economic damages in 2090 "assume limited or no adaptation."[42]

The 2021 TSD says little about adaptation, stating only that IAM analysis of adaptation and technological change is "incomplete" and that the potential extent and costs of adaptation is a source of uncertainty.[43] The 2016 TSD provides more detail and includes a subsection on the PAGE model's treatment of adaptation. Here is the gist. In PAGE2002, "Beyond 2°C, no adaptation is assumed to be available to mitigate the impacts of climate change." And in PAGE09, "adaptation is assumed to alleviate 25-50 percent of the damages from the first 0.20 to 0.25 meters of sea level rise but is assumed to be ineffective thereafter."[44]

Those assumptions are not reasonable. Industrial civilization's virtuous circle of wealth creation and technological innovation endlessly updates mankind's adaptive capabilities, including our ability to make the Earth's naturally dangerous climate more livable.[45] Since the 1920s, global CO_2 concentrations increased from about 305 parts per million to more than 410 ppm, and average global temperatures increased by about 1°C.[46] Yet, globally, the individual risk of dying from weather-related disasters such as hurricanes, floods, and drought decreased by 99 percent.[47] If we are in a "climate crisis" today, what words can adequately describe the climate regime of the 1920s?[48]

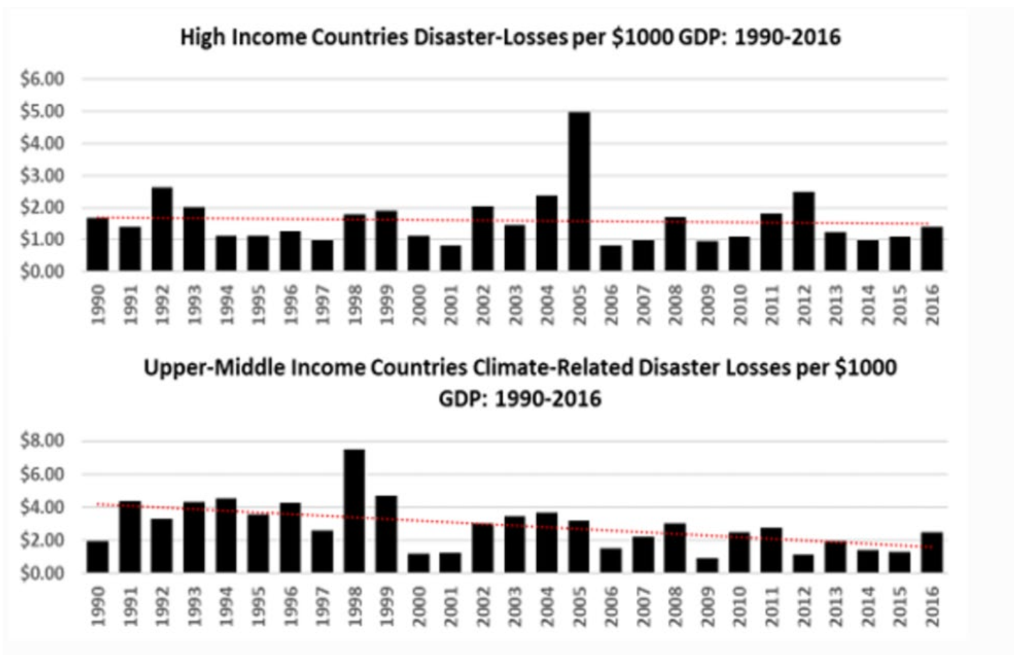
Figure 8: Average annual deaths and death rates from all EWEs, 1900–2018.

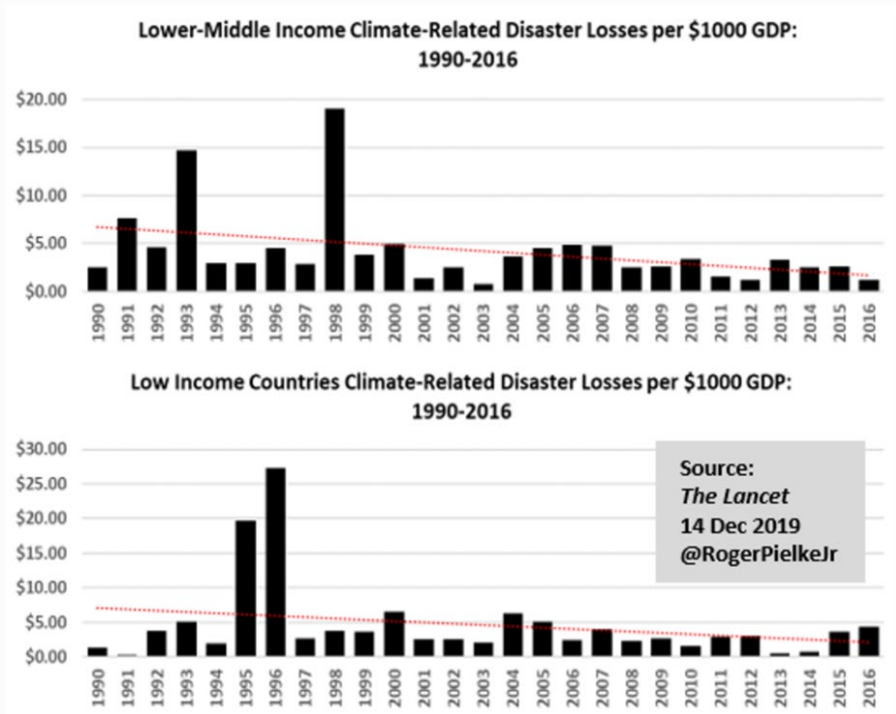
Source: Updated from Goklany (2009b), using WDI (2019) and EM-DAT (2019).



It is not possible to discern a social cost of carbon in that data. Nor is an SCC detectable in several other trends of fundamental relevance to human flourishing. The past 70 years have been marked by unprecedented improvements in life expectancy,[49] per capita income,[50] food security,[51] and various health-related metrics.[52] Yields of all major food crops keep increasing,[53] nearly 3 billion people gained access to improved water sources since 1990,[54] and deaths from malaria (the most consequential climate-sensitive disease) declined by 52 percent during 2000-2015.[55]

Even in recent decades, the warmest in the instrumental record, mortality and economic loss data point to an increasingly sustainable civilization. Formetta and Feyen (2019) found that climate-related hazards show a "clear decreasing trend in both human and economic vulnerability, with global average mortality and economic loss rates that have dropped by 6.5 and nearly 5 times, respectively, from 1980–1989 to 2007–2016."[56] Similarly, as University of Colorado professor Roger Pielke, Jr. discovered, Munich Re data buried in the appendix of a 2019 study published in *The Lancet* reveal that disaster loses as a percentage of GDP are declining, with the greatest declines occurring in low-income countries.[57]





Disaster losses as a percentage of GDP for four different country regions. Source: The Lancet, R. PIELKE, JR.

It is thus fundamentally important to pursue policies that will make the United States and other countries wealthier, which will make them better able to handle potential problems that may occur in the future, whatever those may entail. Carbon-based regulations, on the other hand, are likely to make nations less wealthy while providing negligible impact on the climate.[58]

A useful counterpoint to the PAGE model's pessimism about the futility of adaptation beyond 2°C of warming and 0.20-0.25 meters of sea-level rise is Hinkel et al. (2014), a study published in *Proceedings of the National Academy of Sciences* and reviewed by Bjorn Lomborg in his recent book *False Alarm*. The study includes a worst-case warming scenario in which sea levels rise up to six feet and flood up to 350 million people every year by century's end, with costs reaching $100 trillion or 11 percent of global GDP annually.[59] However, those extraordinary damages are projected to occur only if people do nothing more than maintain current sea walls.

If "enhanced" adaptive measures are taken, annual flood costs increase from $11 billion in 2000 to $38 billion in 2100. Similarly, annual dike costs increase from $13 billion to $48 billion. However, Lomborg notes, "the total cost to the economy will actually decline, from 0.05 percent of GDP to 0.008 percent." Moreover, the number of people experiencing flood damages drops from 3.4 million in 2000 to 15,000 in 2100—a 99.6 percent reduction in flood victims. In other words, with reasonable adaptation, people are projected to be much safer, and the global economy much less affected by sea-level rise in 2100, despite high-end warming. [60]

If the IWG continues to do SCC analysis, it should eschew models that assume humanity is powerless to mitigate the costs of even modest levels of warming and sea-level rise.

Section 10: Implausible Emission Baselines

We have discussed several ways modelers can inflate SCC estimates: assume climate sensitivities derived from general circulation models that repeatedly overshoot observed warming, run IAMs with below-market discount rates, use models that depreciate (or simply ignore) CO_2 fertilization benefits, and use models that lowball human adaptive capabilities. An additional way is to run the IAMs with implausibly high emission scenarios. Pielke, Jr. recently spotlighted this fatal flaw in the IWG exercise.[61]

As indicated above, to estimate the incremental impact of one ton of CO_2 emissions, SCC modelers must first estimate how global emissions and concentrations will change over time. Such estimates are only as credible as the socio-economic development scenarios on which they are based. The IWG calculates SCC values with five emission trajectories. Four are no-climate-policy ("baseline") emission trajectories projected by four socio-economic models participating in a 2009 Stanford Energy Modeling Forum study known as EMF-22.[62] The fifth, a climate policy scenario, is the average trajectory produced by the same four models run with a CO_2 stabilization target of 550 parts per million. For more detail, see the Electric Power Research Institute's (EPRI) 2014 technical assessment report.[63]

Here is the key point. All the EMF models estimated emissions growth through 2100. The IWG then extended their trajectories out to 2300. According to EPRI, "the extensions lack a coherent, viable, and intuitive storyline (or set of storylines)" that could explain the emission trajectories after 2100. That is not surprising. As noted above, nobody can foresee how the global economy will evolve centuries into the future. The IWG did not even try to guess how economies would develop after 2100, yet nonetheless plotted emissions growth over the next 200 years. Based on what assumptions? Apparently, the IWG assumed that, absent specific climate change mitigation policies, the global economy would burn through all fossil fuel reserves and do so repeatedly.

As EPRI put it, all four reference (no-climate-policy) scenarios (USG1 – USG4) "result in post-2100 cumulative CO_2 emissions in excess of estimated fossil reserves."

Table 4-6
Cumulative fossil and industrial CO_2 emissions in the USG assumptions and estimated fossil fuel reserves

Cumulative CO_2 emissions ($GtCO_2$)		
	By 2200	By 2300
USG1	11,207	16,741
USG2	20,024	33,023
USG3	8,113	10,864
USG4	14,092	20,504
USG5	3,691	4,843
Estimated reserves ($GtCO_2$)	3,674 - 7,113	

For example, in the USG2 scenario, cumulative CO_2 emissions reach 22,024 gigatons in 2200 and 33,023 gigatons in 2300—multiples of the estimated reserves (3,674 – 7,113 gigatons).

Thus, the IWG's SCC estimates "envision cumulative carbon dioxide emissions that are far, far in excess of any plausible current expectation about the future," Pielke, Jr. observes. "In fact," he continues, "to even approach these massive amounts of cumulative emissions, the world would have to make it a policy goal to burn as much coal as possible over the coming centuries. That seems unlikely."

The IWG's 300-year emission baselines are even more implausible than the RCP8.5 representative concentration pathway used in the IPCC AR5, the U.S. National Climate Assessment, and literally hundreds of other climate impact studies.[64] For RCP8.5 to be a realistic projection of future CO_2 emissions and concentrations, coal consumption would have to increase approximately tenfold during 2000-2100,[65] achieving market shares not seen since the 1940s.[66]

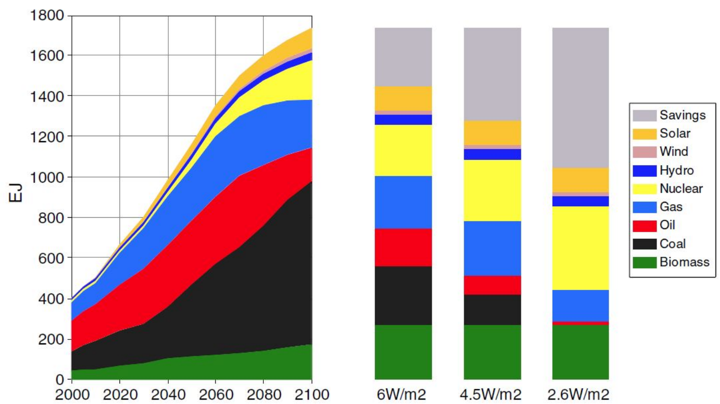


Fig. 5 Development of global primary energy supply in RCP8.5 (*left-hand panel*) and global primary energy supply in 2100 in the associated mitigation cases stabilizing radiative forcing at levels of 6, 4.5, and 2.6 W/m^2 (*right-hand bars*). Note that primary energy is accounted using the direct equivalent method

In "The 1000 GtC coal question: Are cases of vastly expanded future coal combustion still plausible?"[67] Justin Ritchie and Hadi Dowlatabadi show that all of the IPCC's five assessment reports "use business-as-usual (BAU) scenarios that combust most or all coal reserves before the year 2100." The basic idea is that coal is the inexpensive backstop energy source for the global economy, with reserve-to-production (R-P) ratios increasing over time as technological progress decreases extraction costs. Ritchie and Dowlatabai further note that DICE, FUND, and PAGE "adopt similar reference case assumptions for coal," as do the Energy Modeling Forum baseline scenarios.

Such scenarios are no longer plausible projections for the 21st century. The current coal R-P ratio is about 100 years—an order of magnitude lower than 1960s vintage assessments (>900 years) and two-thirds lower than the 300-year R-P ratio estimated in 1990.

J. Ritchie, H. Dowlatabadi / Energy Economics 65 (2017) 16–31 21

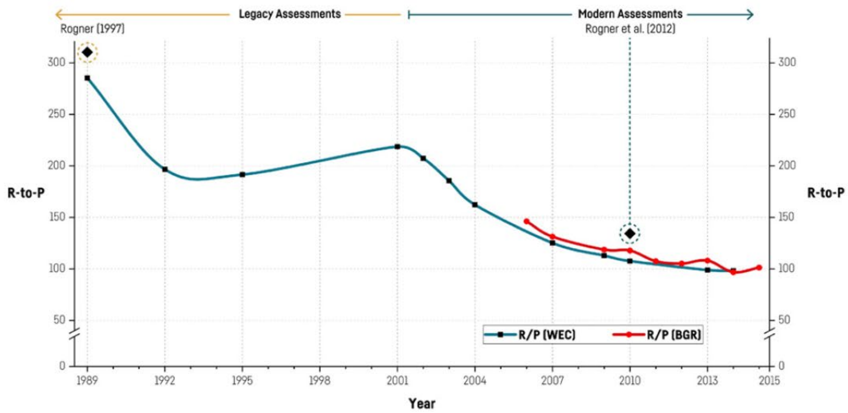


Fig. 1d. Reserve-to-production ratio for global coal [mass-basis] – Rogner (1997) and Rogner et al. (2012) illustrate the distinction between legacy and modern assessments; note y-axis break.

Moreover, instead of real coal prices falling, as assumed in the IPCC, IAM, and EMF baseline scenarios, prices in 2016 were about the same as in 1990, and have risen since the late 1990s.

20 J. Ritchie, H. Dowlatabadi / Energy Economics 65 (2017) 16–31

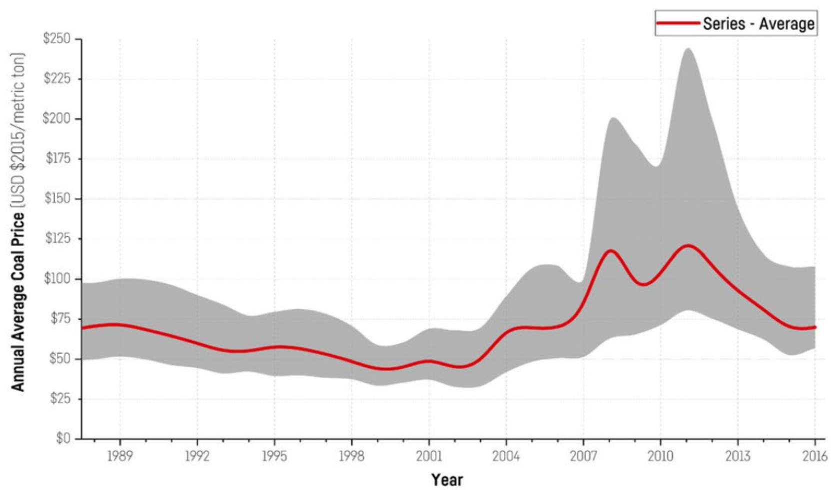


Fig. 1a. Trends in global coal market benchmark prices (BP, 2016; EIA, 2012, 2017; World Bank, 2017), minimum and maximum values indicated by gray range, while red line follows the average of benchmark prices.

Ritchie and Dowlatabadi comment: "All else equal, conventional resource economists theorize that higher sustained commodity prices lead to a reclassification of marginal geologic deposits as economically recoverable reserves. Yet, since the doubling of coal prices and production in 2000, reserves declined by roughly 15 percent."

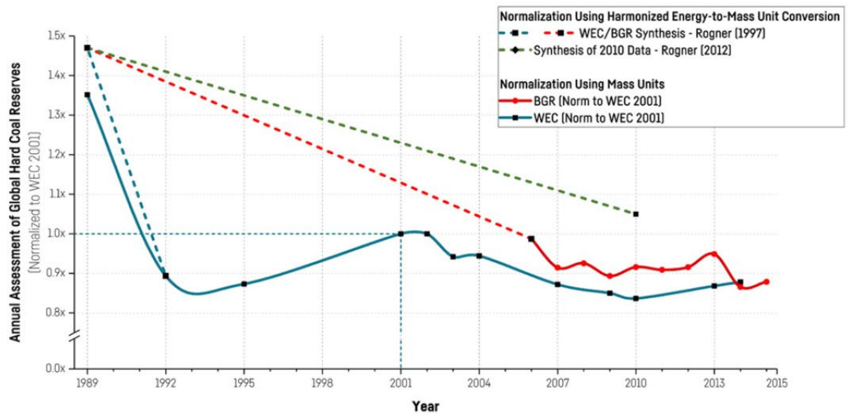


Fig. 1c. Coal reserves in mass units from successive WEC and BGR reports indexed to WEC (2001). The WEC-BGR synthesis reported by Rogner (1997), and the updated Rogner et al. (2012) normalized to WEC (2001) using harmonized energy-to-mass units; note y-axis break.

In short, "today's [coal] reserves are now more costly and less abundant than assumed 30 years ago." That is due to several factors including constraints on extraction related to air and water quality regulations, declining social acceptance of mining operations near populated areas, the replacement of human labor with excavation machines too large to access smaller deposits, the absence (despite decades of R&D) of significant markets for coal-to-liquid (CTL) and underground coal gasification (UCG) production, and increased competition from unconventional oil and gas.

It is therefore no longer reasonable to view "all geologic coal resources as eventual reserves" that sooner or later will be combusted. That is akin to assuming that "all oceans should be on a supply curve for drinkable water" just because "the total quantity of ocean water is vast and existing technology could theoretically convert all saltwater to replace fresh water."

Ritchie and Dowlatabadi acknowledge that "technological breakthroughs" may reverse the decline in coal R-P ratios. "However, to assume [such breakthroughs] as constituting a plausible reference case is a tall ask." To sum up, there is no evidence the world is on the verge of a "return to coal" during the 21st century, much less over the next 280 years.[68]

Section 11: Conclusions

The social cost of carbon lacks robustness to be a useful tool in federal agency regulatory, permitting, and procurement decisions. Agencies should not use the metric to guide policy, but if they do, they should present the results under a variety of plausible assumptions. The current Technical Support Document needs to be substantially rewritten to accommodate this requirement.

The social cost of carbon is too speculative and assumption-driven for any government to adopt official SCC estimates. If the IWG insists on doing so, it should:

- Use sensitivity estimates from recent empirically-constrained studies.
- Include benefit-costs estimates based on a 7 percent discount rate, as required by OMB Circular A-4.
- Present the probabilities of negative SCC values.

- Do not run the IAMs with time horizons that exceed the limits of informed speculation.
- Use IAMs that reflect updated empirical information on the agricultural and ecological benefits of CO_2 fertilization.
- Do not use IAMs that assume adaptation is futile beyond mid-range global warming and sea-level rise scenarios.
- Do not run IAMs with baseline scenarios that assume the world "returns to coal" during the 21st century and beyond absent additional climate policies.

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[1] Interagency Working Group on Social Cost of Greenhouse Gases, United States Government (hereafter IWG), Technical Support Document: Social Cost of Carbon, Methane, and Nitrous Oxide Interim Estimates under Executive Order 13990, February 2021, https://www.whitehouse.gov/wp-content/uploads/2021/02/TechnicalSupportDocument_SocialCostofCarbonMethaneNitrousOxide.pdf (hereafter TSD 2021).

[2] Kevin D. Dayaratna, "Climate Change, Part IV: Moving Toward a Sustainable Future," Testimony before Subcommittee on Environment Committee on Oversight and Reform, U.S. House of Representatives, September 24, 2020;

[3] As explained below, DICE and PAGE effectively assign a dollar value of zero to the immense, empirically-validated, agricultural and ecological benefits of CO_2 fertilization.

[4] "In PAGE2002, adaptation was assumed to reduce economic sector damages up to 2°C by 50-90 percent after 20 years. Beyond 2°C, no adaptation is assumed to be available to mitigate the impacts of climate change." Similarly, in PAGE2009(c), "adaptation is assumed to alleviate 25-50 percent of the damages from the first 0.20 to 0.25 meters of sea level rise but is assumed to be ineffective thereafter." IWG TSD 2016, p. 15, https://www.epa.gov/sites/production/files/2016-12/documents/sc_co2_tsd_august_2016.pdf.

[5] TSD 2021, p. 2.

[6] Program for Climate Model Diagnosis and Intercomparison, CMIP5 – Coupled Model Intercomparison Project Phase 5 – Overview, https://pcmdi.llnl.gov/mips/cmip5/.

[7] The CMIP5 predictions are available at https://climexp.knmi.nl/start.cgi.

[8] Climate reanalyses produces synthetic histories of recent climate and weather using all available observations, a consistent data assimilation system, and mathematical modeling to fill in data gaps. See National Center for Atmospheric Research, Atmospheric Reanalysis: Overview & Comparison, https://climatedataguide.ucar.edu/climate-data/atmospheric-reanalysis-overview-comparison-tables and ECMWF, Climate Reanalysis, https://www.ecmwf.int/en/research/climate-reanalysis

[9] Christy, J.R.: 2017, [in "State of the Climate in 2016"], *Bull. Amer. Meteor. Soc*. 98, (8), S16-S17, https://journals.ametsoc.org/view/journals/bams/98/8/2017bamsstateoftheclimate.1.xml.

[10] Frédéric Hourdin et al. 2017. The Art and Science of Climate Model Tuning, *Bulletin of the American Meteorological Society*, Volume 98: Issue 3, https://journals.ametsoc.org/view/journals/bams/98/3/bams-d-15-00135.1.xml.

[11] Voosen, P., 2016. Climate scientists open up their black boxes to scrutiny**.** *Science* 354,401-402, https://science.sciencemag.org/content/354/6311/401.

[12] R. McKitrick and J. Christy. 2020. Pervasive Warming Bias in CMIP6 Tropospheric Layers. *Earth and Space Science* Volume 7, Issue 9, https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2020EA001281.

[13] Most (not all) of the CMIP-6 models were available for McKitrick and Christy (2020); this figure is the mean ECS of what was released through late 2020.

[14] Zeke Hausfather, "Cold Water on Hot Models," The Breakthrough Institute, February 11, 2020, https://thebreakthrough.org/issues/energy/cold-water-hot-models.

[15] NOAA National Centers for Environmental Information, Early Eocene Period, 54 to 48 Million Years Ago, https://www.ncdc.noaa.gov/global-warming/early-eocene-period.

[16] Jiang Zhu, Christopher J. Poulsen & Bette L. Otto-Bliesner. 2020. High climate sensitivity in CMIP6 model not supported by paleoclimate. *Nature Climate Change* volume 10, pages 378–379, https://www.nature.com/articles/s41558-020-0764-6.

[17] John R. Christy and Richard T. McNider. 2017. Satellite bulk tropospheric temperatures as a metric for climate sensitivity. *Asia-Pacific Journal of Atmospheric Sciences* volume 53, pages 511–518, https://link.springer.com/article/10.1007/s13143-017-0070-z; Nicolas Lewis and Judith Curry. 2018. The Impact of Recent Forcing and Ocean Heat Uptake Data on Estimates of Climate Sensitivity. *Journal of Climate* Volume 31: Issue 15, https://journals.ametsoc.org/view/journals/clim/31/15/jcli-d-17-0667.1.xml.

[18] Kevin D. Dayaratna, Ross R. McKitrick, Patrick J. Michaels, Climate sensitivity, agricultural productivity and the social cost of carbon in FUND, *Environmental Economics and Policy Studies* volume 22, pages 433–448, https://link.springer.com/article/10.1007/s10018-020-00263-w.

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