Response of RFI Title:

Calculating the cost of implementing climate change adaptation and resilience measures in Vermont

Respondent’s Names:

Paul Chinowsky, Kelly Sanks, and Richard Wiles

Contact Person:

Kelly Sanks

Telephone Number:

(443) 938 0636

Mailing Address:

The Center for Climate Integrity
1201 Connecticut Ave NW, Ste 600
Washington, D.C. 20036

Email Address:

kelly@climateintegrity.org

QUESTIONNAIRE

The State is seeking to gather input and obtain information about the development of (i) a liability and cost recovery demand approach for "responsible parties" as defined in Act 122 and (ii) the Treasurer's report on the cost to Vermont of covered greenhouse gas emissions. We expect the Respondents to consider and estimate the effort and cost in engaging contractor support in meeting the specific requirements of Act 122 included here. Respondents to this RFI may choose to respond to one or both of the questions below.

1. Describe a stepwise process to identify responsible parties, determine their applicable share of covered greenhouse gas emissions, and determine the cost recovery demand amount as described in Act 122. In doing so, please identify the datasets (publicly available) and describe the methodology and research the approach is based on. Provide an evaluation of the comprehensiveness and accuracy of those data sets. If appropriate, evaluate the utility of using additional information not publicly available to determine cost recovery demands.

We do not outline a method for attributing emissions to responsible parties, as we do not specialize in this field of science. However, the adaptation and resilience costs from our methodology below can be attributed to responsible parties if we know the percentage of emissions each party emitted during the study period.

2. 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;

To determine the cost recovery demand of responsible parties, the first step is to determine the cost of the climate change adaptation projects specified in the bill. The Vermont Climate Superfund Act states that a "climate change adaptation project" means a project designed to respond to, avoid, moderate, repair, or adapt to negative impacts caused by climate change and to assist human and natural communities, households, and businesses in preparing for future climate-change driven disruptions. This definition describes three very different costs and should be broken down into both (1) climate change adaptation or resilience projects, (2) responding, repairing, and/or recovering from damage due to extreme weather and climate events, and (3) general sector-wide impacts (e.g., impacts on the food system). The detailed methodology presented below describes a defensible methodology for estimating the cost of implementing climate change adaptation and resilience projects.

The cost of climate change adaptation or resilience projects typically refers to projects that aim to avoid, moderate, or adapt to the worsening impacts of climate change; think sea walls, improved stormwater drainage, or increased cooling costs for government buildings. The cost of implementing certain climate change adaptation or resilience projects is well studied and defensible. The following climate change adaptation and resilience projects outlined in the Vermont Climate Superfund Act already have established methodology:[1]

- Implementing nature-based solutions and flood protections;
  - ☑ Installing green stormwater infrastructure;
  - ☑ Installing flood protection systems, like levees, in rural communities;
- Home buyouts;
- Upgrading stormwater drainage systems;
  - ☑ Installing green stormwater infrastructure;
- Making defensive upgrades to roads, bridges, railroads, and transit systems;
  - ☑ Making defensive (proactive) upgrades and reactive repairs to roads;
  - ☑ Making defensive upgrades to bridges;[2]
  - ☑ Making railroads more resilient to heat by painting tracks with reflective painting;
- Relocating, elevating, or retrofitting sewage treatment plants and other infrastructure vulnerable to flooding;
- Installing energy efficient cooling systems and other weatherization and energy efficiency upgrades and retrofits in public and private buildings, including schools and public housing, designed to reduce the public health effects of more frequent heat waves and forest fire smoke;
  - ☑ Installing and upgrading HVAC systems in public buildings;
  - ☑ Net change in energy costs to heat and cool public buildings;
- Upgrading parts of the electrical grid to increase stability and resilience, including supporting the creation of self-sufficient microgrids.

(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

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[1] Center for Climate Integrity, Resilient Analytics, and Scioto Analysis, "Confronting Wisconsin's Climate Costs: At Least $16.7 Billion to Protect Communities from Climate Change through 2040," 2024, https://climateintegrity.org/uploads/media/Wisconsin-ClimateCostStudy-2024.pdf.

[2] Len Wright et al., "Estimated Effects of Climate Change on Flood Vulnerability of U.S. Bridges," *Mitigation and Adaptation Strategies for Global Change* 17, no. 8 (December 1, 2012): 939–55, https://doi.org/10.1007/s11027-011-9354-2.

(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.

To estimate climate adaptation and resilience projects, we will use a baseline climate period (1973-1993) and the climate period from the bill (1994-2024). We also recommend using a projection climate period (2024-2060) to ensure that the implemented adaptation and resilience projects are built to protect communities across Vermont in the coming decades. We will use publicly-available climate data to determine temperature, precipitation, and other climate indices as needed for analysis for both periods. Estimating adaptation costs follows a relatively simple methodology that:

1. Determines the change in the climate variable of interest (average temperature, days above 90°F, inches of precipitation during a wet weather event, wildfire days, etc.) between the baseline and study period, as well as the baseline and projection time period.
2. Determines the cost to adapt to the change in the climate variable (increased cooling costs in public buildings, installing green stormwater infrastructure, etc.) because of climate change.

The exact cost data used for each climate adaptation and resilience project will vary. In the bulleted list of adaptation projects, you will find links to relevant peer-reviewed publications and other reports that detail the methodology for each adaptation project. New methodologies can be developed for other adaptation projects that do not have an existing methodology, if viable. However, we note that these methodologies will be based on the same general process described above. Below we detail a sample methodology for implementing green stormwater infrastructure to adapt to the increase in extreme wet weather events expected in Vermont because of climate change.

First, we will gather the relevant climate data. The climate data will be derived from the U.S. Geological Survey National Climate Change Viewer,[3] which utilizes Localized Constructed Analogs (LOCA) statistically downscaled Coupled Model Intercomparison Project Phase 6 (CMIP6) climate projections for North America. We select the climate projections for a moderate greenhouse gas and aerosol emission scenario (Shared Socioeconomic Pathway 2-4.5 [SSP2-4.5]).

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[3] "USGS National Climate Change Viewer," 2024, https://apps.usgs.gov/nccv/loca2/nccv2_loca2_counties.html.

The climate baseline for temperature-related analyses can be derived from Livneh et al. (2015).[4] The climate baseline for precipitation-related analyses can be derived from Pierce et al. (2021).[5] We will use a 20-year baseline time period centered on 1983 (1973-1993) for all climate adaptation analyses. A shapefile for Vermont municipalities will be used to determine municipal bounds throughout the study.[6] Note that costs for some adaptations will be computed as a time series and costs for other adaptations will be assessed once in 2024 (study period) and then again in 2060 (projection period).

To estimate the cost to install green stormwater infrastructure, we need to determine how much worse extreme wet weather events were during the study period as compared to the baseline, and the projection period as compared to the baseline. We determine the increase in storm intensity using the U.S. Environmental Protection Agency Climate Resilience Evaluation and Awareness Tool (CREAT).[7] An increase in storm intensity due to climate change will cause large increases of inflow into the wastewater treatment plants.

We calculate the percent change in these events from the change in rainfall depth (inches) for a certain percentile between the two distributions (baseline distribution and the study and projected distribution). For example, if the baseline wet weather event is 3 inches and the projected wet weather event is 3.3 inches, then we would say the extreme wet weather event increased by 10%.

Given a change in wet weather events, we assume that the municipality must invest to offset additional runoff (thus infiltration and inflow) into the wastewater treatment plant. We assume the offset is proportional to the change in wet weather events. For example, if the wet weather events are increasing by 10%, then 10% of the developed impervious area needs to be offset by drainage infrastructure. We derived the per-unit cost for green stormwater infrastructure from the following equation:[8]

- $Cost = A * \mathbf{\Delta} WWE * GSI$
- Where:

[4] Ben Livneh et al., "A Spatially Comprehensive, Hydrometeorological Data Set for Mexico, the U.S., and Southern Canada 1950–2013," *Scientific Data* 2, no. 1 (August 18, 2015): 150042, https://doi.org/10.1038/sdata.2015.42.

[5] David W. Pierce et al., "An Extreme-Preserving Long-Term Gridded Daily Precipitation Dataset for the Conterminous United States," *Journal of Hydrometeorology* 22, no. 7 (July 1, 2021): 1883–95, https://doi.org/10.1175/JHM-D-20-0212.1.

[6] "Vermont Data - Town Boundaries," 2024, https://geodata.vermont.gov/datasets/3f464b0e1980450e9026430a635bff0a.

[7] US EPA, "Creating Resilient Water Utilities," Data and Tools, August 13, 2021, https://www.epa.gov/crwu/access-data-creating-resilient-water-utilities.

[8] Allegheny County Sanitary Authority, "Staring at the Source: How Our Region Can Work Together for Clean Water - Appendix E-3: GIS Cost Literature Review," 2015, https://www.alcosan.org/docs/default-source/clean-water-plan-documents/cwp-appendixe/cwp-appendix-e-3_gsi-cost-literature-review.pdf?sfvrsn=6d863977_2.

- A is area of developed impervious surfaces (acres)
- ΔWWE is the change in wet weather events (%)
- GSI is the unit cost of implementing green stormwater infrastructure

GSI unit costs will be based on local green infrastructure projects to ensure localized pricing is used in the analysis.

A similar approach can be applied to determine the cost of implementing other adaptation projects of interest.[9]

Table 1: Outline of method for computing the cost of implementing 15 other adaptation measures with existing methodology.

Impact	Adaptation	Explanation	Data
Increased temperature	Installing and upgrading heating and cooling infrastructure in public buildings	The cost to install or upgrade HVAC systems in public buildings.	Cooling Degree Days;[10] Vermont building footprints[11]
Increased temperature	Combating heat islands	Planting trees can help decrease ambient air temperature by cooling the air through evapotranspiration. The adaptation is planting and maintaining trees in urban areas and accounts for both initial costs and yearly maintenance costs. The initial costs include labor and materials. The maintenance costs include water, fertilizer, pruning, and pest spraying.	National Land Cover Database[12] of Land Use[13] and Canopy Coverage[14]
Increased temperature	Proactively and reactively fixing	When pavement temperature rises above its mixture threshold, increased degradation	7-day ambient temperatures;

[9] Center for Climate Integrity, "Los Angeles County's Climate Cost Challenge," 2024, https://climateintegrity.org/uploads/media/LACounty-ClimateCosts-2024.pdf; Center for Climate Integrity, Resilient Analytics, and Scioto Analysis, "Confronting Wisconsin's Climate Costs: At Least $16.7 Billion to Protect Communities from Climate Change through 2040."
[10] Cooling degree days (CDD) is a measure of how much (in degrees), and for how long (in days), the outside air temperature is above a specified temperature threshold.
[11] State of Vermont, "VT Building Footprints," 2023, https://geodata.vermont.gov/datasets/VCGI::vt-building-footprints/about.
[12] National Land Cover Database, "National Land Cover Database Class Legend and Description," Multi-Resolution Land Characteristics (MRLC) Consortium, (accessed June 21, 2023), https://www.mrlc.gov/data/legends/national-land-cover-database-class-legend-and-description.
[13] National Land Cover Database, Land Cover/CONUS/2019, (2019), distributed by Multi-Resolution Land Characteristics Consortium, https://www.mrlc.gov/data.
[14] National Land Cover Database, "NLCD 2016 Tree Canopy Cover (CONUS)," distributed by Multi-Resolution Land Characteristics Consortium, https://www.mrlc.gov/data/nlcd-2016-tree-canopy-cover-conus.

and increased precipitation	roads	occurs. In the reactive scenario, this increased cracking requires more maintenance to avoid a decrease in the projected lifespan of the road. In the proactive scenario, adaptation includes installation of roads with pavement rated to projected future temperatures. Excess precipitation above what the road was designed to handle can also increase degradation. Road maintenance costs are informed by the percentage decrease in lifespan based on the level of projected damage as compared to the climate baseline. In the proactive road scenario, adaptation requires strengthening the roadbase to resist the increased potential for erosion. In the reactive road scenario, adaptation is fixing roads after precipitation-induced damage.	maximum monthly precipitation rates; Vermont roads database[15]
Increased precipitation	Maintaining bridges	As rivers flow faster during extreme precipitation events, bridges will degrade faster due to enhanced scour. To combat enhanced damage to bridges, we estimate the cost to proactively rehabilitate bridges in order to prevent disruption. Rehabilitation consists of applying riprap to stabilize bridges and additional concrete to strengthen piers and abutments.	24-hour precipitation rates; National Bridge Inventory[16] subsetting to include only inland bridges spanning bodies of water; 8-digit Hydrologic Unit Code boundaries[17]
Increased temperature	Protecting residents during heatwaves	To help residents escape the increasing summer heat, cooling centers will need to be expanded and operated. The cost of opening and operating cooling centers due to increased days with temperatures above 85°F, as compared to the climate baseline are estimated.	U.S. Census Block Groups; report on operational costs of cooling centers[18]
Increased precipitation	Protecting public roads from landslides	Increased precipitation falling on unstable slopes across Vermont threaten infrastructure and roads. To establish the cost to protect high-risk areas from increasing landslide risk, we will estimate appropriate mitigation measures based on the current FEMA and State of Vermont practices[19] in vulnerable areas.	Vermont landslide vulnerability inventory and maps[20]

[15] State of Vermont, "VT Road Centerline," 2021, https://geodata.vermont.gov/maps/VTrans::vt-road-centerline.
[16] Federal Highway Administration, National Bridge Inspection ASCII files, (2022), distributed by United States Department of Transportation, https://www.fhwa.dot.gov/bridge/nbi/ascii.cfm.
[17] United States Geological Survey, Hydrologic Unit Maps, (n.d.), distributed by United States Department of the Interior, https://water.usgs.gov/GIS/huc.html.
[18] Carol Parks, "Cooling Center Operations in Los Angeles City," City of Los Angeles Emergency Management Department (2002), https://clkrep.lacity.org/onlinedocs/2021/21-1277_rpt_07-29-22.pdf.
[19] Agency of Natural Resources, "Landslides, Rockfalls and Erosion," Government, 2024, https://dec.vermont.gov/geological-survey/hazards/landslides.
[20] Benjamin B. Mirus et al., "Landslides across the USA: Occurrence, Susceptibility, and Data Limitations," *Landslides* 17, no. 10 (October 2020): 2271–85, https://doi.org/10.1007/s10346-020-01424-4.

Increased temperature	Estimating the change in energy costs to heat and cool public buildings	Changes in energy costs are estimated based on the number of days below (heating) or above (cooling) a certain threshold as compared to the climate baseline.	Cooling and heating degree days; Vermont Building Footprint
Increased temperature	Implementing cool pavements in public parking lots	Converting existing areas of pavement to high-albedo (light reflecting) cool pavement has been shown to decrease proximal ambient temperature and is a complementary approach to combat increased summer temperatures in urban areas. The cost to convert public parking lots to cool pavements is estimated.	Environmental Protection Agency (EPA) study on cool pavement costs;[21] Vermont roads database
Increased temperature	Painting rail tracks with high-albedo paint	Rail slow downs and shutdowns can be avoided by painting the tracks with a high-albedo paint to keep the tracks cool. Australia, Italy, and Switzerland already implement this technique with success.	USGS National Transportation Dataset for Vermont[22]
Increased precipitation	Constructing flood protection systems in rural areas	Increased wet weather events, which increase the flow in rivers, threaten rural areas that are not protected from overbank flooding. To combat damage to rural communities, we assess the cost to install flood protection systems.	Federal Emergency Management Agency (FEMA) 100-year floodplain maps from the National Flood Hazard Layer (NFHL;,[23] National Land Cover Database (NLCD); 8-digit Hydrologic Unit Code boundaries
Public Health: Increased temperature	Increased costs from pediatric asthma hospital visits	Increased temperatures correlates to increased pollen levels, which lead to more cases of pediatric asthma that require emergency room visits. We estimate the government-incurred cost of increased pediatric asthma visits as compared to the climate baseline.	National Environmental Public Health Tracking Network[24]
Public Health: Increased temperature and increased precipitation	Initial and long-term costs to treat increased West Nile Virus manifestations	Mosquitoes thrive in warm temperatures and near water, so increased temperatures and precipitation due to climate change will make West Nile Virus more prevalent. We estimate the increased government-incurred cost to treat both initial and long-term manifestations	West Nile Virus Historic Data[25]

[21] U.S. Environmental Protection Agency, *Reducing Urban Heat Islands: Compendium of Strategies. Cool Pavements.*, 2012, https://www.epa.gov/sites/default/files/2017-05/documents/reducing_urban_heat_islands_ch_5.pdf.
[22] USGS, "USGS National Transportation Dataset (NTD) for Vermont," 2024, https://www.sciencebase.gov/catalog/item/5a61c940e4b06e28e9c3bdcc.
[23] Federal Emergency Management Agency, "National Flood Hazard Layer," August 26, 2021, https://www.fema.gov/flood-maps/national-flood-hazard-layer.
[24] Centers for Disease Control and Prevention, "National Environmental Public Health Tracking Network," n.d., https://ephtracking.cdc.gov/DataExplorer/.
[25] Centers for Disease Control and Prevention, "West Nile Virus Historic Data (1999-2022)," June 13, 2023, https://www.cdc.gov/westnile/statsmaps/historic-data.html.

		of West Nile Virus.	
Public Health: Increased temperature	Initial and long-term cost to treat Lyme disease	The range of ticks has expanded due to increased temperatures. As the climate continues to warm, increased Lyme disease from ticks is expected.	Lyme disease incidence data[26]

Although we do not outline a methodology for attributing the amount of emissions to each responsible party during the study period, the percentage of emissions for each company, determined via other researchers methods, can be multiplied by the total cost of implementing the resilience and adaptation projects to attribute costs accordingly.

3. Please provide any other materials, suggestions, cost, and discussion you deem appropriate

The methodology described above is only viable for implementing climate change adaptation and resilience measures. The bill also aims to determine the cost of recovering from extreme weather events. To do this, the State must determine if there were any extreme weather events in Vermont during the study period that can be attributable to climate change. This would entail conducting an extreme event attribution[27] study for each potential event. Where extreme weather events occurred that are attributable to climate change, the cost of recovery can be divided into two components: direct physical recovery and indirect economic recovery. In terms of the direct costs, data from local officials is needed to summarize repair requirements to physical systems including transportation, power, telecommunications, and water. This data should be available from city, county, and state emergency management as well as sector-specific oversight authorities. In terms of indirect costs, this would focus on business interruption which can be characterized by loss of tax revenue or similar measurement. Once again, this data is available through appropriate economic offices as well as tax assessors or similar positions.

The bill also aims to determine the cost of sector-wide impacts. For example, the cost of the loss of topsoil or the cost of impacts to the food system. To do this, the State must determine if these impacts are attributable to climate change in Vermont during the study period. If the impacts are attributable to climate change, an economic model should be considered to determine the loss of revenue and gross domestic product related to these sector-wide impacts.

[26] Centers for Disease Control and Prevention, "Lyme Disease Surveillance and Available Data," November 15, 2022, https://www.cdc.gov/lyme/stats/survfaq.html.
[27] "World Weather Attribution – Exploring the Contribution of Climate Change to Extreme Weather Events," 2024, https://www.worldweatherattribution.org/.