Toward a True Cost of Climate Pollution:
How Vermont Can Better Incorporate the Latest Research on the Social Costs of Greenhouse Gases

By Evelyn Hatem
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This report is the result of a 10-week internship led by EAN Senior Fellow Christine Donovan.

Executive Summary

This report explains the term "the social costs of greenhouse gases (SC-GHG)," describes how the costs are determined, and examines how they are currently being used in Vermont climate policy and related activities. The 2021 Vermont Climate Action Plan (CAP) identified SC-GHG values to be used in Vermont climate policy, as well as determined that the values should be reviewed prior to development of the updated plan due to the Legislature by December 2025. Methods used for this report included a literature review of relevant state government reports, academic articles, and teaching resources, largely from the Vermont Climate Council, Resources for the Future, and the U.S. Environmental Protection Agency. Interviews were conducted with state government climate and energy professionals, academic researchers, and environmental consultants. This research took place from June to August 2023.

First, this report defines the social costs of greenhouse gases, including how they are estimated, key assumptions used to determine such costs, why they are important to estimate, and related equity considerations. The report explains how the social costs of greenhouse gases have been implemented in Vermont, before discussing updated estimates by Resources for the Future, University of California: Berkeley, and the U.S. Environmental Protection Agency, as well as implications going forward.

There are three primary takeaways identified by this research:

1. New research and analysis have been completed at the national level by Resources for the Future-Berkeley and the EPA since the 2021 CAP was approved by the Vermont Climate Council. The value for the social cost of carbon dioxide used during development of the Vermont Climate Action Plan (referred to as the "social cost of carbon" in the CAP) was $121/metric tonne to describe the impacts of a pulse of emissions in 2020.[1] This value was based on the best available information at the time. Since then, RFF-Berkeley has estimated the social cost of CO_2 to be $185/metric tonne, and the EPA has developed an estimate of $190/metric tonne.
2. In the 2021 CAP, the Vermont Climate Council committed to revising the social costs of greenhouse gases used during development of the 2021 CAP as new research and analysis becomes available. The development phase of the upcoming 2025 Vermont CAP could be a key time to do so.
3. The estimates by RFF-Berkeley and the EPA are likely to underestimate the true social costs of greenhouse gases, since their damages modules lack impacts on morbidity, biodiversity, and ecosystem services, among others. Researchers continue to update and add to the available models.

[1] David G. Hill et al. "Social Cost of Carbon and Cost of Carbon Model Review," 2021.

I. What are the Social Costs of Greenhouse Gases?

'Social costs of greenhouse gases (SC-GHG)' is a concept that estimates a dollar amount to represent the marginal damages brought by an additional unit of greenhouse gas emissions into the atmosphere. Because different greenhouse gases exhibit different global damage potentials, each gas has its own social cost. The National Academy of Sciences defines the social cost of carbon dioxide, the most emitted greenhouse gas, as:

> *"An estimate, in dollars, of the present discounted value of the future damage caused by a metric ton increase in carbon dioxide (CO2) emissions into the atmosphere in that year or, equivalently, the benefits of reducing CO2 emissions by the same amount in that year"* [2]

In other words, **what is the cost to society from emitting one metric tonne[3] of carbon dioxide?** Estimating the social cost of carbon dioxide seeks to answer this question.

Similar estimates can be made for other greenhouse gases, such as methane and nitrous oxide, as well as less common greenhouse gases such as chlorofluorocarbons (CFCs) and hydrofluorocarbons (HFCs). The umbrella term for these estimates is the 'social costs of greenhouse gases' (SC-GHGs), although the simplified term the 'social cost of carbon (SCC)' is often used in research and policy work to refer to the same concept. To clarify that this concept can be applied to different greenhouse gases, not all of which contain carbon, the term the 'social costs of greenhouse gases' is used in this report. There are a few key elements to the definition of the social costs of greenhouse gases. These concepts will be described in greater detail throughout the report, but they can be understood in these quick terms:

- **Damages**: the impacts of climate change, such as heat-related mortality, agriculture, energy expenditures for heating and cooling, and coastal impacts from sea level rise
- **Discounting:** a calculation, using a 'discount rate,' which accounts for preferences between short-term and long-term costs and benefits. The discount rate is especially important when assessing the impacts of long-lasting greenhouse gas emissions over long periods of time.

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[2] National Academies of Sciences, Engineering, and Medicine. *Valuing Climate Changes,* 2017. Note: This is also the definition used in the 2021 Vermont CAP.

[3] This report uses the spelling 'tonne' to clarify that metric tonnes, rather than imperial tons, are being discussed. Though, the National Academies of Sciences, Engineering, and Medicine uses 'metric ton' to refer to the same unit.

History

The concept of the social costs of greenhouse gases began with academic research in the 1990s. In 2008, the concept first entered U.S. federal policy. Participants in the rulemaking efforts for emission standards noted that policymakers in the United Kingdom were considering using the social costs of greenhouse gases. This led to a lawsuit in which the U.S. Court of Appeals for the Ninth Circuit rejected an agency's rule; the Court noted that, without providing a monetary estimate for the benefits of greater fuel efficiency, the National Highway Traffic Safety Administration was inaccurately estimating the benefits to be $0.[4]

When President Obama entered office in 2009, he convened an Interagency Working Group (IWG) to develop a social cost of carbon dioxide to be used throughout all federal agencies in regulatory impact analysis. The IWG utilized the models available at the time (DICE, FUND, and PAGE) to estimate the social cost of carbon dioxide. In a 2016 technical support document, the IWG responded to recommendations from the National Academies of Sciences, Engineering, and Medicine, as well as added estimates for the social costs of methane and nitrous oxide. The National Academies then issued a final report in 2017 with recommendations for methodological changes to be used in the IWG's future updates to the SC-GHG.

In 2017, President Trump's Executive Order 13783 disbanded the Interagency Working Group and established a working federal estimate of the SC-GHG that utilized a high discount rate and calculated U.S. damages rather than global damages. Reports from the Government Accountability Office and from expert testimony described the Trump administration's estimates as ill-positioned "to ensure agencies' future regulatory analyses [we]re using the best available science"[5] and based on "methodological changes that in my judgment cannot be justified by science or economics."[6]

Shortly after taking office, President Biden reconvened the Interagency Working Group in 2021, which opted to use the 2016 IWG estimates, adjusted for inflation, as interim social cost of carbon dioxide values. In 2022, a team of researchers from Resources for the Future (RFF) and University of California Berkeley published an article in *Nature* titled "Comprehensive Suggests a Higher Social Cost of CO_2." Along a similar timeframe, the EPA began drafting its "Report on the Social Costs of Greenhouse gases: Estimates Incorporating Recent Scientific Advances." The EPA's report is currently in its peer review phase. The remainder of this report focuses on the work of the RFF-Berkeley team and the EPA, since their estimates are the most recent and comprehensive in the peer-reviewed literature.

[4] Center for Biological Diversity vs. National Highway Traffic Safety Administration, 2008.

[5] Government Accountability Office. "Social Cost of Carbon: Identifying a Federal Entity to Address the National Academies' Recommendations Could Strengthen Regulatory Analysis," 2020.

[6] Michael Greenstone. "Statement of Michael Greenstone for U.S. Senate Committee on Budget," 2023.

II. How are the Social Costs of Greenhouse Gases Estimated?

Marginal Damages Approach

The social costs of greenhouse gases are typically estimated using Integrated Assessment Models, which combine modules to 'convert' a metric tonne of a specific greenhouse gas into future discounted damages. As of July 2023, the most recently updated Integrated Assessment Model is the Resources for the Future-Berkeley Greenhouse Gas Impact Value Estimator (GIVE). The GIVE model is comprised of four open-source software modules:

1. **Socioeconomic Module**: Determines future projections of GDP, population, and emissions.
2. **Climate Module**: Translates emissions projections into changes in the climate system.
3. **Damages Module:** Translates changes in the climate system into economic damages.
4. **Discounting Module**: Translates future economic damages into present-day dollars.

Each module was developed independently from one another using the best available scientific and economic literature.

Researchers may choose to use GIVE in its entirety, or to use only select modules. Between GIVE and the Environmental Protection Agency's model, three of the four modules are the same. However, they differ in their damages module. Resources for the Future and Berkeley utilized a sectoral damages approach (described below), while the EPA utilized three different models, ran them separately, and then averaged their outcomes to determine their damages estimate. The three models that the EPA used in their damages module include:

1. "Subnational-scale, sectoral damage function (based on the Data-driven Spatial Climate Impact Model (DSCIM) developed by the Climate Impact Lab (CIL 2022, Carleton et al. 2022, Rode et al. 2021)),
2. Country-scale, sectoral damage function (based on the Greenhouse Gas Impact Value Estimator (GIVE) model developed under RFF's Social Cost of Carbon Initiative (Rennert et al. 2022b)), and a
3. Meta-analysis-based damage function (based on Howard and Sterner (2017))." (EPA Supplementary Information)."[7]

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[7] U.S. Environmental Protection Agency, "EPA External Review Draft of Report on the Social Cost of Greenhouse Gases: Estimates Incorporating Recent Scientific Advances," 2022.

Marginal Abatement Cost Approach

The "marginal abatement cost" (MAC) approach is a concept complementary to the social costs of greenhouse gases that provides economic analysis to describe the costs of climate change. The marginal abatement cost estimates the "cost of abating the last metric ton of carbon dioxide needed to meet a particular emissions target at least cost to society."[8] Simply, this value is the marginal cost (or savings) of action to mitigate climate change, whereas the social costs of greenhouse gases describe the marginal cost of *in*action. The MAC approach is also known as the target-consistent approach since it begins by identifying a temperature threshold and works backwards to determine the cost for greenhouse gas emissions abatement. Vermont uses both a MAC approach and a damages approach in the 2021 Climate Action Plan. Vermont, via the Climate Council, used the MAC approach to compare the mitigation potentials of various measures. Each measure was compared to a value for the social cost of carbon dioxide to evaluate cost-effectiveness.[9] In terms of estimating the social costs of greenhouse gases, Vermont utilized the damages approach by citing Resources for the Future's estimates for the New York State Department of Environmental Conservation. The marginal damages approach will be discussed from here on.

Assumptions

Within each of the modules of the marginal damages approach, even the best available scientific and economic literature embeds specific assumptions about human behavior, climate dynamics, and economic growth based on empirical observations. These assumptions are then used to develop a value for the social cost of greenhouse gas emissions.

One key assumption that must be developed is referred to as the "discount rate." Discount rates are used in many economic calculations, not just those related to the social cost of greenhouse gas emissions. A discount rate is used to understand the value of future cash flows in terms of present value. By definition, a discount rate is a value used to address the differing value of money over time. Economists apply discounting not to represent inflation but to represent the fact that a dollar in your hand today is not as valuable as a dollar promised to you in 20 years.

The value determined for a discount rate becomes especially relevant when predicting the impacts of climate change because greenhouse gases can remain in the atmosphere for thousands of years.[10] Since carbon dioxide (a major climate pollutant) is known to remain in the atmosphere for 300 to 1,000 years,[11] it is very important that special consideration be given to

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8 Resources for the Future. "Estimating the Value of Carbon," 2021.

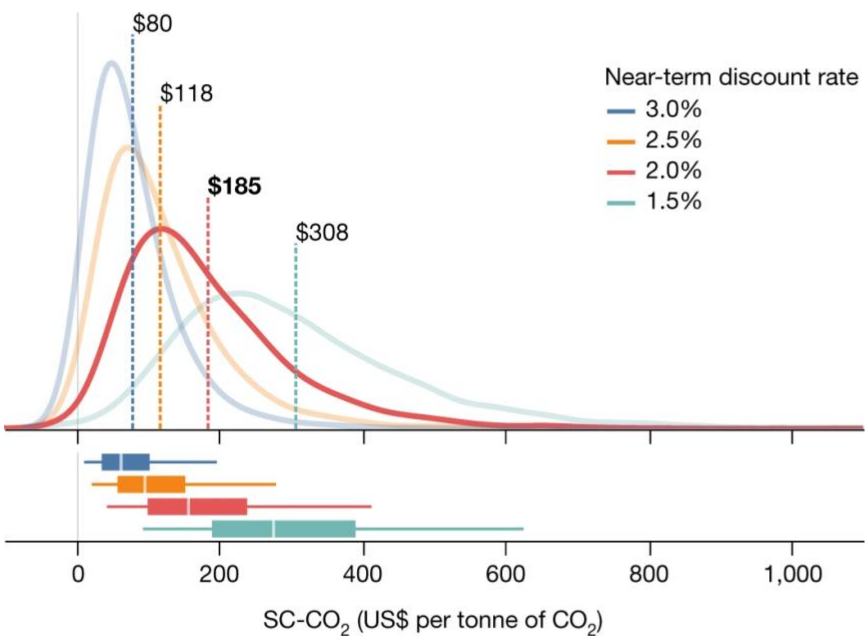
9 David G. Hill et al. "Marginal Abatement Cost Curves: Examining the Mitigation Potential and Cost per Tonne of Emissions Reductions of Measures in the Vermont Pathways Analysis," 2022.

10 US EPA. "Overview of Greenhouse Gases," 2015.

11 Alan Buis. "The Atmosphere," 2019.

how short-term economic costs and benefits of such pollutants affect the economy over both the short- and long-term. These costs and benefits will impact the well-being of generations to come. Discount rates are estimated by analyzing market interest rates and assessing preferences for short-term vs. long-term benefits. Informed by the Vermont Climate Council's Science and Data Subcommittee, the Climate Council recommended that Vermont use a 2% discount rate in social cost of greenhouse gas calculations during development of the 2021 Vermont Climate Action Plan. They also requested that additional analyses be done using 1% and 3% discount rates to determine and illustrate the sensitivity resulting from the use of different discount rates. In general, the use of a "high discount rate means that future effects are considered much less significant than present effects, whereas a low discount rate means that they are closer to equally significant."[12] The selection of which discount rate to use can have significant impacts on the results of economic calculations. The following figure illustrates the mean values and distributions of the social cost of carbon dioxide using discount rates ranging from 1.5-3.0%, as calculated using the GIVE model.

Figure 1: Distributions of SC-CO_2 by Near-term Discount Rate[13]



In addition to discount rates, the GIVE model incorporates parameters with specific ranges of uncertainty. Each module is underpinned by scientific and economic literature, but the literature includes embedded assumptions and degrees of uncertainty. These uncertain parameters are present in various components of the model, which are underpinned by scientific and economic literature. Sources of uncertainty in the GIVE model's estimation of SC-CO2 can be found in a

[12] Kevin Rennert and Cora Kingdon. "Social Cost of Carbon 101," 2019.

[13] Rennert et al. "Comprehensive Evidence Implies a Higher Social Cost of CO2," 2022.

supplementary data table in their article in *Nature.*[14] According to RFF-Berkeley, each of their modules was developed independently of the others utilizing the best available scientific and economic literature. The term 'best available' refers to an informed choice that researchers make when creating a model. For example, in their damages module, the RFF-Berkeley team chose to use a sectoral approach, which adds together separate sectoral damages (health, agriculture, energy, and coastal impacts). An alternative, aggregate approach, could utilize aggregate damage functions from academic literature, such as William Nordhaus's DICE damage function, which "use[s] a single equation to estimate global climate-induced GDP losses as a function of temperature."[15]

III. Why are the Social Costs of Greenhouse Gases Important?

Michael Greenstone, the former chief economist in the Obama administration, described the social cost of carbon dioxide as:

> *"The most important number you've never heard of."*[16]

Greenstone identified a mismatch; when analyzing regulations, the costs are often described in dollars, while the benefits are measured in avoided emissions. From this mismatch was borne the idea that the U.S. government should estimate and utilize a uniform social costs of greenhouse gases. This reasoning is one component of the SC-GHG: addressing the need for the costs and benefits of carbon emissions to be described in the same units. The second unique component of cost-benefit analysis in the context of greenhouse gas emissions is the residence time of greenhouse gases in the atmosphere, and thus the long-term, intergenerational nature of the impacts of greenhouse gases. The social costs of greenhouse gases provide a method of quantifying intergenerational costs and benefits over time – for generations and generations. Using an appropriate discount rate, as discussed above, the social costs of greenhouse gases provide a helpful metric that acknowledges the unique longevity of climate change impacts. In addition, estimating and articulating the impacts of carbon emissions in a dollar amount provides a useful starting point for determining effective carbon prices or taxes in mitigation approaches.[17]

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[14] Ibid.

[15] Brian Prest et al. "Social Cost of Carbon Explorer," 2022.

[16] Peter Coy. "'The Most Important Number You've Never Heard Of,'" 2021.

[17] Isabelle Backman. "Professors Explain the Social Cost of Carbon," 2021.

IV. What are the Equity Considerations?

The primary equity concerns about the SC-GHG revolve around the global nature of the damages. First, because greenhouse gases affect the entire atmosphere, the largest GHG emitters are often not the populations that experience the greatest harm due to climate change. In the RFF-Berkeley model, as well as the EPA's model, there are currently no 'equity weights' that reflect this dynamic. In the health damages sector (quantifying climate change impacts on mortality), an economic concept called the 'value of a statistical life' (VSL) is scaled according to income to address, in this specific component, the fact that a pure VSL would assign a greater dollar value to a wealthy person's life than a poor person's life. Pending further technical and philosophical discussion, the RFF-Berkeley team is considering including equity weights in their modeling in early 2024. Equity weights would differentiate the social costs of greenhouse gases by region, based on which regions will experience the damages of climate change. Second, the notion of discounting impacts to future generations is a question of intergenerational equity. Because these impacts will be borne by human beings who do not yet exist, or who are youth that do not often have a vote, some say that using discount rates to prioritize the needs of today's generation over future generations is inequitable. The choice of a discount rate is a question of economics and moral philosophy. Conducting analyses with a range of discount rates seeks to address this concern.

V. How has the Social Costs of Greenhouse Gases been used in Vermont thus far?

2021 Vermont Climate Action Plan

During the 2021 drafting process for the CAP, the Science and Data Sub-committee (SDSC) of the Vermont Climate Council engaged consultants from the Cadmus Group and Energy Futures Group to review an existing environmental externality model used by the Vermont Public Service Department (the Cost of Carbon Reduction Model, or CCR model).[18] The SDSC oversaw the development of the social costs of greenhouse gases for use in the CAP and reviewed relevant assumptions used in the estimates (e.g., the discount rate). The social costs of greenhouse gases conversation were incorporated into the Climate Action Plan (CAP) as part of a cost-effectiveness criteria. Cost-effectiveness is one of five foundational criteria that informed the priorities for reducing GHG emissions established in the CAP. In addition to cost-effectiveness, the criteria included impact, co-benefits, equity, and technical feasibility. According to the CAP, cost-effectiveness "incorporates estimated social and environmental 'externalities,' including health costs and benefits and a Social Cost of Carbon."[19] Informed by

[18] David G. Hill et al. "Social Cost of Carbon and Cost of Carbon Model Review," 2021.
[19] Vermont Climate Council. "Initial Vermont Climate Action Plan," 2021.

reports from Cadmus/EFG, the SDSC recommended, and the Council agreed, that Vermont should:

- "Value greenhouse gas emissions costs (and avoided costs) by utilizing a global damages-based estimation of the Social Cost of Carbon, based on models developed for the New York State Department of Environmental Conservation by Resources for the Future.
- Recognize that the estimation of the Social Cost of Carbon is highly dependent on the discount rate. Based on polling exercise with the Science and Data Sub-Committee and discussion with the whole Council, the Council determined it is reasonable to utilize the Social Cost of Carbon using a 2% discount rate.
- Plan for updates to the Social Cost of Carbon and the discount rate on a regular basis, taking into account new research that may be published that impacts the Social Cost of Carbon and application of the discount rate."[20]

Additionally, the Council recommended that analyses be done with 1% and 3% discount rates to illustrate a range of possible economic outcomes.

Implementation of the Social Costs of Greenhouse Gases in Vermont

In Vermont, SC-GHG has been used in various regulatory impact analyses. The following are three examples of the concept of SC-GHG being utilized in Vermont rulemaking and regulatory proceedings.

Agency of Natural Resources

From June 2022 to December 2022, the Agency of Natural Resources (ANR) amended its low emission vehicle (LEV) and zero emission vehicle (ZEV) rules, as is done periodically to maintain consistency with California's vehicle emissions standards.[21] The Low Emission Vehicle rules establish standards for criteria air pollutants and greenhouse gases for specific vehicle types and engines for sale or placed in service in Vermont. The Zero Emission Vehicle rules ultimately require auto manufacturers to deliver more electric vehicles to Vermont.

In describing the environmental and economic benefits of this rule, ANR calculated the 2026-2040 Statewide Estimated Avoided Social Cost of CO2 from Advanced Clean Cars II vehicle rules, as well as the 2025-2050 Statewide Estimated Avoided Social Cost of CO2 from Medium- and Heavy-duty vehicle rules. The time frames were chosen to reflect the time frame of the rules.

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[20] Vermont Climate Council. "Initial Vermont Climate Action Plan," 2021. Acronyms written out for clarity.
[21] Vermont Agency of Natural Resources, Department of Environmental Conservation. "Recently Adopted and Proposed Regulations," 2023.

Both analyses were conducted with 1%, 2%, and 3% discount rates, with 2% selected as the preferred discount rate in accordance with the 2021 Climate Action Plan and the Avoided Energy Supply Components in New England (AESC) study by Synapse Energy Economics. [22]

Public Service Department

At the Public Service Department, the social cost of carbon dioxide was utilized in a proceeding regulating Vermont Gas System's (VGS) purchase of renewable natural gas contracts at the Seneca Meadows Landfill in Waterloo, New York. To assess the cost-effectiveness of the proposed contract, the Department considered the price of the contract relative to the benefits of the contract, including the value of the estimated emissions reductions relative to fossil gas. Relevant files, including the testimony can be found on ePUC under proceeding 22-2230-PET.[23] The Department also referenced the 2021 New England Avoided Energy Supply Cost study (AESC) produced by Synapse Energy Economics[24] to describe their approach to using the social cost of greenhouse gases in regulatory proceedings.

Efficiency Vermont

Efficiency Vermont uses the social costs of greenhouse gases as part of its societal cost-effectiveness testing, which guides the portfolio of efficiency measures they support as an Energy Efficiency Utility. When evaluating cost-effectiveness, Efficiency Vermont includes various groupings of benefits:

1. Energy savings – such as electric (kWh, kW) and thermal (MMBtu) savings
2. Greenhouse gas avoided externality costs
3. Non-energy benefits (such as comfort, improved health, and resiliency benefits)

The social costs of greenhouse gases are incorporated in the societal cost-effectiveness test's greenhouse gas avoided externality costs. The SC-GHG ($/CO2e) is combined with electric (or fuel) greenhouse gas emissions rates to assign $/kWh (or $/MMBtu) avoided externality cost. In societal cost-effectiveness screening, efficiency measures then receive a benefit of $/kWh (or $/MMBtu) greenhouse gas avoided externality cost based on the energy savings profile of a measure.

[22] Synapse Energy Economics et al. "Avoided Energy Supply Components in New England: 2021 Report," 2021.
[23] Vermont Public Utility Commission, "Search by Case Number."
[24] Synapse Energy Economics et al. "Avoided Energy Supply Components in New England: 2021 Report," 2021.

VI. What has the Most Recent and Credible Research Found to be the Value of the Social Costs of Greenhouse Gases?

Estimates of the social costs of greenhouse gases are different from year to year because of discounting and the fact that specific climate impacts of greenhouse gases in the atmosphere vary from year to year. When a single value is stated as "the social cost of CO_2", it can refer to the initial value (the cost of a pulse of emissions in the starting year), or it can refer to a levelized cost over a series of years. Rather than produce a single value, Integrated Assessment Models produce a stream of values, which exhibit a general trend that the social cost of carbon dioxide increases by approximately 2% each year.[25] This increase is a result of interactions within the model, rather than any normative assumptions. For this report, the initial values of the social cost of carbon dioxide are used, which describes the social cost from a pulse of emissions in 2020. This is the initial year that RFF-Berkeley and EPA use in their most recent reporting. The EPA's estimates by year for carbon dioxide, methane, and nitrous oxide can be found in Appendix A. RFF-Berkeley's estimates by decade can be found in Appendix B.

Table 1: Social Cost of CO_2 for a Pulse of Emissions in 2020, by Damage Function

Damage Function	**Near-term Discount Rate**			
	1.5%	**2%**	2.5%	3%
DSCIM, Howard & Sterner, and GIVE; Outcomes averaged, unrounded. (EPA) *Under peer review.	$337	**$193***	$117	Not available
GIVE sectoral (RFF-Berkeley)	$308	**$185**	$118	$80

VII. How Other States use the Social Costs of Greenhouse Gases

The U.S. Climate Alliance is a bipartisan coalition of governors advancing state-led climate action. In their social costs of greenhouse gases guide, the Alliance provides guidance for state

[25] Lisa Rennels (University of California: Berkeley) in discussion with the author, July 2023.

officials on the implementation of the social costs of greenhouse gases.[26] The guide and an associated table (below) were published on August 29, 2022, shortly before the September 1, 2022 publication of RFF-Berkeley's "Comprehensive evidence implies a higher social cost of CO_2" report.[27] This table provides a snapshot of states' uses of the SC-GHG, and further research could update the table as new uses are implemented in the United States. The guide by the U.S. Climate Alliance could be useful in Vermont for identifying future applications of the social costs of greenhouse gases. The discussion of states' uses of the social costs of greenhouse gases begins on Page 57 of the Guide.

Table 2: States' Uses of the SC-GHG as of August 2022[28]

		States													
Type of Use		CA	CO	DE	IL	ME	MD	MN	NV	NJ	NY	OR	VA	VT	WA
Cost-benefit analysis	*Rulemaking (informational)*	•	•								•				
	Electric Utility IRPs	•	•					•	•			•	•		•
	Gas Distribution System														
	Planning Info.		•												
	Land Use	•		•						•	•			•	
Grants & Investments		•	•[38]												•
Procurement															•
Penalties															
Royalties															
Resource Compensation		•			•	•	•				•				

VIII. What are the Implications for Vermont Moving Forward, Given Recent National Research?

Based on updated national research by RFF-Berkeley and the EPA as well as the Vermont Climate Council's commitment to periodically update the social costs of greenhouse gases, the implications of this research focus on the upcoming 2025 revisions of Vermont's Climate Action Plan. The dollar amount identified during research for this report suggests the social cost of carbon dioxide used in future Vermont regulatory impact analysis should likely be increased from its current $121/metric tonne of carbon dioxide to $185-190/metric tonne of carbon dioxide.

[26] Justin Gundlach and Iliana Paul. "The Social Cost of Greenhouse Gases: A Guide for State Officials," 2022.
[27] Rennert et al. "Comprehensive Evidence Implies a Higher Social Cost of CO2," 2022.
[28] Justin Gundlach and Iliana Paul. "The Social Cost of Greenhouse Gases: A Guide for State Officials," 2022.

Additional research and analysis (beyond the scope of this report) could develop updated year-by-year estimates that include additional damages and identify additional applications for the social costs of greenhouse gases in climate-related policy. However, research conducted for this report confirms there is updated, credible, publicly available research that suggests the value currently being used in Vermont is no longer up to date.

In addition, it is important to note that it is possible (and likely) that even the most recent national estimates *underestimate* the true social cost of greenhouse gas emissions, since there are projected damages not yet included in the GIVE model used to develop the values. Furthermore, it is reasonable to expect that the upcoming final publication and public release of the EPA's most recent work and anticipated model revisions from RFF-Berkeley will result in changes to the updated estimates. Such future additional updates may continue to inform similar updates in Vermont moving forward. These conclusions are summarized as follows:

1. New research and analysis have been completed at the national level by Resources for the Future-Berkeley and the EPA since the 2021 CAP was approved by the Vermont Climate Council. The value for the social cost of carbon dioxide used during development of the Vermont Climate Action Plan (referred to as the "social cost of carbon" in the CAP) was a mean value of $121/metric tonne, and the value refers to the impacts of a pulse of emissions in 2020. This value was based on the best available information at that time. Since then, RFF-Berkeley has estimated the comparable social cost of carbon dioxide estimate to be $185/metric tonne, and the EPA has developed an estimate of $190/metric tonne.

2. In the 2021 Vermont CAP, the Vermont Climate Council committed to revising the social costs of greenhouse gases as new research and analysis become available. The development phase of the upcoming 2025 Vermont CAP will be a key time to do so.

3. The estimates by RFF-Berkeley and the EPA are likely to underestimate the true social costs of greenhouse gases, since their damages modules lack impacts on morbidity, biodiversity, and ecosystem services, among others. Researchers continue to update and add to the available models, as work continues on this important topic.

Appendix A: EPA External Review Draft Social Costs of Carbon Dioxide, Methane, and Nitrous Oxide[29]

A.4. Annual Unrounded SC-CO_2, SC-CH_4, and SC-N_2O Values, 2020-2080

Table 4.2.1: Unrounded SC-CO_2, SC-CH_4, and SC-N_2O Values, 2020-2080

	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	117	193	337	1,257	1,648	2,305	35,232	54,139	87,284
2021	119	197	341	1,324	1,723	2,391	36,180	55,364	88,869
2022	122	200	346	1,390	1,799	2,478	37,128	56,590	90,454
2023	125	204	351	1,457	1,874	2,564	38,076	57,816	92,040
2024	128	208	356	1,524	1,950	2,650	39,024	59,041	93,625
2025	130	212	360	1,590	2,025	2,737	39,972	60,267	95,210
2026	133	215	365	1,657	2,101	2,823	40,920	61,492	96,796
2027	136	219	370	1,724	2,176	2,910	41,868	62,718	98,381
2028	139	223	375	1,791	2,252	2,996	42,816	63,944	99,966
2029	141	226	380	1,857	2,327	3,083	43,764	65,169	101,552
2030	144	230	384	1,924	2,403	3,169	44,712	66,395	103,137
2031	147	234	389	2,002	2,490	3,270	45,693	67,645	104,727
2032	150	237	394	2,080	2,578	3,371	46,674	68,895	106,316
2033	153	241	398	2,157	2,666	3,471	47,655	70,145	107,906
2034	155	245	403	2,235	2,754	3,572	48,636	71,394	109,495
2035	158	248	408	2,313	2,842	3,673	49,617	72,644	111,085
2036	161	252	412	2,391	2,929	3,774	50,598	73,894	112,674
2037	164	256	417	2,468	3,017	3,875	51,578	75,144	114,264
2038	167	259	422	2,546	3,105	3,975	52,559	76,394	115,853
2039	170	263	426	2,624	3,193	4,076	53,540	77,644	117,443
2040	173	267	431	2,702	3,280	4,177	54,521	78,894	119,032
2041	176	271	436	2,786	3,375	4,285	55,632	80,304	120,809
2042	179	275	441	2,871	3,471	4,394	56,744	81,714	122,586
2043	182	279	446	2,955	3,566	4,502	57,855	83,124	124,362
2044	186	283	451	3,040	3,661	4,610	58,966	84,535	126,139
2045	189	287	456	3,124	3,756	4,718	60,078	85,945	127,916
2046	192	291	462	3,209	3,851	4,827	61,189	87,355	129,693
2047	195	296	467	3,293	3,946	4,935	62,301	88,765	131,469
2048	199	300	472	3,378	4,041	5,043	63,412	90,176	133,246
2049	202	304	477	3,462	4,136	5,151	64,523	91,586	135,023
2050	205	308	482	3,547	4,231	5,260	65,635	92,996	136,799

[29] U.S. Environmental Protection Agency. "EPA External Review Draft of Report on the Social Cost of Greenhouse Gases: Estimates Incorporating Recent Scientific Advances," 2022.

Appendix B: Resources for the Future – U.C. Berkeley Social Costs of Carbon Dioxide, Methane, and Nitrous Oxide[30]

	Social Cost of Carbon Dioxide (2020 $/metric tonne)	Social Cost of Methane (2020 $/metric tonne)	Social Cost of Nitrous Oxide (2020 $/metric tonne)
2020	$185	$1,939	$54,820
2030	$226	$2,916	$68,853
2040	$263	$4,067	$82,072
2050	$329	$5,447	$99,665
2060	$368	$7,079	$120,205
2070	$423	$8,743	$140,887
2080	$482	$10,519	$162,437
2090	$566	$13,136	$190,611
2100	$663	$15,872	$225,540

[30] Brian Prest et al. "Social Cost of Carbon Explorer," 2022.

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