Testimony from Dr. Justin S. Mankin
Senate Judiciary Committee S. 259
Thursday, February 22, 2024

(Slide 1): Good morning. My name is Justin Mankin. I am a professor of Geography at Dartmouth and an associate research scientist in the Division of Ocean & Climate Physics at Lamont-Doherty Earth Observatory of Columbia University[i]. At Dartmouth I direct the Climate Modeling & Impacts Group[ii] where we work to understand the human impacts of global warming, studying how human-caused climate change impacts our water, food, recreation, infrastructure, and economic and physical security. Much of our scientific research centers on using observations and models to quantify the impacts and costs of global warming to date and to estimate how those impacts and costs may evolve into the future. My goal is to improve our understanding of the consequences of warming for people and the things they value and to inform the difficult decisions those consequences will compel. My climate attribution work has been published in leading peer-reviewed scientific journals, like *Science*, *Nature,* and the *Proceedings of the National Academy of Sciences*[iii]. I hold an undergraduate degree and a Masters of Public Administration from Columbia University, a Master of Science from the London School of Economics, and a PhD in climate science from Stanford University.

I am here to provide testimony on S.259 "An act relating to climate change cost recovery."

I hope you take away the following four key points from my testimony:

- **Firstly, using peer-reviewed, consensus scientific methods, scientists can *quantify* the economic losses a region like Vermont has endured from the impacts of global warming to date[iv].**

- **Secondly, using peer-reviewed, consensus scientific methods, scientists can *attribute* those losses back to particular emissions or emitters.[v]**

- **Thirdly, using peer-reviewed, consensus scientific methods, scientists can estimate the net present value of future damages associated with *both* historical and future emissions.[vi]**

- **Lastly, it is my opinion that we are systematically underestimating the economic costs of climate change to date, and that is because all of these climate damage cost accounting methods are inherently conservative or limited by data.**

(Slide 2): Losses from climate change abound. But who pays and how much? While these questions are ultimately being resolved in courts and in legislative bodies such as this, science can help provide answers to these questions. In particular, science can help by quantifying climate damages and attributing them to particular parties.

(Slide 3): In general, there are three sets of costs to consider in assessing total damage due to climate change[vii], and there are different methods to estimate each of these.

- The first is the cost of the damage promulgated by historical emissions. So these are the costs that have already manifested in Vermont's economy owing to the hazards from the human-caused global warming to date.

- The second set of costs to consider are the costs that will arise from future hazards, which have their origins in historical emissions. The effects of carbon dioxide (CO_2) are cumulative, and CO_2 has a very long residence time in our atmosphere, such that some fraction of the first ton released at the dawn of the industrial revolution is still up there, warming our climate and generating impacts[viii]. This means that the emissions already released from fossil fuel combustion, and to which we can already attribute historical climate damages in a place like Vermont, will continue to cause Vermont damage into the future.

- The last cost to consider is the cost from future emissions. Decarbonizing our economy will take time and will itself be energy intensive; to the extent that it is reliant on fossil fuels, future emissions will generate future impacts, and those impacts, costs.

(SLIDE 4): There are different approaches to calculating the costs attributable to each of these terms, but I would generally classify the damage attribution work into two approaches. Both of these are scientifically defensible, implying that the Treasurer would have options in how best to approach any accounting:

- The first approach relies on using the social cost of carbon or SCC, which is a dollar estimate of the discounted welfare costs associated with emitting one additional ton of carbon dioxide into the atmosphere. Right now, using various methodologies, the EPA places the SCC at $190 per ton[ix]. With that legally binding estimate in hand, one could calculate the economic damage attributable to particular emitters, essentially by multiplying the SCC by the number of tons emitted by particular firms[x]. There are nuances there, and I imagine Rick Heede, who I believe will be testifying later this morning, has some insights on this approach.

- A second approach is one my research team has been working on, which we call an 'end-to-end' attribution. Our approach isolates and quantifies *particular* climate damages attributable to *particular* emitters and, owing to its modularity and flexibility, can be applied to myriad contexts (from single events to cumulative harms), emitters (from individual firms to nations), and climate change-driven hazards (from heat waves to storms, droughts, floods, and others), given data availability. Our framework uses consensus, peer-reviewed methods and resolves nonlinearities in the relationships between greenhouse gas emissions, atmospheric concentrations, temperature changes, physical hazards, and damage. Our rigorous treatment of causation is designed to meet scientific and legal standards, resolving uncertainties major polluters have hidden behind for decades.

(SLIDE 5): Climate attribution science is a well-established consensus science, informing synthesis reports like the Intergovernmental Panel on Climate Change[xi] and the National Climate Assessment[xii], and has been used to establish causal links between global warming various climate hazards, like floods[xiii], droughts[xiv], heat waves[xv], snow loss[xvi], tropical cyclones[xvii], and other hazards. Similarly, there is considerable peer-reviewed, consensus work that documents and attributes the monetary losses from climate impacts—so called “climate damage assessments”[xviii]. Damage assessments are often grounded in empirical or semi-empirical models called “damage functions” that connect climate-related extremes, like heat waves or floods, to policy-legible socioeconomic outcomes, like lives or income lost. With these damage estimates, decision-makers can then better understand the costs of climate inaction and weigh them against the net benefits of adaptation and mitigation.

These attribution methods rely on comparing outcomes in two groups, just like in a medical drug trial. In a drug trial, participants are randomly assigned into treatment and control groups. The individuals in the treatment group, here represented by the orange bars, get the drug, those in the control group, represented by the blue bars do not, and the medical outcomes among the two groups are compared. Here we can see that even though individuals respond differently, that on average we can make an attribution of the efficacy of the treatment. Some deleterious medical outcome is reduced from the drug.

(SLIDE 6): We can extend this toy example to climate attribution in general. We compare outcomes in a world with versus without climate change. The distinction here is that we use models, rather than a randomized control trial, to construct the control group, or counterfactual world without climate change.

(SLIDE 7): I am happy to delve into the mechanics of the approach if the Committee has questions. I also include three scientific manuscripts with my testimony today, documenting our approach. Briefly, we use an integrated modeling framework built on consensus, peer-reviewed methods that allows us to build a transparent and reproducible chain of causality from emissions to damage, sampling the range of outcomes that are possible at each step. We do this by simulating from emissions to damage, leaving out a particular emitter, or set of emissions, creating a control group. We can then compare the two worlds, one as it is, and one without a particular set of emissions and compare the economic outcomes. That is our damage attribution.

The power of this approach is that we can port in different emissions, different hazard models, like a flood model, or a tropical cyclone model, and different damage functions, and make a new assessment, all in a “but for” context: but for the considered emissions, the hazard and its associated damages would have been thus. Given an assumed trajectory of economic growth and of emissions, it can also be extended into the future.

We have applied this framework to assess the income lost due to historical emissions-driven changes in average temperature and heat waves. I note, however, that it can be extended to other hazards, like floods, or drought, and to other damages, like mortality or morbidity, depending on the use case.

(SLIDE 8): What we know from these individual damage assessments is that the costs of climate change to date are far higher than previously understood. We have shown that for average temperatures, for extreme heat, and for climate variations that could be affected by climate change, like El Niño. Because the costs attributable to these individual hazards so far are so large, and they focus on quantities that are easily measured, it is my assessment that any accounting of the damages to date are an undercounting, and are therefore conservative.

Thank you for the opportunity to speak with you today and I will standby for your questions.

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[i] See enclosed academic c.v.

[ii] Website: https://jsmankin.github.io/

[iii] E.g., Callahan & Mankin, *Climatic Change* (2022); Callahan & Mankin, *Science* (2023); Gottlieb & Mankin, *Nature* (2024); Callahan & Mankin, *Science Advances* (2022); Callahan & Mankin, minor revisions, *Nature* (2024).

[iv] E.g., Callahan & Mankin, Science Advances (2022); Callahan & Mankin, Climatic Change (2022); Diffenbaugh & Burke, *PNAS* (2019); Burke, Hsiang, Miguel, *Nature* (2015).

[v] E.g., Callahan & Mankin, *Science Advances* (2022); Callahan & Mankin, minor revisions, *Nature* (2024).

[vi] EPA Report on the Social Cost of Greenhouse Gases: Estimates Incorporating Recent Scientific Advances: https://www.epa.gov/system/files/documents/2023-12/epa_scghg_2023_report_final.pdf

[vii] Burke et al. *NBER Working Paper 3165* (2023).

[viii] Matthews & Caldeira, *Geophysical Research Letters* (2008).

[ix] EPA Report on the Social Cost of Greenhouse Gases: Estimates Incorporating Recent Scientific Advances: https://www.epa.gov/system/files/documents/2023-12/epa_scghg_2023_report_final.pdf

[x] See, for example, Burke et al. *NBER Working Paper 3165* (2023); and Schleussner et al. *ESS Open Archive* (2023).

[xi] E.g., Bindoff et al., 2013: Detection and Attribution of Climate Change: from Global to Regional. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_Chapter10_FINAL.pdf

[xii] USGCRP, 2023: Fifth National Climate Assessment. U.S. Global Change Research Program, Washington, DC, USA. https://nca2023.globalchange.gov/chapter/3#key-message-5

[xiii] Pall et al., *Nature* (2011).

[xiv] Diffenbaugh, Swain, & Touma, *Proceedings of the National Academy of Sciences* (2015).

[xv] Callahan & Mankin, *Science Advances* (2022).

[xvi] Gottlieb & Mankin, *Nature* (2024).

[xvii] Patricola & Wehner *Nature* (2018).

[xviii] E.g.., Carleton, et al*., Q. J. Econ.* (2022); Hsiang, et al*., Science (2017);* Auffhammer et al., *Rev. Environ. Econ. Policy* (2013); Carleton & Hsiang, *Science* (2016); Diffenbaugh and Burke *PNAS* (2019).