The Social Cost of Greenhouse Gases and Its Use in U.S. Federal Policy

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Abstract

The social cost of greenhouse gases (SC-GHG) is a metric that puts the effects of climate change into monetary terms to help policymakers and the public understand the welfare impacts of decisions that affect greenhouse gas emissions. Estimates of the SC-GHG have been used for over a decade in U.S. federal analyses and have evolved over time to reflect increased scientific understanding of climate change impacts and methodological advances. This chapter provides an overview of what the SC-GHG measures, describes the methodologies used to estimate the SC-GHG, and summarizes its use in U.S. Federal policy analysis to date.

Keywords

Benefit-cost analysis, Climate change, Integrated assessment models, Social cost of carbon, Social cost of greenhouse gases, Social cost of methane

Key points

- The social cost of greenhouse gases (SC-GHG) is the discounted monetary value of the future net climate change damages due to one additional metric ton of greenhouse gas (GHG) emissions.
- SC-GHG estimates are primarily derived from integrated assessment models (IAMs) that combine climate processes, economic growth, and connections between the climate and the global economy into a single modeling framework.
- The use of SC-GHG estimates in U.S. Federal policy analysis has grown over time to help policymakers and the public understand the economic consequences of decisions that would increase or decrease GHG emissions, while acknowledging the uncertainties involved and understanding the need for updates over time to reflect evolving science and economics of climate impacts.

I. Introduction

The effects of climate change are already impacting public health and the economy in dramatic and worsening ways. Climate change is increasing net mortality rates due to exposure to extreme temperatures and wildfire smoke; affecting agricultural yields, labor productivity, and energy expenditures; and damaging coastal infrastructure. The most recent scientific assessments project that additional climate change will have further consequences for human welfare by affecting our food and water, the air we breathe, the weather we experience, and our interactions with the natural and built environment.

Global climate change is the result of, arguably, the most complex and wide-reaching negative externality the world has ever seen. Each additional ton of a greenhouse gas (GHG) released into the atmosphere, regardless of where it is emitted, generates near and long-term impacts all around the world. GHG emissions lead to increases in global temperature, which in turn leads to increases in sea levels; changes in drought, flooding, and precipitation patterns; alters ecosystems, and more. These impacts are referred to as externalities because most of the effects of emissions are not borne by those responsible for the emissions, and therefore, the emitters do not internalize those costs when making decisions that result in emissions. Designing efficient policy interventions to address this market failure requires evidence of the impacts of GHG emissions that can be readily compared to the costs of mitigating those emissions.

This chapter focuses on the Social Cost of Greenhouse Gases (SC-GHG), which is a metric that puts the net effect of the impacts of climate change on society into monetary terms to help policymakers and the public understand the economic consequences of decisions that would increase or decrease greenhouse gas emissions. This chapter provides an overview of what the SC-GHG measures, describes the methodologies used to estimate the SC-GHG, and summarizes its use in U.S. Federal policy analysis to date.

II. Social Cost of Greenhouse Gases Defined

The social cost of carbon (SC-CO_2) is defined as the monetized present value of the future net impacts from emitting a metric ton of CO_2 into the atmosphere.[1] In principle, it is a comprehensive metric that reflects the value of all future climate change impacts (both negative and positive), including changes in net agricultural productivity, human health effects, property damage from increased flood and fire risk, changes in the frequency and severity of natural disasters, disruption of energy systems, risk of conflict, environmental migration, and the value of ecosystem services. It is also intended to include the valuation of the risks and uncertainty in future climate impacts. The value of the SC-CO_2 changes based on the year that emissions are released into the atmosphere as a result of changes in concentrations of GHGs in the atmosphere and socioeconomic conditions (e.g., economic and population growth and adaptation). While CO_2 is the most abundant GHG, other pollutants contribute to global climate change, including methane (CH_4), nitrous oxide (N_2O), and fluorinated gases (HFCs and CFCs). These gases differ in the timing and magnitude of their effects on temperature and other environmental outcomes and, therefore, their impacts on society. In other words, the social damages

[1] SC-CO_2 is measured in dollars per metric ton of CO_2. Another commonly used abbreviation of the social cost of carbon is SCC, which is sometimes reported in dollars per metric ton of carbon.

will be gas-specific.[2] Collectively, these values – the social cost of carbon (SC-CO_2), social cost of methane (SC-CH_4), and social cost of nitrous oxide (SC-N_2O) – are often referred to as the "social cost of greenhouse gases" (SC-GHG).

The SC-GHG has a strong foundation in economic theory and provides important information to policymakers and the public regarding the economic efficiency of options to address the externalities of GHG emissions. By measuring the net damage to society from a marginal (or one additional) ton of GHG emissions, the SC-GHG provides an aggregate measure of what affected individuals would be willing to pay to reduce or abate GHG emissions by a ton. That is, the SC-GHG provides a measure of the incremental or marginal benefit of abatement, which allows the monetized benefits of GHG emission reductions to be compared to the costs of abatement in benefit-cost analysis (BCA). For policies that increase GHG emissions, the SC-GHG is used to monetize their damages.

SC-GHG estimates can also be used to inform the stringency of a GHG pricing policy, such as an emissions tax. In unregulated markets, GHG emissions will be overproduced relative to the socially optimal level because firms and consumers do not bear the full burden of the global externalities in market prices and do not internalize them in decision making. This market failure can be addressed by placing a per-unit price on emissions based on the external social damages from an additional ton of GHG pollution. This would lead firms and consumers to internalize these damages in their market decisions, resulting in lower GHG emissions than in the unregulated market. The socially optimal level of GHG emissions is achieved when the benefit of reducing one more unit of emissions is equal to the cost of doing so – that is, when the marginal benefit of abatement is equal to the marginal cost of abatement across all sources of emissions.

Since the SC-GHG measures the present value of the marginal benefit of abatement, it can be used to help set the level of a GHG tax. Note, however, that an SC-GHG calculated along a business-as-usual (or baseline) emissions path is not necessarily the socially optimal one; it is a measure of the current marginal benefits of abatement. In theory, an optimal GHG tax could be developed, but only if the economically efficient level of emissions could be determined at the outset. A more practical approach might be to set a near-term GHG tax equal to the best estimate of the current SC-GHG and then adjust it over time to match the SC-GHG that is re-estimated as new measures to reduce emissions are adopted (Griffiths et al. 2012).

Because GHG emissions are a global externality (that is, a ton of emissions creates the same global effects regardless of where it was emitted), models and SC-GHG research efforts have focused on measuring total global damages, rather than the damages to any particular region or country.[3] The only way to achieve an efficient global allocation of resources for emissions abatement is for all

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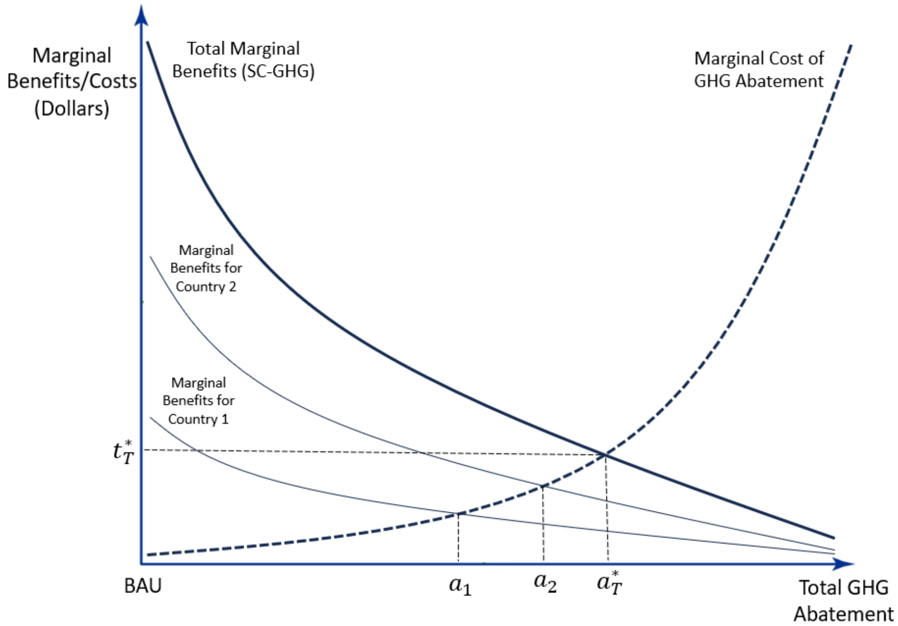
[2] Greenhouse gas comparison metrics, such as the global warming potential (GWP), offer a way to measure the warming impact of non-CO_2 GHG emissions relative to CO_2 (e.g., GWP reflects the net effect of gas lifetime and energy absorption) over a specified time period but do not measure how those attributes will manifest into differences in the pathway of environmental and socioeconomic impacts that lead to monetized societal damages. See, for example, Marten et al. (2015) for a full discussion.

[3] In some contexts, there may be interest in estimating only the climate damages accruing to populations in one's own country. While calculating this "domestic" share of the SC-GHG is possible in principle, it requires careful consideration of what is meant by a domestic impact in the case of a global pollutant. Even if a decision maker is focused entirely on national self-interest, businesses and residents of one country can be impacted by climate change damages occuring outside of the country's national boundaries. A comprehensive domestic SC-GHG would include the domestic implications of climate impacts occuring in, and actions taken by, other countries (National Academies of Sciences, Engineering, and Medicine, 2017).

countries to base their policies on global estimates of damages. This is illustrated in Figure 1, which presents a simplified model of the marginal benefits and marginal costs of abatement in a world with only two countries. The marginal abatement cost curve reflects the marginal cost of reducing GHG emissions worldwide. If the least expensive abatement options are undertaken first, the marginal abatement costs increase with the level of abatement.[4] The first marginal abatement benefit curve shows the marginal benefits of abatement accruing only to country 1. This is the amount that country 1 would be willing to pay for each unit of abatement. As more abatement occurs, the marginal benefits decline. The second marginal abatement benefit curve represents the benefits accruing only to country 2, which experiences higher marginal damages from climate change and has a higher willingness to pay than country 1. Because GHGs are global pollutants, abatement benefits both countries regardless of which country reduces emissions. The total marginal benefits curve (SC-GHG) represents the combined marginal benefits of abatement for both countries, and the aggregate willingness to pay by both countries is the vertical sum of the individual marginal abatement benefit curves.

Figure 1: A two-country model of the marginal benefits of abatement for each country and the global marginal benefits of abatement



If country 1 were to consider only the marginal benefits accruing to its own citizens, it would consider total abatement of emissions (that is, the combined abatement of both countries) up to point a_1 to be optimal because this is the point at which its marginal benefits of abatement are equal to the marginal costs of abatement. If country 2 were to consider only its share of marginal benefits, it would consider a higher level of abatement optimal to undertake (up to a_2 emissions). The additional abatement beyond a_1 provides added benefits for country 1. When each country considers only the marginal benefits accruing to its own citizens, abatement would stop at point a_2 because, beyond that point, the marginal costs exceed the marginal benefits of abatement for both countries. However, global economic efficiency is achieved when the marginal cost of abatement equals the global

[4] This graph shows one global MAC curve because GHG emissions reductions can occur anywhere. This assumes that one country can pay for emissions reductions in another country, for example, through perfectly functioning carbon offset markets.

marginal benefit of abatement (the SC-GHG). The point that maximizes the net benefits of abatement (the total benefits minus the total costs of abatement, which is represented by the area under the curves) is a_T^* . This level of abatement can be achieved by setting a carbon tax of t_T^* (which is equal to the SC-GHG at point a_T^*) or an emissions cap that achieves the a_T^* level of abatment.

The SC-GHG should not be confused with the emissions price resulting from a policy that imposes an environmental target, such as a temperature limit or cap on GHG emissions (for example, through international climate treaties). As shown above, the SC-GHG is a measure of the marginal benefits of GHG abatement, which when combined with estimates of marginal abatement costs, can be used to determine the economically efficient level of abatement. However, the GHG emissions price derived from policies that prescribe an environmental target (often called the "shadow price of carbon") provides a measure of the marginal cost of abatement to meet that emissions level. As described above, these two measures will only be equal at the socially optimal level of GHG emissions. While a GHG price is useful in determining the cost-effectiveness of a policy, it cannot substitute for the SC-GHG in BCA of policies that affect GHG emissions. However, comparison of the SC-GHG at the emissions limit to the GHG price can be useful for evaluating policies that set environmental targets. An estimated GHG price smaller than the SC-GHG at the emissions cap or limit suggests that the marginal benefits of abatement exceed the marginal costs of abatement, and thus, increasing the stringency of the environmental target would improve social welfare under the benefit-cost criterion.

III. Calculating the SC-GHG

The long-lived nature of GHG emissions and the complexity of how their global effects cascade through natural and human systems makes calculating the SC-GHG an exceedingly challenging task. One extra ton of a GHG emitted today can lead to increased atmospheric concentrations of GHGs for decades or centuries. Thus, calculating its effects necessitates projecting what the world will look like—in terms of population, economic activity, and GHG emissions—far into the future. One must then trace out how an incremental increase in emissions in a particular year will affect the future path of climate outcomes and, ultimately, lead to physical impacts. The next challenge involves estimating how the physical impacts will manifest into net economic damages, in which the damages are calculated as the amount of money that individuals experiencing the climate change impacts would be willing to pay to avoid them. Finally, discounting is used to convert the future stream of monetized net damages into a single present value of damages in the year that the emissions are released into the atmosphere.

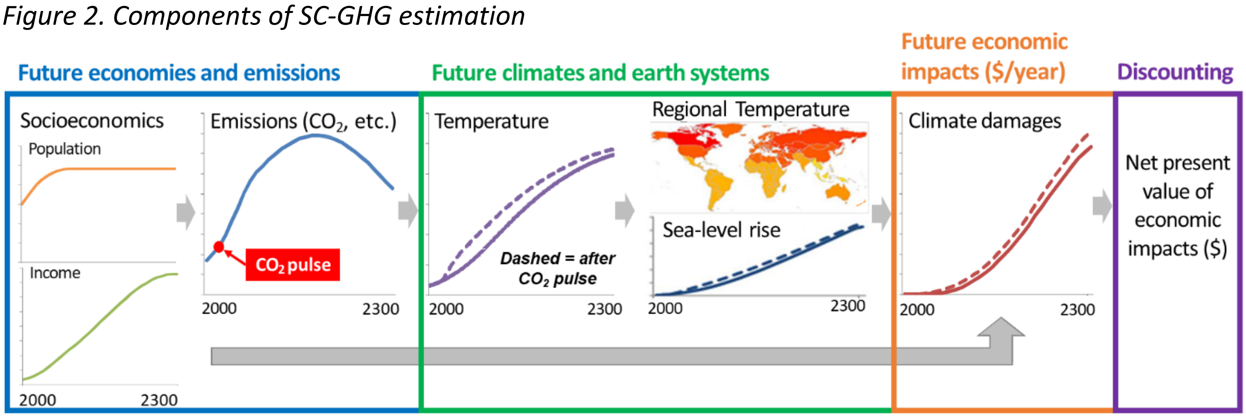
As noted above, the SC-GHG is a comprehensive measure and accounts for all impacts of climate change in principle. In practice, all estimates of the SC-GHG are a partial measure of net damages given that data and modeling limitations restrain the ability of analysts to include all physical, ecological, and societal impacts of climate change across a complex global landscape. Most published SC-GHG estimates have been developed with the use of integrated assessment models (IAMs) that integrate climate processes with the global economy into a single modeling framework. There have been some efforts to use other approaches for estimating the SC-GHG. For example, some researchers have conducted surveys of climate and economic experts' opinions to estimate a distribution of SC-CO_2 values directly rather than modeling each step or component (e.g., Pindyck 2019). This chapter focuses on the IAM approach that links the components of SC-GHG estimation in a modular way. Because the definition of an IAM is broad, we highlight the more common methodologies.

The remainder of this section provides an overview of the methods used in IAM-based SC-GHG estimation and is followed by a description of U.S. Government efforts to date to synthesize this research into a set of SC-GHG values for use in policy analysis.

A. Components and Methodology

In the most general sense, IAMs are "approaches that integrate knowledge from two or more domains into a single framework" (Nordhaus 2018). They have been used across a variety of scientific disciplines to study environmental problems for decades, varying greatly in structure and scope depending on the type of question they aim to answer. In the context of climate change, IAMs must be able to link physical climate impacts to monetized economic damages in order to estimate the SC-GHG. These models tend to be reduced-form in nature and generally take an enumerative and sequential approach to estimating four components of SC-GHG estimation (see Figure 2). While IAMs can include complex feedbacks and interactions between components, such as feedbacks from damages to socioeconomic conditions, or general equilibrium (GE) representations of the economy,[5] these inclusions are less common in SC-GHG IAMs to date due to computational challenges and data limitations. Some examples of prominent SC-GHG IAMs include those used by the U.S. Government: DICE (Dynamic Integrated model of Climate and the Economy), FUND (Climate Framework for Uncertainty, Negotiation, and Distribution), and PAGE (Policy Analysis of the Greenhouse Gas Effect); and more recently, DSCIM (Data-driven Spatial Climate Impact Model) and GIVE (Greenhouse Gas Impact Value Estimator).[6]

Figure 2. Components of SC-GHG estimation



Adapted from Rose et al. (2014) and NASEM (2016)

Socioeconomics and Emissions

The first component in SC-GHG modeling requires developing long-term projections of future socioeconomic conditions, including population and economic growth, and GHG emissions. To do so, many researchers have looked to readily available sources of projections that have been developed for climate change policy simulations. These sources generally provide scenario-based national or

[5] For example, GE components can account for feedbacks and interactions between different regions and time periods, such as trade flows and savings, and different economic sectors, such as household consumption and firm input decisions. GE representations also allow for endogenous solutions, meaning that variables and prices fluctuate and are determined within the model, allowing for a rich variety of responses to economic and environmental changes.

[6] For more information about these IAMs as well as references to model documentation and citations in the academic literature, see Interagency Working Group on Social Cost of Greenhouse Gases (IWG) (2021) and U.S. Environmental Protection Agency (EPA) (2023).

regional level trajectories of key variables—GDP, population, and emissions – out to 2050 or 2100 and are without explicit representations of the uncertainty in these projections. Examples include the Stanford Energy Modeling Forum (EMF-22) that produced baseline and policy scenarios from ten well-recognized peer reviewed models and the Shared Socioeconomic Pathways (SSPs) that provide scenarios consistent with five distinct narratives around challenges to mitigation and adaptation. Each SSP has been implemented by multiple models, and the resulting trajectories have been widely used by the Intergovernmental Panel on Climate Change (IPCC), the global scientific community, and SC-GHG researchers. Other SC-GHG IAM researchers have assembled projections of socioeconomic variables from disparate sources. For example, the 2016 version of the DICE model is calibrated to economic growth data based on a survey of experts, population data from the United Nations, and CO_2 emissions data from the Carbon Dioxide Information Analysis Center (Nordhaus 2017). Because many of these projections do not extend beyond the end of the 21st century, researchers have used various approaches for extrapolating to the multi-century timescales required for capturing the impacts of long-lived GHGs.

While many IAMs use exogenous projections of economic production or income, such as those described above, other IAMs, such as the DICE model, may calibrate to external projections but utilize economic theory or structure to endogenously model economic growth whereby feedbacks from climate change on economic activity can be partially captured (Nordhaus 2017). These models still require projections of economic inputs such as population and labor, total factor productivity, and initial capital stock and services. This method allows for climate damages to impact economic output directly as well as indirectly through the impact to investment and the stock of capital and services.

IAMs commonly build up emissions estimates from socioeconomic projections. A simple way to illustrate this relationship is with the Kaya identity. The Kaya Identity (equation 1) is a mathematical identity stating that total anthropogenic GHG emissions can be written as the product of four factors: (1) the GHG intensity of energy consumption, (2) the energy intensity of economic activity, (3) economic activity per capita, and (4) total population.

$$GHG\ Emissions = \frac{GHG\ Emission}{Energy\ Consumption} \times \frac{Energy\ Consumption}{GDP} \times \frac{GDP}{Population} \times Population \qquad (1)$$

Some SC-GHG IAMs, such as DICE, directly use the identity by combining the emissions intensity and energy intensity components in the Kaya identity to a measure of emissions intensity of economic activity (Nordhaus 2017). The SSPs use models that include an energy sector and an emissions component to project energy consumption and fuel mixes (e.g., coal, oil, gas, nuclear, biomass, and renewables) for the five GDP and population projections. These energy sector models generate emissions estimates out to 2100 consistent with target levels of atmospheric concentrations of GHGs. In these models, emissions mitigation targets are met by reducing the GHG intensity of economic activity (i.e., through changes in the final energy and fuel mixes) at a faster rate than the increase in economic activity.

In contrast to the scenario-based projections mentioned above that don't have explicit representation of uncertainty, a few efforts have been made to develop probabilistic socioeconomic and emissions projections. For example, in 2012, researchers used a computable general equilibrium model (CGE), the MIT Emissions Prediction and Policy Analysis (EPPA) Model, coupled with expert elicitation, to generate a library of socioeconomic and emissions projections (Abt Associates 2012). CGE models have the advantage of being able to better capture feedbacks and interdependencies when exploring sources of uncertainty. More recently, a set of probabilistic projections for population, income, and GHG emissions (CO_2, CH_4, and N_2O) was developed under the Resources for the Future (RFF) Social Cost of Carbon Initiative (Rennert et al., 2022a). These RFF socioeconomic projections (RFF-SPs) are an internally consistent set of projections out to the year 2300. They were developed using a mix of statistical and expert elicitation techniques and capture uncertainty. For emissions, experts were asked to incorporate their views on technology, energy consumption and fuel mix, and the evolution of policy.

Climate and Other Earth Systems

The second component in an SC-GHG IAM is a model of how GHG emissions lead to changes in physical climate variables and other Earth system outcomes. The IPCC Sixth Assessment Report (2021) provides a highly detailed overview of the latest science on the effects of GHG emissions on temperature and the subsequent biophysical effects across Earth systems, such as changes in sea level, precipitation, drought, wildfires, flooding, and hurricanes. A variety of these climate and Earth system outcomes can be represented explicitly in IAMs, but the outcomes of focus in SC-GHG IAMs to date have been changes in global mean surface temperature (GMST) and global mean sea level (GMSL). That is, the models assume that changes in GMST provide enough information about the associated changes in other physical variables to estimate many of the monetized impacts on health and human welfare (as discussed in the next section). Some IAMs also use GMSL as a direct input in estimating damages associated with sea level rise.[7]

There are a variety of methodologies for estimating the relationship between GHG emissions and climate variables including compute-intensive, regionally-detailed Earth system models (ESMs), and reduced-complexity (RC) models, which tend to represent fewer regions and climate variables. Some RCs only produce global means, such as GMST. RC climate models are useful in SC-GHG IAMs for their computational expediency and capability to quickly generate a large number of probabilistic future climate outcomes. The uncertainty about the future climate arises from the underlying uncertainty about future emissions as well as a myriad of aspects of physical climate processes, such as equilibrium climate sensitivity (ECS) (a measure of the long term GMST response to a doubling in atmospheric CO_2) and transient climate response (TCR) (a measure of the speed and magnitude of the climate response). The ECS, TCR, and other parameters in climate models are typically represented with a distribution or range to characterize their uncertainty. Some IAMs require additional models to represent other aspects of the Earth system, such as sea levels.

An important evolution in the history of SC-GHG IAMs has been the improved representation of climate and the adoption of the latest RC approaches. The Finite amplitude Impulse Response (FaIR) climate model is an RC model that has been used in several recent IAMs.[8] To facilitate a probabilistic analysis, FaIR includes many uncertain climate parameters, including parameters related to the carbon cycle, the strength of different radiative forcing agents, and a climate feedback term, among others.

[7] While SC-GHG IAMs primarily use GMST and GMSL as inputs to their damage functions, many of the underlying damage studies rely on much richer sets of climate and Earth system variables from Earth system models (ESMs). For example, information from ESMs can be inputs to regionally disaggregated dose response functions, which are then aggregated to global damage functions for the purposes of SC-GHG estimation. The exact methodologies vary across IAMs, and we refer the reader to the documentation of each IAM for details on their specific approaches.
[8] For more information on FaIR, see Smith et al. (2018), IPCC (2021), and EPA (2023).

As discussed in EPA (2023), compared to representation of climate system dynamics in early SC-GHG IAMs, FaIR and other related models can better emulate the behavior of the high-resolution ESMs. For example, FaIR exhibits a faster temperature increase and faster decay after an incremental pulse of CO_2 compared to the climate representations in earlier IAMs, such as DICE, FUND, and PAGE (Dietz et al. 2021). Accurately accounting for the temporal path of temperature change, and thus damages, is important because near-term marginal damages are discounted less than damages far in the future (discussed in more detail below). For modeling changes in sea level resulting from temperature changes (e.g., from FaIR), two RC models used in recent IAMs are BRICK (Building blocks for Relevant Ice and Climate Knowledge) and FACTS (Framework for Assessing Changes To Sea-level).[9] These models account for many aspects of the effect of temperature increases on ocean systems, including ice sheet melting and thermal expansion.

Damages

The third component of SC-GHG modeling involves translating changes to the climate and other Earth systems into a monetary value of economic damages. This valuation is based on the affected individuals' willingness to pay to avoid those damages – that is, the monetary amount that a consumer or producer would be willing to pay to decrease the negative externality.[10] Implicit in this measure is not just the willingness, but also the ability, to pay. For this reason, willingness to pay is higher when incomes are higher. For damage categories that involve impacts on goods and services traded in markets (e.g., changes in agricultural crop yields or energy use), analysts can look to market prices for valuation. For damages that involve impacts not traded in a market (e.g., changes in mortality risk), there is no readily available price information. For these non-market impacts, IAMs generally draw upon existing willingness to pay estimates from the economics literature to assign values to each endpoint.

Approaches to estimating how damages are a function of GMST and other Earth system outcomes can generally be grouped into two categories: those that calibrate or estimate an aggregate global damage function directly and those that build up an estimate of global damages by summing disaggregated impact-specific damage functions (sometimes called a "bottom up" approach). The more aggregated (or so called, "top-down") approach often relies on meta-analysis techniques or statistical studies that estimate the relationship between GDP and a climate variable, usually temperature. In general, there is a tradeoff across these two approaches between their intended comprehensiveness and their transparency in the contribution of different biophysical effects and associated damages to the SC-GHG. Top-down damage functions based on total economy statistical studies, for example, aim to provide a comprehensive estimate of the market damages of climate change, but they lack traceability to individual damage pathways and do not account for non-market damages. The bottom-up approach provides a more transparent accounting of which climate change damages, including non-market damages, are incorporated in the SC-GHG, but in practice, offers only a partial accounting of climate change impacts due to data limitations and methodological challenges in estimating damage functions for each impact category.

[9] For more information on BRICK, see Vega-Westhoff et al. (2019). For more information on FACTS, see Garner et al. (2021). For applications of both models in IAMs, see EPA (2023).

[10] A closely related concept is willingness to accept, which is the monetary amount that the individual would need to accept to be indifferent between a world with the negative externality and one without it. In theory, in the absence of income effects and with certain assumptions, the willingness to accept and pay are equivalent.

One of the most widely used SC-GHG IAMs that uses an aggregated approach to estimating a damage function is the DICE model. In early versions of DICE, a quadratic function representing the relationship between global net climate damages and temperature was based on a calibration of sectoral damages (Nordhaus and Boyer 2000).[11] Later versions of the model use a meta-analysis approach in which the shape of the aggregate damage function is based on a quantitative summary or synthesis of a larger set of studies (Nordhaus and Moffat 2017, Howard and Sterner 2017). Other IAMs employing an aggregated approach have started looking to recent empirical studies that econometrically estimate the relationship between GDP and temperature to develop a damage function, such as in recent versions of the PAGE model (Kikstra et al. 2021).[12] Within these studies, the functional form of the relationship, especially with respect to whether impacts on GDP are found to be temporary or to also affect the rate of economic growth, has important implications for the magnitude of damages. This is because even small changes in growth rates accumulate into large economic damages over time. Differentiating the impacts of climate change on long-run GDP growth from the effects on short-run levels of GDP is an active area of research.

Several IAMs employ a more disaggregated approach to estimating global climate damages. One of the earliest SC-GHG IAMs, the FUND model, takes a regional approach and estimates damage functions for fourteen separate damage categories using studies and assumptions relating to each category (Anthoff and Tol, 2013). Impacts are generally computed in physical units first (such as for mortality and morbidity effects), with explicit representation of adaptation for some sectors (such as agriculture), and many parameters are defined with probability distributions instead of point estimates. Two recently developed IAMs, DSCIM and GIVE, also use a bottom-up approach to enumerate damages (Rennert et al. 2022b, Climate Impact Lab (CIL) 2023). In DSCIM, subnational-scale sectoral damage functions are econometrically estimated for nearly 25,000 regions, accounting for local conditions and inclusive of adaptation investments. The model currently estimates damages occuring in five impact categories: health, energy, labor productivity, agriculture, and coastal. When aggregated up across the globe, a reduced form and aggregate damage function can be estimated. In GIVE, country-scale sectoral damage functions are developed based on recent published scientific literature. In some categories of damages, the underlying response functions are based on a statistical combination of a larger number of studies. In other categories, GIVE relies on market equilibrium models. The model currently estimates damages occuring in four impact categories: health, energy, agriculture, and coastal.

Discounting

The fourth component in estimating the SC-GHG is translating the monetized stream of future climate damages into present values. In this context, the present value is the amount of money that would make society indifferent between the loss of that value in the year that the additional unit of emissions are released or the economic losses from climate impacts in the future. Climate damages are discounted in IAMs at a social discount rate, which is the rate at which society is willing to trade current consumption for future consumption. The social discount rate is one of the most widely debated

[11] One version of the model, DICE 2010, disaggregated the damage function into sea level rise related damages and non-sea level rise (temperature) related damages (Nordhaus 2010).

[12] Earlier versions of the PAGE model employed a regionalized hybrid approach with an estimate of four categories of damages: market, non-market, sea-level rise, and “discontinuities” (nonlinear extreme events). See, for example, Hope (2008).

components of estimating the SC-GHG. Because of the long time frame over which damages from GHG emissions are projected to occur, the rate at which they are discounted is a critical factor in estimating the SC-GHG, and even small adjustments to the discount rate can result in large changes to the SC-GHG estimates.

A positive discount rate means that money in the future is worth less to people today than the same amount of money today. This can arise for several reasons. First, people prefer increases in well-being today rather than in the future because the future is inherently uncertain and people are generally impatient; this is commonly referred to as the pure rate of time preference. Second, monetary investments can be made today that are expected to yield returns in the future. Therefore, money invested today on climate resiliency has an opportunity cost, or the loss of potential gain from alternative investments that were not chosen. A similar way to view this is that society is expected to become wealthier in the future through economic investments and technological innovations. A positive discount rate, in this case, is appropriate because a dollar given to a person when they are wealthier will increase their well-being less than a dollar given to that person when they are less wealthy.

There are two main approaches to determining an appropriate discount rate for use in SC-GHG IAMs: the descriptive approach and the prescriptive approach. The descriptive approach infers the discount rate from market rates of return and reflects the observed choices made by consumers. The prescriptive approach considers the normative judgements of policymakers and reflects their perspective on how society should consider tradeoffs across generations. Discount rates, using either the prescriptive or descriptive approach, are often described in terms of the "Ramsey equation" (equation 2), which is derived from work by Frank Ramsey (1928). This equation describes the social discount rate (r) as a function of three parameters: the pure rate of time preference (ρ), the elasticity of the marginal utility of consumption (η), and the growth rate of consumption (g), which is typically measured net of the baseline climate damages.[13]

$$r = \rho + \eta g \tag{2}$$

A positive ρ implies that future periods are discounted to some degree regardless of any growth in consumption. The second term in the Ramsey equation (ηg) reflects the change in the marginal utility of income as society grows wealthier.[14] This term in the Ramsey equation will be positive when the consumption growth rate is positive (and negative if there is negative consumption growth) because economic theory suggests that the η parameter is strictly positive. The discount rate is therefore higher when consumption growth is higher due to the declining marginal utility of consumption. That is, additional consumption is less valuable to people when their consumption is otherwise high, which implies that damages occuring in wealthier future periods are discounted more.

[13] The economic literature finds that estimates of the social discount rate (r) range from 1.4 to 6 percent, with the parameter ρ ranging from 0 to 3, the parameter η ranging from 1 to 4, and estimates of growth rate of consumption (g) of approximately 2 percent (National Academies, 2017).

[14] This term reflects the diminishing marginal utility of income and is generally described as the change in marginal utility over time as society, as a whole, grows wealthier. However, the concept can be considered in a similar way regarding differences in income across or within geographical regions. In this context, the same amount of climate damages in richer and poorer locations have different impacts on welfare. Welfare-adjusted damages are sometimes used in IAMs to create an "equity-weighted" SC-GHG, which takes into account the differences in income, the relative magnitude of climate damages across geographies, and the preferences over the distribution of consumption across society.

Earlier studies that estimated the SC-CO_2 applied higher discount rates on average than those used in more recent studies (Tol 2023). A combination of recent evidence supports the use of a 2 percent discount rate (in the near-term), including analyses of long-term interest rates (Giglio et al. 2015), surveys of economists (Drupp et al. 2018), and lower real Treasury returns in recent decades (Bauer and Rudebusch 2020). Federal government guidance on BCA, commonly known as Circular A-4,, has also adjusted discount rates downward. The 2003 version of Circular A-4 recommended the use of two discount rates based on empirical evidence of interest rates: 3 percent and 7 percent (OMB 2003). The guidelines suggested additional analysis with lower discount rates for intergenerational policies with long-term impacts such as climate change. However, a recent update of Circular A-4 considers more recent empirical evidence and now recommends the general use of a 2 percent discount rate (OMB 2023).

When the stream of climate damages occurs over a long time horizon, as it does with climate change, care must be taken to capture the impact of uncertainty on the appropriate discount rate. Weitzman (1998) argued that if there is uncertainty over the discount rate, either due to changing societal preferences (ρ or η in the Ramsey equation) or uncertain future socioeconomic conditions (g), one should apply a discount rate schedule that declines over the time horizon toward the lowest rate. This is because the discount factor,[15] not the discount rate, is averaged over the uncertain outcomes. The discount factor is a convex function of the discount rate, and averaging uncertain discount factors results in the lower of the uncertain rates dominating over the long term. While IAMs have previously used constant discount rates to discount future climate damages, there is an emerging consensus among economists that the discounting methodology should address discount rate uncertainty as opposed to applying a constant discount rate. This can be achieved through an uncertain discount rate (Newell and Pizer 2003) or by introducing uncertainty in future consumption growth into the Ramsey formula (Rennert et al. 2022a).

Recent research has focused on incorporating society's preferences for avoiding the risks associated with climate change into the discounting methodology by using a risk-adjusted discount rate instead of a "risk-free" discount rate. Most individuals are risk averse and would prefer a slightly worse outcome with certainty than face a range of potential outcomes with a slightly better average outcome. To understand how climate mitigation policies may affect the aggregate consumption risk facing society, researchers explore the correlation between marginal climate damages and consumption (GDP) growth, also known as the climate beta (Dietz et al. 2018). Because marginal climate damages can also be viewed as the marginal benefits of climate mitigation, the climate beta provides insight into whether climate policies may pay off more in uncertain future states of the world in which society is either relatively rich or relatively poor. If the correlation is negative, climate mitigation policies provide more insurance against future states of the world with worse economic outcomes, and the risk-adjusted discount rate will be lower than the risk-free rate. The limited research on this topic using outputs from IAMs has found that the correlation is positive (Dietz et al. 2018, Prest 2023), implying that money spent today on climate mitigation increases aggregate consumption risk, and the risk-adjusted discount rate will be higher than the risk-free discount rate. However, the sign and magnitude of the climate beta is still an open area of debate in the literature,

[15] The discount factor is a decimal that when multiplied by future climate damages will yield the present value of those damages. Mathematically, it is defined (in discrete time) as: $1/(1 + discount\ rate)^t$, where t is the number of years into the future that the damages occur.

and the limited theoretical research on this topic has argued that the climate beta is negative (Lemoine, 2021).

Integrating the Model Components

Combining the four components described above is the final step in calculating the SC-GHG. In their simplest form, SC-GHG IAMs can be thought of as a scaffolding that passes information from one component to the next. For example, a common first task for the IAM is to read and pass emissions trajectories to the climate module. The climate module works independently to produce estimates of relevant climate variables, such as GMST and GMSL, along a baseline emissions path. The IAM then passes the climate variables and relevant socioeconomic variables to the damage module that, in turn, estimates the damages to relevant environmental and economic systems. The result is a stream of undiscounted damages associated with a baseline emissions trajectory. Because the SC-GHG is a measure of climate damages from a marginal increase in emissions, the IAM must be run a second time with the only difference being that one GHG emission trajectory, such as CO_2, is perturbed in a specific year within the model. For example, the same baseline emissions trajectory mentioned above is passed to the climate module but with one additional metric ton of CO_2 added in the year 2030.[16] This results in a stream of undiscounted damages associated with the baseline emissions plus the additional metric ton of CO_2 added in the year 2030. Subtracting the baseline stream of damages from the perturbed stream of damages results in an undiscounted stream of marginal damages. The final task is to discount and sum the stream of marginal damages to recover a single estimate of the net present value of all future damages, or the SC-CO_2. Depending on the discounting approach used (e.g., constant or Ramsey-based), the IAM may also incorporate socioeconomics and baseline damages within the discounting module, such as adjusting exogenous economic growth for baseline climate damages (i.e., the g in the Ramsey formula above).

One primary advantage of the IAM is that it allows for a more coordinated accounting of uncertainty throughout the estimation process. Uncertainty comes in many forms including structural uncertainty, such as which damage function to apply, and parametric uncertainty, such as the climate sensitivity or damage function parameters themselves. Because there are many forms of uncertainty within each of the model components, the IAM can be run using a Monte Carlo approach. That is, the processes described above that recover an SC-GHG are repeated tens of thousands of times. With each iteration of the model, uncertain parameters, socioeconomic projections, emission pathways, or damage functions can be randomly drawn. This approach results in a distribution of discounted marginal damages that reflect the range of all quantified uncertainty within the model, of which the average is the SC-GHG.[17]

Finally, many IAMs have the ability to add, remove, or swap each of the components to evaluate the sensitivity of the SC-GHGs to model assumptions and structure. This has been especially true for the DICE model, which has long been used as a sandbox for climate economists and modelers to test

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[16] The size and chemistry of the perturbation often varies by IAM and gas. For example, it is common to perturb carbon emissions with one gigaton of carbon, not CO_2, as many climate models use carbon as an input. The pulse size is typically determined by the researcher, ensuring that the pulse is large enough for the climate model to respond to the change but small enough that the damage functions respond on the margin. Both the size of the pulse and the chemistry (e.g., CO_2 versus carbon) can be transformed back into a single metric ton of the gas when discounting the stream of marginal damages.

[17] See EPA (2023), Section A.3, for a more thorough discussion on what the distribution of SC-GHGs are and the various ways to summarize them.

various assumptions and alterations to the model. More recently, the GIVE model has adopted a similar open-source approach that uses a modular framework with updated components—allowing researchers to expand upon, or build new, components and modify the model's assumptions.[18] While the modular approach adopted in recent SC-GHG IAMs causes components to appear relatively distinct and independent, the framework also provides the opportunity to add relationships and feedbacks between components. Improved accounting of feedbacks and processes both within and across components is an important area of ongoing research.[19]

B. U.S. Government Estimates of the SC-GHG

U.S. Federal agencies started incorporating SC-CO_2 estimates in policy analysis in 2008 after the U.S. Courts remanded a fuel economy rule for failing to monetize the value of the CO_2 emission reductions, stating that "the value of carbon emissions reduction is certainly not zero."[20] Agencies initially adopted values based on published estimates in the academic literature, but there was considerable variation across agencies. Thus, in early 2009, a White House led Interagency Working Group (IWG) was established to develop a set of estimates recommended for agency use that was reflective of the best available science. The methodology underlying the IWG's recommendations over time are summarized in Figure 3. Initially, the IWG recommended a range of interim SC-CO_2 values based on a synthesis of the DICE, PAGE, and FUND estimates published in the peer reviewed literature.[21] These were the IAMs that were most widely used during this period for estimating the SC-CO_2. In 2010, the IWG developed a set of SC-CO_2 values based on DICE, PAGE, and FUND, with a few adjustments made to apply a common set of input assumptions in each model (IWG 2010). All other IAM features pertaining to the representation of climate dynamics and damage functions were left unchanged. The IWG issued one methodological update in 2013 to use more recent versions of each of the three IAMs. In 2016, the IWG expanded its recommendations to include published SC-CH_4 and SC-N_2O estimates that were consistent with the methodology underlying the IWG SC-CO_2 estimates.

In January 2017, the National Academies of Sciences, Engineering, and Medicine (National Academies, 2017) issued a report on the SC-CO_2 providing a comprehensive set of near- and longer-term updating recommendations. The IWG commissioned this review to obtain expert multi-disciplinary advice on how best to approach an updating process to keep the SC-GHG values reflective of the rapidly expanding scientific understanding of climate change and its impacts on human welfare. Shortly after the report's release, a Presidential Executive Order (E.O.), E.O. 13783, was issued that disbanded the IWG and instructed Federal agencies to use SC-GHG values that reflected two adjustments to the 2016 IWG estimates: to consider only damages estimated to occur within U.S. borders, and to only apply the default discount rates of 3 and 7 percent recommended by Circular A-4 (OMB 2003). Thus, as depicted in Figure 3, Federal analyses began applying SC-GHG values that reflected these two changes until E.O. 13990 was issued in January 2021 that reconstituted the IWG. The new IWG issued

[18] For example, Tan, Rennels, and Parthum (2024) modified GIVE to estimate the social cost of various hydrofluorocarbons (SC-HFCs).

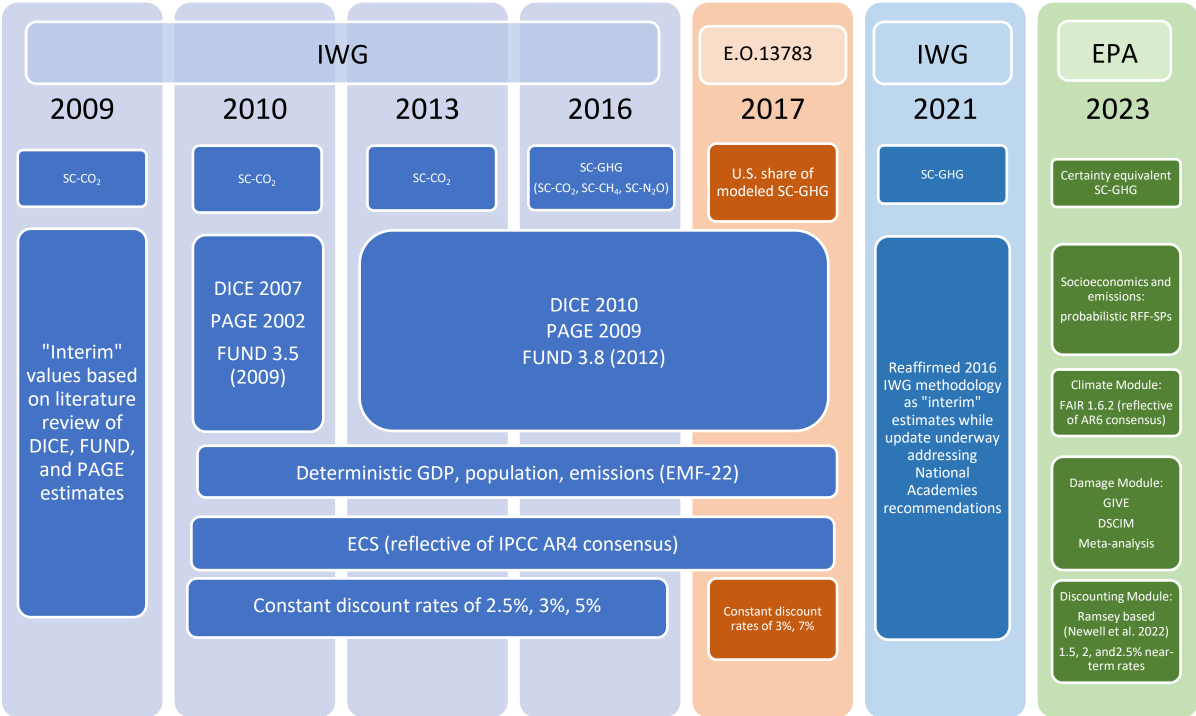
[19] See EPA (2023) for a fuller discussion on the omissions and shortcomings of current SC-GHG IAMs.

[20] *Ctr. for Biological Diversity v. Nat'l Highway Traffic Safety Admin.*, 538 F.3d 1172, 1200 (9th Cir. 2008).

[21] Specifically, the IWG filtered the SC-CO_2 estimates contained in the Tol (2008) meta-analysis to use those that (1) were derived from peer-reviewed studies; (2) did not apply equity weighting of damages across countries; (3) used a business-as-usual climate scenario; and (4) were based on the most recent published version of DICE, PAGE, and FUND. See EPA and DOT (2009) for more discussion of how the filtered estimates were combined to form a set of five recommended interim values.

recommendations reaffirming the 2016 IWG methodology until a comprehensive update of the SC-GHG methodology addressing the National Academies 2017 recommendations was completed.

Figure 3. Methodology underlying U.S. Government developed SC-GHG estimates, 2009-2023



In 2023, the U.S. EPA developed an updated set of SC-GHG estimates that reflected the increase in scientific understanding of climate change impacts and methodological advances in SC-GHG estimation since 2013. As recommended by the National Academies (2017), the EPA adopted a modular approach in which each component of the SC-GHG estimation was updated individually to reflect the best available scholarship from the scientific disciplines relevant to that module. The methods underlying each module are summarized in Figure 3 and described in detail in EPA (2023). First, the EPA adopted the probabilistic RFF-SPs, which provide projections of population, GDP per capita, and GHG emissions on a multi-century time scale. Consistent with the recommendations of the National Academies, these projections were developed using expert elicitation and statistical methods that account for connections between economic growth and emissions as well as future policies. For the climate module, the EPA relied on the widely used reduced-complexity climate model, FaIR 1.6.2. This model was recommended by the National Academies because it is calibrated to the latest scientific consensus from the IPCC (2021) regarding the relationship between global emissions and GMST and the probability distributions for key parameters such as the ECS.

For the damage module, EPA adopted three separate damage functions to represent the main scientific lines of available evidence on the economic impacts on climate change. Two of the damage functions (GIVE and DSCIM) map GMST and GMSL changes to damages in four and five impact categories, respectively. These models follow the National Academies' recommendations and provide impact-specific modeling of relevant processes, which allows for a greater understanding about the mechanisms through which climate impacts occur as well as the contribution of each monetized category to the overall SC-GHG estimate. The third damage function was based on the most recent published peer-reviewed meta-analysis available at the time (Howard and Sterner 2017). As explained in EPA (2023), the Agency included this damage function to reflect the synthesis of knowledge across the rest of the published climate damages literature. Finally, EPA adopted Ramsey-based discounting in which the discount rate depends on estimates of economic growth. The parameters of the Ramsey formula were empirically calibrated using observed interest rates and economic growth (following Newell et al. 2022). Multiple lines of evidence support the use of a 2 percent near-term rate, and uncertainty in the initial discount rate is addressed by using three near-term rates (1.5, 2, and 2.5 percent). EPA (2023) provides a thorough discussion of the ways in which the EPA estimates are still incomplete – for example, due to impact categories and feedback effects omitted from the models and sources of uncertainty that have not been fully characterized due to data limitations – and how the Agency is continuing to investigate ways to address the longer-term recommendations from the National Academies.

The EPA's SC-GHG estimates are larger in magnitude than the previous IWG recommended values. For example, Figure 4 shows how the EPA's SC-CO_2 estimates for 2020 emissions compare to the set of recommended values resulting from the IWG's earlier assessments. The updated central SC-CO_2 value is \$190 per metric ton CO_2 (in 2020 dollars), whereas the mean SC-CO_2 value in the IWG's February 2021 Technical Support Document (TSD), which relied on a 3 percent constant discount rate and IAMs published between 2009 and 2012, is \$51 per metric ton CO_2. The updated estimates reflect a large set of scientific advances since the previous estimates were developed. The differences are the result of all the methodological updates employed in the new modeling and not attributable to a single change. The degree to which the combined updates affect the SC-GHG varies by gas, due to the time-dependent nature of GHG emissions, the resulting paths of temperature anomalies, the shape of the damage functions, and the relationship of these interactions with discounting. For CH_4, which has a notably shorter atmospheric lifetime than the other two gases, the updates lead to a smaller increase in the SC-GHG. The updated central SC-CH_4 value in 2020 is \$1,600 per metric ton CH_4, whereas the SC-CH_4 value using a 3 percent constant discount rate in the February 2021 TSD is \$1,500 per metric ton CH_4.

Figure 4. U.S. Government estimated SC-CO_2, 2020 emissions (2020 dollars)

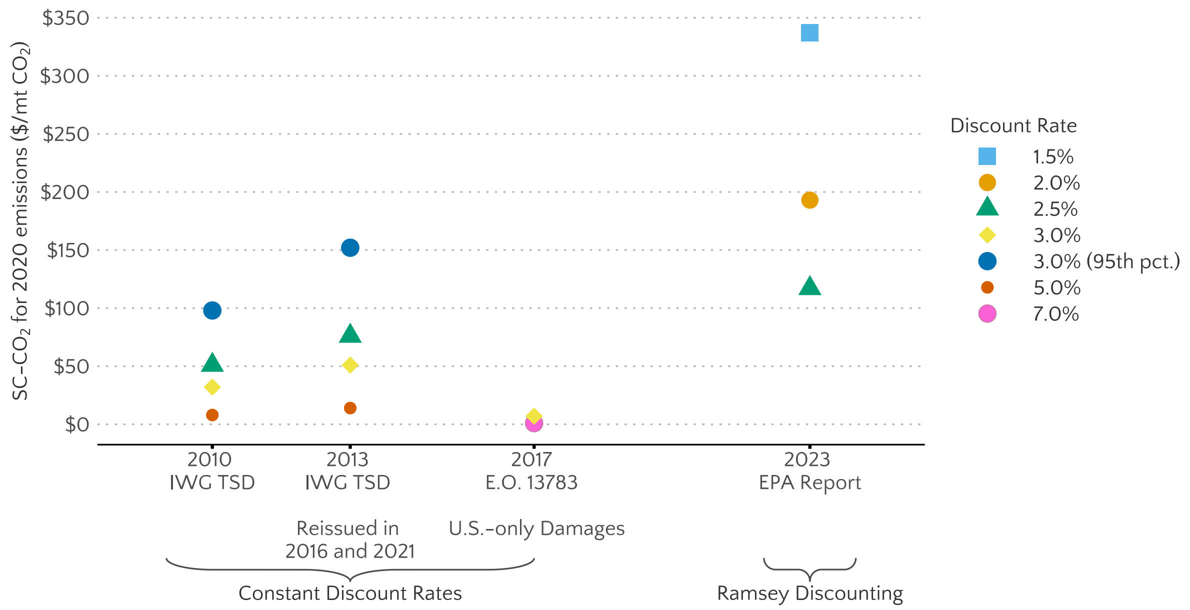


Table 1 presents the EPA's SC-CO_2, SC-CH_4, and SC-N_2O estimates for emission years out to 2080 under near-term Ramsey discount rates of 1.5, 2, and 2.5 percent. As seen in the table, for all three gases, estimates based on a higher near-term discount rate are consistently lower, while lower near-term discount rates result in higher SC-GHG estimates. The SC-GHG estimates also increase over time. Emissions further in the future produce larger incremental damages as Earth systems and the economy become more stressed in response to greater climatic change and because income is growing over time. As income grows, so does the willingness to pay to avoid economic damages.

Table 1. EPA estimates of the social cost of greenhouse gases (SC-GHG), 2020-2080 (in 2020 dollars per metric ton)

	SC-GHG and Near-term Ramsey Discount Rate								
	SC-CO_2 *(2020 dollars per metric ton of CO_2)*			SC-CH_4 *(2020 dollars per metric ton of CH_4)*			SC-N_2O *(2020 dollars per metric ton of N_2O)*		
Emission Year	2.5%	2.0%	1.5%	2.5%	2.0%	1.5%	2.5%	2.0%	1.5%
2020	120	190	340	1,300	1,600	2,300	35,000	54,000	87,000
2030	140	230	380	1,900	2,400	3,200	45,000	66,000	100,000
2040	170	270	430	2,700	3,300	4,200	55,000	79,000	120,000
2050	200	310	480	3,500	4,200	5,300	66,000	93,000	140,000
2060	230	350	530	4,300	5,100	6,300	76,000	110,000	150,000
2070	260	380	570	5,000	5,900	7,200	85,000	120,000	170,000
2080	280	410	600	5,800	6,800	8,200	95,000	130,000	180,000

Source: EPA (2023)

IV. SC-GHG Use in U.S. Federal Policy Analysis

The predominant use of SC-GHG estimates in U.S. Federal policy analysis to date has been in benefit-cost analysis (BCA) of regulations that affect GHG emissions. Since 2009, its use has been a standard part of BCAs conducted under a long-standing Executive Order, E.O. 12866, that requires agencies to examine and monetize the benefits and costs of their regulatory actions. The SC-GHG values used by the EPA and other Federal regulatory agencies from 2009 to 2016, and 2021 to 2023, have been consistent with those developed and recommended by the IWG described above. The values used from 2017-2020 were consistent with those required by E.O. 13783, which made two adjustments that greatly reduced the SC-GHG values but otherwise maintained the modeling of the IWG recommended estimates.

Overall, SC-GHG estimates have been applied in hundreds of U.S. regulatory impact analyses (RIAs) supporting proposed and final rulemakings, primarily from Department of Energy (DOE), EPA, Department of Transportation (DOT), and Department of Interior (DOI). These include regulations promulgated under the Clean Air Act (e.g., GHG emissions standards for new power plants, oil and natural gas sources, passenger vehicles or trucks, landfill gas emissions standards, and various national emissions standards for hazardous air pollutants), Clean Water Act (e.g., wastewater discharge standards for coal-fired power plants), Energy Policy and Conservation Act (e.g., energy efficiency standards for vehicles and various residential products and commercial and industrial equipment), and the Mineral Leasing Act (e.g., requirements pertaining to venting, flaring, and leaks of emissions from oil and natural gas sources on Federal lands), among others.[22] See Aldy et al. (2021) for a list of 60 of the final regulations in which SC-CO_2 or SC-CH_4 estimates were applied in their supporting RIAs. The extent to which the monetized climate impacts is considered in setting the stringency of these regulatory actions is guided by the statutes under which those decisions are made. For most rules to date, the monetized climate impacts within these RIAs are presented for informational purposes under E.O. 12866. However, at times, the BCA results are noted as part of the rationale for the stringency of the regulation (e.g., DOI's 2018 Rescission of the Waste Prevention Rule under Mineral Leasing Act[23]).

SC-GHG estimates have also appeared in non-regulatory contexts in recent years. SC-GHG estimates have been used in numerous environmental impact statements conducted under the National Environmental Policy Act (NEPA) for proposed infrastructure and other projects requiring federal permitting. Recent examples include the Bureau of Ocean Energy Management's Draft Programmatic Environmental Impact Statement (EIS) of the 2023-2028 National Outer Continental Shelf Oil and Gas Leasing Proposed Program, the U.S. Postal Service's Final EIS for Next Generation Delivery Vehicle Acquisitions, and the Federal Energy Regulatory Commission's Final EIS for the Spire STL Pipeline Project.[24] In such environmental reviews, estimates of the SC-GHG have provided information to decision makers and the public for the purposes of analyzing and disclosing the impacts of a project's

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[22] EPA has also developed estimates of the social cost of hydrofluorocarbons (SC-HFCs) that are consistent with the methodology underlying the SC-CO_2, SC-CH_4, and SC-N_2O estimates and used them in analysis of regulations phasing down HFC use under the American Innovation and Manufacturing (AIM) Act of 2020.

[23] https://www.federalregister.gov/documents/2018/09/28/2018-20689/waste-prevention-production-subject-to-royalties-and-resource-conservation-rescission-or-revision-of

[24] Federal Environmental Impact Statements (EIS) are available on lead agency websites and in the EPA's EIS Database: https://cdxapps.epa.gov/cdx-enepa-II/public/action/eis/search/search?searchCriteria.primaryStates=GU#results. See Howard and Schwartz (2019) for examples of the use of SC-CO_2 estimates in NEPA analyses.

GHG emissions and providing transparency into the tradeoffs associated with an action and its alternatives. Agencies often use SC-GHG estimates in an EIS even if no other costs or benefits are monetized to offer additional context about a proposed action's impacts through its effect on climate change. For example, if alternatives or mitigation strategies would have different effects on CO_2, CH_4, and N_2O emissions, the SC-GHG provides dollars per year as a common unit for comparison. Only quantifying total GHG emissions over the life of a proposed project does not disclose or explain when and how society will be affected by those emissions. In general, Federal case law supports the use of the SC-GHG in NEPA analysis; however, courts often have deferred to agency rationales for whether to apply SC-GHG estimates in an environmental impact statement (EIS) under NEPA.[25] The use of SC-GHG estimates in a proposed project's EIS continues to be encouraged in both White House guidance documents[26] and by EPA in its formal review role in the NEPA process.[27]

Other examples of SC-GHG use in non-regulatory analyses can be found in federal procurement, grant programs, and legislative proposals.[28] In September 2023, President Biden approved recommendations to expand the use of the SC-GHG for budgeting, procurement, and other agency decisions.[29] The DOT December 2023 update to its BCA guidance for applicants to DOT's discretionary grant programs includes recommendations for applicants to apply EPA's updated SC-GHG estimates in BCA of a wide range of surface transportation infrastructure projects.[30]

Finally, there has been increasing use of SC-GHG estimates by non-Federal entities. For example, numerous states use values in various types of analyses and decision-making contexts.[31] Other countries that use SC-GHG estimates in policy analysis include Canada, Germany, and Israel (EPA 2023). The Canadian Government adopted the IWG recommended estimates in 2016, with some modifications, and recently adopted EPA's updated estimates to inform their regulatory analysis.[32] Through the North American Leaders Summit, Mexico has also committed to "come together to align approaches on estimating the social cost of greenhouse gas emissions."[33]

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[25] See, e.g., Hein and Jacewicz (2020) and Palenik (2020) for a review of case law around the use of SC-GHG estimates under NEPA, and other statutes (e.g., Natural Gas Act).

[26] See the January 2023 Council of Environmental Quality draft guidance, *Guidance on Consideration of Greenhouse Gas Emissions and Climate Change*, and the September 2023 White House Factsheet on expanding the use of SC-GHG estimates in policy making (https://www.whitehouse.gov/briefing-room/statements-releases/2023/09/21/fact-sheet-biden-harris-administration-announces-new-actions-to-reduce-greenhouse-gas-emissions-and-combat-the-climate-crisis/)

[27] See, e.g., Letter from EPA to USPS, on the Final Environmental Impact Statement for Next Generation Delivery Vehicle Acquisitions, Feb. 2, 2022.

[28] For example, the IWG SC-CO_2 estimates informed the starting carbon tax proposed in the American Opportunity Carbon Fee Act (introduced in 2014, updated in 2018, 2019). Similarly, the IWG recommended SC-CH_4 estimates informed the Waste Emissions Charge schedule set in the 2022 Inflation Reduction Act (IRA) for applicable methane emissions from oil and gas industry sources (i.e., starting at \$900/mtCH_4 in 2024, increasing to \$1200/mtCH_4 in 2025, and \$1,500/mtCH_4 in 2026 and beyond). See discussion in EPA (2023) for examples of SC-GHG use in federal procurement and grant programs.

[29] https://www.whitehouse.gov/briefing-room/statements-releases/2023/09/21/fact-sheet-biden-harris-administration-announces-new-actions-to-reduce-greenhouse-gas-emissions-and-combat-the-climate-crisis/

[30] https://www.transportation.gov/sites/dot.gov/files/2023-12/Benefit%20Cost%20Analysis%20Guidance%202024%20Update.pdf.

[31] https://costofcarbon.org/

[32] https://www.canada.ca/en/environment-climate-change/services/climate-change/science-research-data/social-cost-ghg.html

[33] https://www.whitehouse.gov/briefing-room/statements-releases/2023/01/10/declaration-of-north-america-dna/

V. Conclusion

Addressing global climate change requires an all-hands-on-deck approach to find solutions that are both effective and economically viable. Under-investing in climate mitigation can lead to climate damages beyond society's ability to adapt. On the other hand, over-investing resources in programs designed to tackle climate change can detract from our ability to remedy other important issues. The SC-GHG provides policy makers with an important tool for evaluating the tradeoffs between different types of investments. As outlined in this chapter, there are important limitations of the SC-GHG based on the currently available science, nevertheless, the metric provides meaningful information on the welfare implications of changes in GHG emissions. Its development has been a monumental interdisciplinary effort, and improving upon it will require continuing and strengthening existing collaborations, as well as establishing new ones. This includes evolution of methods and applications, careful examination of each of the components and their linkages, broadening the scope of modeled impacts from GHG emissions, expansive data collection and analysis efforts, and the building out of models to incorporate each of these advancements as they arise. Finding solutions to the global problem of climate change will require global involvement and cooperation, and improving and applying the SC-GHG is an important component of these efforts.

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