Response of RFI Development of a Climate Superfund Cost Recovery Program

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Scope of this response to the RFI

In this RFI we provide a response to question number 2 of the RFI: "*Describe a stepwise process to develop the cost to Vermont of the covered greenhouse gas emissions. In doing so, identify the data sets available and describe the methodology and research approach to develop: (1) a summary of the various cost-driving effects of covered greenhouse gas emissions on the State of Vermont, including effects on public health, natural resources, biodiversity, agriculture, economic development, flood preparedness and safety, housing, and any other effects that may be relevant; (2) a categorized calculation of the costs that have been incurred and are projected to be incurred in the future within the State of Vermont of each of the effects identified under subdivision (1) of this section; and (3) a categorized calculation of the costs that have been incurred and are projected to be incurred in the future within the State of Vermont to abate the effects of covered greenhouse gas emissions from between January 1, 1995 and December 31, 2024 on the State of Vermont and its residents. Provide an evaluation of the comprehensiveness and accuracy of available data sets, methodology, and research to develop the cost to Vermont of the covered greenhouse gas emissions".*

Summary

In response to a part of the State of Vermont's Request for Information under Law 122, the Climate Superfund Law, we propose a comprehensive methodology to assess both past and future losses created by greenhouse gas (GHG) emissions from 1995 to 2024. Our methodology is straightforward, transparent, and grounded in established methods and peer-reviewed literature. The methodology consists of the following steps: (1) establishing Vermont's climate hazard profile; (2) applying probabilistic event attribution to determine, for each identified climate hazard, the fraction of risk attributable to anthropogenic GHG emission between 1995 and 2024; (3) assessing the potential impacts of these hazards based on peer-reviewed studies; (4) identifying datasets to measure these impacts; (5) employing estimates from peer-reviewed literature when available, and using econometric techniques to quantify damages from extreme weather events when such estimates are not available; (6) projecting future losses using climate, demographic, and economic projections based on multiple Shared Socioeconomic Pathways (SSPs) and Representative Concentration Pathways (RCPs); and (7) reporting total losses attributable to anthropogenic climate change from 1995-2024 as well as projected future losses under several climate scenarios.

Methodology for Cost Assessment

Our proposed stepwise methodology is designed to identify, calculate, and categorize the costs that Vermont and its residents have incurred and are projected to incur due to climate change. The key steps are as follows:

Step 1: Vermont's Climate Hazard Profile

Vermont faces multiple climate-related hazards. These hazards can arise from both gradual changes in the climate system and extreme weather events. A preliminary review based on the Vermont Climate Assessment (Galford et al., 2021) suggests that key climate-related hazards that threaten Vermont include:

A. **Long-Term Changes in Temperature:** Vermont's average annual temperature has increased by nearly 2°F since 1900, and rising temperatures are projected to continue to increase. Winters have warmed 2.5 times faster than the annual average since 1960. This warming trend is also expected to increase damaging freeze-thaw cycles and reduce snow cover.
B. **Extreme Cold:** Vermont still experiences extreme cold during the winter, but these events have become less frequent and severe.
C. **Extreme Heat:** Rising temperatures have increased extreme heat days. This warming trend is expected to continue, with more frequent and intense heatwaves during the summer.
D. **Long-Term Changes in Precipitation:** Vermont has experienced long-term shifts in precipitation patterns, such as changes in seasonal rainfall. Overall precipitation has increased by 21% since 1900.
E. **Heavy Rainfall and Flooding:** Vermont has experienced an increase in heavy rainfall events, with 2.4 additional days of extreme precipitation annually compared to the 1960s. This trend is expected to continue, increasing the risk of flash floods, river flooding, urban flooding, and landslides.
F. **Drought Conditions**: While overall precipitation has increased, Vermont still faces prolonged dry spells and droughts as rising temperatures accelerate evaporation and disrupt seasonal precipitation patterns. These drought events are expected to persist, with future climate scenarios predicting more pronounced drought conditions.
G. **Snowstorms and Ice Storms:** Despite warming winters, Vermont remains vulnerable to extreme snow and ice storms. While snow events may become less frequent, ice storms are projected to become more severe as winters warm, leading to increased weather hazards during the winter months.
H. **Extratropical Cyclones:** Vermont occasionally experiences extratropical cyclones, which bring strong winds, heavy rainfall, and sometimes snow. These storms are projected to intensify as climate change progresses, with increased moisture potentially making them more severe.
I. **Wildfires**: Forest fires have historically been rare in Vermont due to its humid climate, but climate change raises the risk. Warming temperatures, prolonged dry spells, and forest vulnerabilities from pests are creating conditions more conducive to wildfires.

Step 2: Computing the Fraction of Attributable Risk

To determine the extent to which climate impacts in Vermont are attributable to human-induced GHG emissions, we propose using Probabilistic Event Attribution (PEA). This methodology is well suited for understanding how extreme weather events have evolved and become more severe due to anthropogenic climate change. It is increasingly used in legal and financial contexts, where it helps assign responsibility for climate-related damages, enabling governments and corporations to hold polluters accountable. The PEA methodology is well-established, with clear guidelines from sources such as the National Academy of Science (NAS, 2016) and the Sixth Assessment of the Intergovernmental Panel on Climate Change (IPCC, 2021).

Outline of the event attribution methodology:

A. **Climate Modeling**: We will utilize state-of-the-art climate models to simulate weather events under two scenarios: one with the influence of human-induced GHG emissions (the "factual" world) and one without these emissions (the "counterfactual" world). By comparing these simulations, we can quantify the specific impact of anthropogenic climate change on extreme weather events.

   For this analysis, we will leverage models commonly used in event attribution studies, such as the Hadley Centre Global Environment Model (HadGEM3-A) and the Community Earth System Model (CESM). These global models are highly suitable for understanding large-scale climate drivers. Additionally, to better capture Vermont's unique geography and local weather patterns, we will employ regional climate models capable of high-resolution downscaling, such as the Weather Research and Forecasting (WRF) Model and the Coordinated Regional Climate Downscaling Experiment (CORDEX). These models will allow for more precise simulations of local conditions, ensuring our results are tailored to Vermont's specific climate dynamics.

B. **Probability Analysis**: A critical aspect of event attribution is determining how much more likely or severe specific extreme events have become due to human activities. This is done by calculating the probability of an event occurring in both the "factual" world, influenced by human-induced GHG emissions, and the "counterfactual" world, without those emissions. By comparing these probabilities, we can quantify the extent to which climate change has increased the frequency and intensity of extreme events, providing a clear, data-driven measure of its impact.

C. **Fraction of Attributable Risk (FAR)**: A key metric for this analysis is the FAR, which calculates the proportion of an event's likelihood that can be directly linked to anthropogenic climate change. FAR is essential for understanding how much of the risk associated with extreme weather events can be attributed to human-induced warming.

By calculating FAR for extreme events, we can provide a scientifically grounded estimation of the portion of risk specifically attributable to greenhouse gas emissions.

FAR is defined as:

$$FAR = 1 - \frac{P0}{P1},$$

Where P0 is the estimated probability of an event occurring in the absence of human influence on the climate (the "counterfactual" world), and P1 is the estimated probability of an event occurring in a world with human influence (the "factual" world).

D. **Hazard-specific FARs**
The hazards that are most relevant to Vermont include:

- Heavy Rainfall and Flooding
- Extreme Heat
- Extreme Cold
- Droughts
- Extreme Snowstorms and Ice Storms
- Extratropical Cyclones
- Long-term Changes in Temperature
- Long-term Changes in Precipitation

By calculating a separate FAR for each hazard, we can conduct a highly localized, event-specific, and long-term analysis of how anthropogenic climate change has influenced the frequency, intensity, and shifts in these events and patterns across Vermont. This approach captures both immediate hazards and evolving climate trends.

Step 3: Identifying Possible Impacts

The potential impacts of climate change in Vermont, driven by the climate-related hazards outlined in Step 1, encompass a wide range of damages, including direct damages (e.g., infrastructure destruction from flooding) and indirect effects (e.g., economic losses from disrupted supply chains), market impacts (e.g., crop failures) and non-market impacts (e.g., loss of biodiversity), tangible damages (e.g., damaged roads) and intangible losses (e.g., cultural heritage loss), as well as both immediate (e.g., storm-related destruction) and long-term consequences (e.g., ecosystem degradation). A preliminary review of the literature, including the Vermont Climate Assessment (Galford et al., 2021) and studies on climate damage functions (Auffhammer, 2018; Botzen et al., 2019; Tol, 2024), highlights several key potential impacts. It is important to note that the following is not an exhaustive list of potential damages and may evolve as climate conditions continue to shift.

A. **Infrastructure and Property Damage**: Flooding, heavy rainfall, snowstorms, ice storms, freeze-thaw cycles, and landslides can cause substantial damage to infrastructure and property, including roads, bridges, public utilities, and residential and commercial buildings, and necessitate significant emergency response efforts, all of which impose financial burdens on state and local resources.

B. **Economic Activity Disruptions**: Flooding, heavy rainfall, snowstorms, ice storms, freeze-thaw cycles, and landslides can significantly disrupt economic activities across various sectors. These events cause road closures, power outages, and interruptions to supply chains, leading to extended business downtimes and the interruption of public services including medical care and education. Sectors such as tourism and manufacturing are particularly vulnerable, facing revenue losses, operational delays, and increased costs due to weather-related disruptions and power failures.

C. **Public Health Concerns**: Vermont is facing growing public health risks due to rising temperatures and erratic weather patterns. Heatwaves are becoming more frequent, increasing the risk of heat-related illnesses, particularly among vulnerable populations, and driving up the demand for cooling. Warmer, wetter conditions are also fostering the spread of vector-borne diseases like Lyme disease and West Nile virus by supporting tick and mosquito populations. Additionally, local and Canadian wildfires are worsening air quality, leading to higher rates of respiratory and cardiovascular conditions.

D. **Agricultural and Forestry Impacts**: Although longer growing seasons may benefit some crops and tree species, erratic freeze-thaw cycles, shifting precipitation patterns, and increased pest pressures contribute to crop failures and reduced forest health, leading to reduced productivity. Droughts during the growing season further threaten agriculture by reducing water availability and stressing crops. Key industries in Vermont, such as apple orchards and maple syrup production, are especially vulnerable to these climate changes, which can result in significant economic losses.

E. **Water Resources and Quality**: Increased heavy precipitation events lead to higher streamflows, contributing to erosion and nutrient runoff that harm water quality. These conditions are also conducive to harmful algal blooms in Vermont's lakes and rivers, threatening both ecosystems and human health. Reduced winter snowpack due to warming winters affects water availability during spring and summer, impacting both agriculture and municipal water supplies.

F. **Ecosystem and Biodiversity Impacts**: Vermont's iconic species, like the sugar maple, are increasingly at risk. Invasive species and forest pests, such as the emerald ash borer, further compound these risks, threatening the health of Vermont's forests and reducing biodiversity. Shifts in habitat and biodiversity could affect Vermont's wildlife, impacting recreational activities like hunting and fishing. Species migration or population decline could hurt the local economy and traditional cultural practices.

G. **Tourism and Recreation Impacts**: Sectors like tourism, especially winter sports, face revenue losses due to shorter winters and reduced snowfall. Additionally, increased summer temperatures and water quality issues may threaten recreational activities like lake-based tourism.

H. **Energy Production Disruptions**: Drought conditions can significantly reduce hydropower production, Vermont's primary energy source, while wildfire smoke plumes can reduce solar power efficiency. These disruptions force the state to rely on dirtier and more expensive fossil fuels to meet energy demand, leading to higher electricity costs.

Strong wind and ice storms can also damage energy infrastructure, resulting in temporary power outages.

I. **Financial Strain on Local Governments**: Climate change could lead to lost revenue for local governments due to reduced tourism, lower property values, and disruptions in key industries such as agriculture. Additionally, more frequent extreme weather events may lead to higher borrowing costs, particularly if local governments face rising insurance costs or credit downgrades. The need to finance large-scale infrastructure repairs and resilience projects could further strain public resources.

Step 4: Data Collection and Evaluation of Available Datasets for Computing Damages

Accurate cost assessment of potential impact requires reliable data. Unless specified as confidential or proprietary, all datasets are publicly accessible. Many of the confidential or proprietary datasets listed are likely to be made available with some restrictions for government or non-profit use.

Datasets for Measuring Extreme Weather Events

1. **ERA5 (ECMWF Reanalysis Dataset):** Provides high-resolution, hourly data on key climate variables such as temperature, precipitation, wind speed, and snow depth. With data spanning from 1950 to the present, ERA5 allows for detailed analysis of extreme weather events, including heatwaves, heavy rainfall, snowstorms, and droughts. Its global coverage and 31 km spatial resolution make it ideal for tracking localized weather patterns in Vermont.
2. **National Oceanic and Atmospheric Administration (NOAA) National Centers for Environmental Information (NCEI) Storm Events Database**: Provides comprehensive data on severe weather events such as floods, snowstorms, hurricanes, and heatwaves. This dataset is useful for tracking the frequency and intensity of extreme weather events, including flooding, extreme rainfall, and cold/heat extremes, across Vermont.
3. **PRISM Climate Group (Oregon State University)**: Offers high-resolution climate data on temperature, precipitation, and extreme weather events. PRISM is particularly useful for analyzing extreme heat events, precipitation variability, and long-term climate trends.
4. **USGS National Water Information System (NWIS)**: Provides streamflow and river gauge data, essential for assessing flood risk and understanding the impacts of increased precipitation on Vermont's water resources. NWIS helps monitor river conditions and flooding potential over time.
5. **National Interagency Fire Center (NIFC) Wildfire Data**: This dataset tracks wildfire incidents, including information on fire size, location, containment efforts, and damage to property. It also includes data on the number of structures lost, injuries, and fatalities. This dataset is valuable for understanding the frequency, severity, and economic impacts

of wildfires on both residential and non-residential properties. For Vermont, it could help assess the growing risk of wildfires due to climate change and the economic implications for affected communities.

6. **PM2.5 Concentration Dataset (Van Donkelaar et al., 2021)**: Because negative air-quality effects can also be driven by fires elsewhere it is also important to be able to measure change in air-pollution. This geophysical-hybrid dataset estimates PM2.5 concentrations by combining data from satellite observations, chemical transport models, and ground-based monitors. It provides monthly estimates at a spatial resolution of 0.01°x0.01° between 1998 and 2021.
7. **EPA Air Quality System (AQS)**: This dataset, maintained by the U.S. Environmental Protection Agency (EPA), contains detailed measurements of air pollutant concentrations, including ozone (O_3), particulate matter ($PM_{2.5}$ and PM_{10}), carbon monoxide (CO), sulfur dioxide (SO_2), and nitrogen dioxide (NO_2). The data is collected from thousands of monitoring stations across the U.S., including Vermont, and is valuable for assessing the impact of greenhouse gas emissions on air quality and public health.
8. **IBTrACS (International Best Track Archive for Climate Stewardship)**: IBTrACS is a global hurricane and tropical storm tracking database that consolidates data from multiple sources. It includes detailed information on storm tracks and intensities, which can be helpful in assessing the long-term trends and risks posed by extratropical cyclones to regions like Vermont, where remnants of storms might have an impact.

Datasets for Measuring Projected Extreme Weather Events

9. **HadGEM3-A (Hadley Centre Global Environment Model)**: A global climate model that is particularly adept at simulating extreme weather events and their future intensification due to climate change. HadGEM3-A can be used to project changes in the frequency and severity of storms, extreme heat events, and rainfall in Vermont under various greenhouse gas emission scenarios.
10. **CESM (Community Earth System Model)**: A comprehensive earth system model that provides detailed projections of future climate extremes such as temperature, precipitation, and wind patterns. CESM is widely used for simulating future climate scenarios with anthropogenic forcing and is suitable for studying Vermont's projected temperature extremes, heavy precipitation events, and shifts in seasonal patterns.
11. **CORDEX (Coordinated Regional Climate Downscaling Experiment)**: Provides high-resolution downscaled climate projections for North America, including Vermont. With spatial resolutions as fine as 25 km, CORDEX is suitable for modeling future extreme weather events like heat waves, extreme rainfall, and droughts. The data is based on global climate models (GCMs) under various Shared Socioeconomic Pathways (SSPs) and Representative Concentration Pathways (RCPs), allowing for projections of future climate conditions and their impacts on local scales.
12. **WRF (Weather Research and Forecasting Model)**: A regional climate model that can be used to downscale global projections and simulate future extreme weather events at high resolution. WRF is highly flexible and capable of providing detailed insights into

localized extreme weather patterns in Vermont, such as changes in snowfall, rainfall intensity, and heatwave frequency.

Datasets for Measuring Exposure to Hazards

13. **Global Human Settlement Layer (GHSL) Database**: This dataset provides population data at a 100-meter spatial resolution, available at five-year intervals. It integrates remote-sensed volumetric information on residential structures and census data to estimate population distribution. This information is useful for analyzing population exposure to environmental risks and impacts from natural disasters.
14. **FEMA Flood Insurance Rate Maps (FIRM)**: These maps provide detailed, official flood hazard boundaries for areas in the U.S., used to determine flood risks and insurance requirements. The FIRM maps identify Special Flood Hazard Areas (SFHAs) and flood zones based on the likelihood of flooding. This dataset is essential for assessing flood risks to properties, infrastructure, and populations, and it is widely used for disaster planning, flood insurance determinations, and mitigation strategies.
15. **First Street Foundation Flood Risk Maps (<u>Proprietary dataset</u>)**: This dataset provides detailed, property-level flood risk assessments across the United States. Unlike FEMA maps, which focus on historical flood risks, the First Street Foundation maps include current and future risk projections based on climate change models, offering insights into both coastal and inland flood risks. These maps are valuable for understanding how flood exposure may evolve, providing critical information for homeowners, developers, insurers, and policymakers.
16. **CoreLogic Tax and Deed Data (<u>Proprietary dataset</u>)**: This dataset provides detailed parcel-level information on home characteristics, including location, value, number of stories, number of bedrooms, and proximity to hazard-prone areas. This data is crucial for assessing housing vulnerability to natural disasters. It enables analysis of how home size, value, and location influence the costs and risks associated with defending properties during extreme weather events. For Vermont, this data could be used to evaluate risks in residential areas and the economic burden of protecting homes.
17. **SafeGraph Mobility Data <u>(Proprietary dataset)</u>**: This dataset provides detailed, anonymized data on mobility patterns derived from smartphones. It measures the percentage of individuals who are completely at home or away from home on any given day. This can be used to assess behavioral responses to extreme events in Vermont by tracking how individuals modify their movements and sheltering behavior in response to hazardous environmental conditions.
18. **U.S. Geological Survey National Land Cover Database (NLCD)**: Provides classifications of developed land areas based on impervious surface percentages. This dataset is used to determine the portion of developed land within Census blocks, which can be helpful for estimating flood exposure and potential damage.
19. **U.S. Geological Survey National Elevation Dataset (NED)**: Offers elevation data, essential for understanding flood risk and assessing the vulnerability of different regions to floods.

20. **FEMA Flood Insurance Policies Dataset**: This dataset contains data on the number of active flood insurance policies in each region, providing a detailed view of flood insurance coverage across various geographical areas. It helps in understanding the extent to which households are insured against flood risks and can be used to evaluate the impact of flood insurance on post-disaster recovery.
21. **U.S. Army Corps of Engineers – National Levee Database**: Tracks levee conditions and flood-related damages. It is useful for assessing the direct financial losses due to levee failures or flood defense infrastructure damages, particularly in flood-prone areas of Vermont.
22. **US EPA Environmental Justice Screening and Mapping Tool (EJSCREEN)**: Provides data on environmental and climate-related public health risks, particularly in vulnerable communities. EJSCREEN can be used to identify populations at greater risk for health impacts from extreme weather events, such as heatwaves and flooding.

Datasets for Measuring Direct and Indirect Economic Losses

23. **SHELDUS (Spatial Hazard Events and Losses Database for the United States):** Provides county-level data on human health impacts and property losses from natural hazards, including extreme weather events like floods, heatwaves, and snowstorms. SHELDUS tracks information on injuries, fatalities, and the economic costs associated with these events, making it useful for understanding the direct impacts of severe weather on public health and well-being in Vermont.
24. **NOAA Billion-Dollar Weather and Climate Disasters Database**: Tracks major U.S. weather and climate events that result in significant economic losses. The dataset provides estimates of direct damages caused by extreme events such as floods, droughts, heatwaves, and snowstorms, making it useful for quantifying large-scale financial impacts on property and infrastructure.
25. **EM-DAT (Emergency Events Database)**: A global database that provides comprehensive data on the occurrence and impacts of disasters, including extreme weather events such as floods, storms, droughts, and heatwaves. EM-DAT tracks economic losses, damage to infrastructure, and impacts on human life, making it useful for measuring direct losses from major weather events in Vermont. The dataset includes estimates of damages to property, agriculture, and public infrastructure, as well as the number of people affected or displaced
26. **FEMA Disaster Declarations**: Contains detailed records of federally declared disasters, including data on public and individual assistance provided. This dataset is valuable for assessing direct losses in terms of damage to infrastructure, homes, and businesses due to extreme weather events like floods, storms, and snowstorms.
27. **FEMA Public Assistance Grant Program (PAGP)**: FEMA's program includes economic loss estimates at the county level, particularly in relation to infrastructure damages and recovery costs. This data can indirectly reflect GDP losses due to extreme weather events.
28. **National Flood Insurance Program (NFIP) Claims Data**: This dataset includes detailed records of flood insurance claims, payouts, and policyholder information. It is particularly

valuable for measuring the direct financial impacts of flooding on homeowners and businesses, as well as understanding the distribution of insurance benefits across different income groups. For Vermont, NFIP claims data can help assess the economic burden of flooding on property owners and the effectiveness of flood insurance in mitigating losses.

29. **Insurance Claims Data (Proprietary datasets)**: This datasets can be accessed via state insurance regulators, private insurers, or through agreements with reinsurance companies such as Munich Re NatCAT or Swiss RE Sigma. These datasets contain information on claims filed due to weather-related damages, particularly property damage and business interruption. Insurance claims data is crucial for measuring direct financial losses to households, businesses, and farms due to extreme weather events like floods and storms.
30. **Small Business Administration (SBA) Federal Disaster Loan Program Data**: This dataset contains administrative data on over one million loan applications from households impacted by natural disasters. It includes detailed information on loan amounts, interest rates, credit scores, and home damage assessments. This dataset is essential for understanding the financial strain on households and the demand for credit to repair housing after natural disasters. It can be used to analyze how extreme weather events affect household borrowing behavior and credit demand in Vermont.
31. **First Data (Fiserv) Transaction-Level Dataset (Proprietary dataset):** Provides detailed, daily transaction data at the zip code level, distinguishing between in-store and online sales across various industries. This dataset can be used to track the economic impacts of extreme weather events on business activity and consumer spending. It is particularly useful for assessing the resilience of local businesses in Vermont's tourism, retail, and hospitality sectors during and after events like floods, snowstorms, or heatwaves.
32. **Federal Reserve Y-14M Dataset (Confidential dataset)**: This dataset collects detailed monthly loan-level data on credit cards and mortgages from large bank holding companies. It includes information on credit terms, balances, payments, and performance at the ZIP+4 level. This dataset is valuable for analyzing household borrowing behaviors in response to natural disasters, it can also be used to track short and long-run migration.
33. **Equifax Credit Dataset (Confidential dataset):** provides detailed consumer credit information, including credit scores, credit inquiries, and outstanding balances. This data can be used to assess the financial impacts of disasters on individuals and communities by tracking changes in credit behavior, delinquency rates, and overall financial health before and after natural disaster events. It is particularly useful for evaluating how disasters influence borrowing behavior and financial recovery.
34. **BEA Local Area Gross Domestic Product (GDP) Data**: The U.S. Bureau of Economic Analysis (BEA) provides county-level GDP data. This dataset allows for tracking the economic output of counties over time and understanding how extreme weather events, such as floods or droughts, affect local economies, including agriculture, manufacturing, and services sectors in Vermont.

35. **BLS Quarterly Census of Employment and Wages (QCEW)**: While not a direct measure of GDP, the QCEW provides employment and wage data at the county level, which can serve as a proxy for economic activity. This data helps track disruptions in the workforce and economic output caused by extreme weather events.
36. **Longitudinal Employer-Household Dynamics (LEHD) Program Data**: Provides detailed administrative data on employment, wages, and earnings for individuals, linked to employer information. This dataset tracks labor market dynamics over time, making it ideal for assessing the long-term impacts of extreme weather events, such as hurricanes or storms, on employment and income trends. It is particularly useful for analyzing how climate-related events affect workers and businesses in specific regions, including Vermont.
37. **IRS Administrative Tax Data (<u>confidential dataset</u>)**: This dataset contains individual federal tax return records, along with third-party information returns (e.g., W-2s and 1099-MISCs). It can be used to track the pre- and post-disaster earnings, residence, and demographic information of affected individuals. The data allows for a detailed analysis of the long-term economic impacts on individuals and families, such as changes in employment and income over time.
38. **Social Security Administration (SSA) Data (<u>confidential dataset</u>)**: Provides comprehensive records on individual earnings, employment history, and benefit claims. This dataset is valuable for analyzing the long-term financial and employment impacts of natural disasters, particularly on individuals receiving Social Security benefits. It can be used to track changes in employment patterns, earnings, and benefit claims in the aftermath of extreme weather events.
39. **Vermont Agency of Transportation (VTrans) Damage Reports**: This dataset is not available online, but the website indicates that information on road and infrastructure damage caused by extreme weather events is being recorded. These administrative records would be useful to determine direct losses to transportation infrastructure due to flooding, snowstorms, and other weather-related incidents.
40. **Vermont Emergency Management (VEM) Damage Assessment Reports**: This dataset is not available online, but the website indicates that local-level damage assessment reports following extreme weather events are performed. These administrative records would help quantify direct losses to public infrastructure, private property, and businesses in Vermont.
41. **National Oceanic and Atmospheric Administration (NOAA) – Tourism and Recreation Satellite Accounts (TRSA)**: Offers detailed data on the economic impact of weather and climate on outdoor tourism and recreation activities, including winter sports and lake-based tourism. This dataset is useful for tracking how changes in snowpack, temperature, and precipitation affect Vermont's tourism industry.
42. **Dartmouth (University of Colorado) Flood Observatory (DFO)**: Provides data on flood locations, timing, duration, and impact. It also includes detailed inundation maps for certain flood events, making it valuable for analyzing the geographic scope and severity of flooding events in Vermont or other regions. The dataset spans multiple years and covers global flood events, including damage estimates and displaced populations.

43. **National Historical Geographic Information System (NHGIS)**: This dataset provides county-level data on population, housing stock, median family income, and poverty rates in the U.S. It is valuable for measuring the economic impacts of natural disasters, including the effects on housing prices, migration, and income levels.

Datasets for Measuring Agricultural and Biodiversity Losses

44. **USDA Crop Loss Data (RMA)**: The U.S. Department of Agriculture's Risk Management Agency (RMA) provides data on insured crop losses due to weather-related events such as droughts, floods, and freezes. This dataset includes information on crop insurance claims, indemnity payments, and the causes of crop loss, making it essential for tracking financial losses in Vermont's agricultural sector.
45. **USDA National Agricultural Statistics Service (NASS)**: NASS offers detailed agricultural statistics, including data on crop yields, livestock losses, and farm income. This dataset is valuable for understanding the broader impacts of extreme weather events on agricultural productivity, particularly in key industries such as apple orchards and maple syrup production in Vermont.
46. **USDA Farm Service Agency (FSA) Disaster Assistance Programs Data**: Provides information on financial assistance provided to farmers impacted by natural disasters, including extreme weather events. This includes payments from programs such as the Livestock Indemnity Program (LIP) and Emergency Assistance for Livestock, Honeybees, and Farm-Raised Fish (ELAP), which track the losses faced by Vermont farmers due to extreme weather.
47. **USDA CropScape (National Agricultural Statistics Service)**: A geospatial dataset providing crop-specific data that can help assess agricultural losses over time due to extreme weather events like flooding and drought. CropScape allows users to visualize the impacts of these events on different crop types in Vermont.
48. **National Drought Mitigation Center (NDMC) – Drought Impact Reporter**: Tracks reports of drought-related impacts on agriculture, such as reduced crop yields, livestock stress, and water shortages. This dataset helps monitor drought conditions and their effects on farming communities in Vermont.
49. **USDA Economic Research Service (ERS)**: Provides data on farm income and agricultural productivity at the county level, which contributes to understanding the agricultural sector's contribution to local GDP, especially after weather-related disruptions.
50. **BioTIME database**: To assess the environmental impacts of economic activities on biodiversity, we recommend utilizing the BioTIME database, which compiles longitudinal ecological sampling information from tens of thousands of locations across the United States. This dataset includes measures of species abundance, richness, and stability over time and is particularly useful for analyzing biodiversity loss linked to economic production and climate change. BioTIME can capture changes in species composition and ecosystem health, providing key insights into the indirect, non-market impacts of climate-related hazards on biodiversity and ecosystem services.

Datasets for Measuring public health impacts

51. **CDC WONDER (Wide-ranging Online Data for Epidemiologic Research)**: Provides access to a wide array of public health data, including mortality and morbidity statistics related to extreme weather events. CDC WONDER can be used to track health impacts such as heat-related illnesses, respiratory issues due to poor air quality, and vector-borne diseases like Lyme disease and West Nile virus.
52. **Vermont Department of Health – Climate and Health Data**: Offers localized data on health impacts associated with climate change and extreme weather events, including heat-related illnesses, tick-borne diseases, and asthma exacerbations from poor air quality. This dataset is essential for tracking public health outcomes in Vermont, which are specifically tied to weather patterns.
53. **National Environmental Public Health Tracking (CDC)**: This system provides data on health outcomes associated with environmental conditions, including extreme heat, air quality, and waterborne diseases. It is particularly useful for analyzing trends in climate-related health impacts, such as heat-related hospitalizations or emergency room visits.
54. **U.S. Centers for Disease Control and Prevention (CDC) Heat and Health Tracker**: A specific tool that monitors heat-related health impacts, such as heat stress illnesses, across the U.S. It includes real-time data on temperature anomalies and heat-related health outcomes, making it ideal for tracking the public health impacts of extreme heat events in Vermont.
55. **National Notifiable Diseases Surveillance System (NNDSS)**: Provides data on vector-borne diseases such as Lyme disease and West Nile virus, which are influenced by weather patterns. This dataset allows for tracking the prevalence of diseases linked to extreme weather, such as warmer temperatures and increased humidity.
56. **Medicare Claims Data (<u>confidential dataset</u>)**: Provides detailed records of healthcare service utilization, including elective and emergency services. This dataset can be used to assess how extreme weather events, such as snowstorms, disrupt healthcare services in Vermont. It is especially valuable for tracking indirect impacts on public health, including delays or cancellations of medical treatments and increased emergency room visits during extreme weather events.

Datasets for Measuring impact on local Governments

57. **Census of Governments Dataset**: This dataset provides comprehensive information on local government revenues, expenditures, and debt. It is ideal for assessing fiscal impacts related to infrastructure and public service disruptions caused by extreme weather events.
58. **Moody's Municipal Bond Ratings <u>(Proprietary dataset)</u>**: This dataset tracks bond ratings and default risks for municipalities. It is useful for understanding how extreme weather events affect local government borrowing costs and creditworthiness.

Step 5: Computing Retrospective Damages

To assess the losses of various climate hazards that Vermont has experienced, we estimate the relationship between losses and each hazard that affected the state between 1995 and 2024. Because some hazards may have more than one type of impact, several damage estimates may be associated with each hazard. For instance, rising temperatures would generate multiple types of damage, including, for example, reduced crop yields (e.g., Schlenker & Roberts, 2009) and increased mortality (e.g., Deschênes & Moretti, 2009).

Our approach to calculating total losses for each hazard is straightforward. Specifically, we multiply damage estimates by the number of events observed between 1995 and 2024 and by a measure of the population or assets exposed to each event. For instance, in the case of assessing excess mortality from heat, we would multiply the damage estimate (excess deaths per day above a critical temperature) by the number of days the state experienced such temperatures and the population exposed each day. This detailed process yields an estimate of excess deaths due to rising temperatures. A similar calculation is performed for crop damage and other temperature-related impacts. For non-monetary damages, such as lives lost, an additional step is taken to convert these into a monetary value using standard economic methods, such as the value of a statistical life. This process results in a time series of loss estimates for each hazard and impact type, which is converted to real terms using a price index before being summed up to compute total damages per hazard.

Next, to determine the losses caused by anthropogenic GHG emission, we multiply the estimated losses by hazard derived in the previous step by the hazard-specific FARs derived in step 2. Last, we sum the resulting series to estimate the losses incurred by the state of Vermont and its residents due to anthropogenic GHG emissions. Note that our retrospective damage calculation implicitly includes the benefits of some adaptation measures, as costs and damages have occurred within the context of past adaptation actions. Therefore, our estimates reflect only the impacts after adaptation and do not capture the full costs of climate change, which would include the expenses of these past adaptation efforts.

Outline of the retrospective damage calculation:

A. To estimate the losses associated with each hazard, we will employ a combination of methodologies:
   i. Literature Review and Extrapolation: We will begin by reviewing existing studies on climate-related damages. When relevant studies are available, we will extrapolate their findings to Vermont, adjusting for local conditions such as geography, economy, and demographics. This approach ensures that we build on established research while tailoring estimates to Vermont's unique context.
   ii. Panel Data Analysis: In cases where no specific studies are available for Vermont, we will estimate the relationship between climate hazards (such as extreme heat) and economic losses using well-established panel data methods (Kolstad and Moore, 2020). Panel fixed effects regression will allow us to isolate

the impact of the hazard on economic outcomes. This method helps control for unobserved factors that are time-invariant or common factors for the region that are time-varying. Importantly, this method will give us a clearer picture of the true cost associated with the hazard.

iii. Synthetic Control Methods: For climate hazards that are intertwined with other factors influencing losses (for example, economic or policy changes), we will employ the synthetic control method. This technique allows us to create a "synthetic" Vermont based on data from other regions that did not experience the same hazard, helping us estimate what Vermont's losses would have been without the hazard. By comparing Vermont to its synthetic counterpart, we can better isolate the specific impact of the hazard.

B. Use datasets detailed in the section "Datasets for Measuring Extreme Weather Events" to calculate the number of events for each hazard of a specific magnitude.
C. Use datasets detailed in the section "Datasets for Measuring Exposure" to calculate the population and/or assets exposed to each event. The type of exposure considered will depend on the units in which the damage estimate is expressed, for example, the relevant exposure measure for excess mortality per million individuals above a certain temperature is population.
D. Multiply estimates from sub-steps A, B, and C to derive losses by hazard and type of impact.
E. If not expressed in dollars, convert loss estimates to a monetary metric using standard methods in economics.
F. Convert series to real terms using a price index.
G. Sum estimates of sub-step F to compute losses per hazard.
H. Multiply loss estimates derived in sub-step G by hazard-specific FAR (described in step 2).
I. Sum the loss estimates derived in sub-step H to compute the total *retrospective* losses incurred by the state of Vermont and its residents as a result of anthropogenic GHG emissions between (1995 and 2024).

Step 6: Computing Projected Damages

To estimate future damages, we will follow a procedure similar to step 5 (retrospective damages), but we will rely on climate and demographic projections to update key parts of the process. Specifically, for each hazard, we will calculate the number of future events using predictions from climate models. Additionally, we will rely on demographic and economic projections to update measures of exposure to these hazards. To ensure consistency across climate, demographic, and economic projections under different climate change scenarios, we will employ the well-established method of pairing Representative Concentration Pathways (RCPs), which outline potential greenhouse gas concentration trajectories, with Shared Socioeconomic Pathways (SSPs), which describe possible future societal trends. This approach allows us to generate robust projections of future risks and damages aligned across both environmental and socioeconomic factors. These projections do not explicitly account for policies or other endogenous responses that could be taken by the state of Vermont or its residents to reduce exposure and vulnerability to these hazards. Nonetheless, it is possible to extend this methodology to assess some of these options by introducing climate adaptation scenarios. See the adaptation subsection under section extensions for details.

Outline of the projected damage calculation:

A. Compute the frequency of hazards expected to affect Vermont by the end of the century using the climate models outlined in the section "Datasets for Measuring Projected Extreme Weather Events" under three climate change scenarios: low emissions scenario (SSP1-RCP2.6), middle-of-the-road scenario (SSP2-RCP4.5), and high emissions scenario (SSP5-RCP8.5).
B. Compute expected changes in exposure to population and assets based on the demographic and economic projections outlined in the same climate change scenarios (low, middle, high).
C. Multiply the damage estimates for each hazard by the projections of the event frequency (A) and the updated exposure (B).
D. If not expressed in dollars, convert loss estimates to a monetary metric using standard methods in economics.
E. Compute present value using a well-established discount factor.
F. Sum estimates of sub-step E to compute losses per hazard and climate scenario.
G. Using the climate models outlined in the section "Datasets for Measuring Projected Extreme Weather Events," compute hazard-specific Fraction of Attributable Risk (FAR) for each climate change scenario (low, middle, high).
H. Multiply loss estimates derived in sub-step F by hazard and climate change-specific FARs (computed in G).
I. Sum the loss estimates derived in sub-step H to compute total *future* losses incurred by the state of Vermont and its residents due to anthropogenic GHG emissions without the introduction of additional adaptation measures. Note that this calculation yields three total cost estimates (one for each SSP-RCP climate scenario).

Step 7: Computing Total Damages

After calculating both retrospective and future losses attributable to anthropogenic climate change, we will aggregate the results to provide comprehensive estimates of total losses for the state and its residents. Depending on the scope of interest, these estimates can be broken down into subtotals for specific impact types or sectors of the economy.

Extensions

Concurrent Hazards: An extension of this analysis could involve estimating damage functions that account for interactions between hazards, such as concurrent heatwaves and droughts or sequential events like heavy rainfall following a prolonged drought. These compound events can result in damages greater than the sum of individual events due to amplified impacts on infrastructure, ecosystems, and public health.

Intensification: The analysis could also be expanded to consider the potential intensification of climate hazards over time. For instance, repeated droughts may cause greater harm to agriculture as groundwater reservoirs become increasingly depleted. While such an analysis is feasible, it presents significant challenges, as it would require datasets spanning several decades.

Adaptation: The projection of damages in step 6 implicitly assumes that future damage estimates are not influenced by private or public adaptation to climate change, that is, actions that reduce future damages through the reduction in exposure and vulnerability to these hazards. Public adaptation includes actions such as building flood defenses, upgrading infrastructure, and implementing early warning systems. Private adaptation may involve different location decisions, retrofitting structures, adopting climate-resilient practices, or using risk transfer mechanisms like insurance. Our methodology could be extended to assess some of these adaptation measures, thereby decomposing the estimate of future damages into the direct cost associated with these adaptation actions and the residual climate damages (i.e., the losses that will continue to accrue after adaptation measures are implemented). This extension would directly address question 2(3) of the RFI: “incorporate the costs incurred and projected to be incurred to abate these effects.”

However, this extension requires several additional assumptions and clarifications. A non-exhaustive list of additional assumptions would include: First, reliable estimates or data on the effectiveness of some adaptation actions may not always be available. Consequently, some adaptation measures may be challenging to incorporate into the analysis, or they may result in residual damage cost estimates with significant uncertainty. Second, adaptation actions may interact with one another. For instance, building protective infrastructure, such as levees, might encourage people and assets to relocate to areas deemed safer by the new protection, thereby increasing exposure to events that exceed the infrastructure’s protective capacity. Modeling these interactions in some cases may be challenging due to the lack of reliable data on the magnitude of such effects, adding further uncertainty to the analysis. Third, some potential adaptation actions have yet to be developed but could emerge as market forces drive innovation. These future adaptation options, being speculative in nature, would need to be excluded from the analysis, as their effectiveness and implementation are currently uncertain. Fourth, the cost-effectiveness of different adaptation strategies may depend on future climate conditions, which are influenced by the success of mitigation efforts to reduce emissions. For example, in a high-emission scenario, very tall levees may be necessary, whereas, in a scenario where emissions are curbed, such infrastructure may not be as critical. This trade-off between mitigation and adaptation means that any cost-benefit analysis for adaptation must be tailored to each of the SSP-RCP scenarios described earlier. Notwithstanding these caveats, a process to extend step 6 and compute projected future damages under several climate adaptation scenarios would encompass the following steps:

A. We would begin by meeting with stakeholders in Vermont to compile a comprehensive list of public and private adaptation actions expected to be implemented.
B. Next, we would quantify the direct costs of various adaptation measures, drawing from engineering studies and economic literature. Some examples of adaptation measures include the construction of public infrastructure, like flood defenses, and private actions, such as retrofitting homes with air conditioning systems. The cost estimates would cover both intensive margin actions (e.g., more frequent maintenance and energy use) and extensive margin actions (e.g., the cost of building infrastructure and new installations or upgrades), capturing the full lifecycle of costs. This approach reflects not just upfront expenses but also the ongoing costs of operation, maintenance, and future upgrades, providing a comprehensive view of long-term financial commitments.
C. For the subset of adaptation measures identified in sub-step B, we would review existing literature to collect information on their effectiveness in reducing climate-related damages.
D. For the subset of adaptation measures identified in sub-step C, we would also evaluate their potential interactions with other adaptation actions. Drawing from additional studies, we would identify how these measures may influence one another (e.g., constructing levees could incentivize new development in areas previously considered at risk, potentially increasing future exposure).
E. Using climate models from the “Datasets for Measuring Projected Extreme Weather Events” section, we would calculate the frequency of hazards expected to affect Vermont by the end of the century under three climate scenarios: low emissions (SSP1-RCP2.6), middle-of-the-road (SSP2-RCP4.5), and high emissions (SSP5-RCP8.5).
F. The damage estimates for each climate scenario, as outlined in step 6 of the methodology, would then be adjusted based on the effectiveness of the adaptation actions specific to each scenario. This adjustment would reflect how different adaptation measures perform under low, middle, and high emissions scenarios (SSP-RCP combinations).
G. For each climate-adaptation scenario, we would compute the expected changes in exposure to populations and assets. This computation would be based on demographic and economic projections used in step 6 and further adjusted according to what is known about the interactions between adaptation actions identified in sub-step D.
H. To calculate residual damages for each hazard, we multiply the adjusted damage estimates by the projected event frequency and the updated exposure levels for every climate adaptation scenario.
I. If damages are not expressed in monetary terms, we will convert them using standard economic methods to ensure consistency across all projections.
J. We would apply a well-established discount factor to compute the present value of projected residual damages derived in the previous step and the costs of adaptation measures identified in sub-step B.
K. Residual damage estimates would be summed by hazard to calculate the total future losses for each climate change scenario, taking into account the effects of adaptation measures.

L. Using climate models, we would compute the hazard-specific Fraction of Attributable Risk (FAR) for each climate change scenario to quantify the portion of each event's risk attributable to anthropogenic emissions.
M. The residual loss estimates for each hazard would then be multiplied by the corresponding FAR for each climate-adaptation scenario to estimate the portion of residual damages directly attributable to anthropogenic GHG emissions.
N. We would then sum the damages derived in the previous step to compute the total residual future damages incurred by Vermont and its residents due to anthropogenic GHG emissions.
O. Last, we would sum the present value of the direct adaptation costs derived in sub-step J with the residual projected damages in sub-step N to compute the total projected damages for Vermont and its residents, accounting for some adaptation measures. Note that this calculation yields several total cost estimates (one for each SSP-RCP climate adaptation scenario).

Alternative Approaches

In addition to the bottom-up methods of damage attribution and cost estimation that focus on specific events or regional impacts, top-down approaches, particularly Integrated Assessment Models (IAMs), offer an alternative for estimating the economic costs of climate change. IAMs, such as DICE (Nordhaus, 1993) and PAGE (Hope, 2006), provide broad, high-level projections by integrating climate science with economic outcomes over long time horizons. These models can simulate the macroeconomic impacts of climate change, helping decision-makers weigh the costs of mitigation and adaptation against economic growth. IAMs are particularly useful for providing global or national-level estimates of climate impacts across multiple climate and emissions scenarios.

However, for a state like Vermont, where specific climate-related hazards and sectoral impacts must be carefully measured, bottom-up approaches are generally preferable. Bottom-up methods, such as the one presented in this document, are preferred as they allow for a more straightforward assessment. These methods use localized data and provide event-specific estimates, offering a detailed and context-sensitive view of how climate hazards (such as floods, extreme heat, and droughts) affect specific sectors like agriculture, infrastructure, and tourism. This makes them better suited to capturing the complex, localized impacts that Vermont may face, especially when addressing region-specific vulnerabilities.

Computable General Equilibrium (CGE) models offer another approach, bridging the gap between the high-level abstraction of IAMs and the detailed specificity of bottom-up approaches. CGE models simulate the economy-wide effects of climate change by modeling how different sectors interact and how a shock to one sector, such as agriculture or energy, ripples through the rest of the economy. For Vermont, CGE models could be useful in understanding the indirect effects of climate hazards, such as how a flood-disrupting infrastructure could lead to losses in productivity across multiple industries.

While IAMs, as discussed in Hallegatte et al. (2011) and CGEs, can be adapted to focus on regional impacts by simulating sector-specific economic consequences at smaller scales, they often rely on simplified damage functions. These functions may not fully capture the nonlinear and sector-specific effects of climate change, particularly when it comes to extreme weather events. Moreover, IAMs and CGEs operate at a higher level of abstraction, making it harder for stakeholders to track how specific costs, such as those related to public health or infrastructure damage, are derived. This can reduce transparency and limit their practical application when detailed regional or state-level cost estimates are needed. In contrast, bottom-up approaches provide a more transparent methodology, as they are based on estimates derived from observational data and peer-reviewed studies, making it easier for stakeholders to understand the process and outputs. For Vermont, these methods offer a more actionable approach, ensuring that the specific risks posed by climate change to the state's residents, economy, and infrastructure are accurately captured and quantified.

In conclusion, while IAMs offer valuable insights for long-term macroeconomic projections, and CGE models can simulate broader economic interactions, both approaches are less suited for capturing the localized, granular impacts of climate change in a region like Vermont. Bottom-up approaches not only offer greater transparency and precision but also ensure that the state's unique vulnerabilities and adaptation needs are better accounted for in the overall cost estimation. A hybrid approach that combines both methods can also be considered, but in our view, the bottom-up approach remains the preferred method for the Climate Superfund Cost Recovery Program.

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