Equity in Climate Resilience Planning and Investments

A Quantitative Approach

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Preface

This study builds upon and draws insights from a body of MITRE work:

- *Benefit-Cost Analysis and Consideration of Distributional Effects and Social Equity* (MP210978), which focused on current practices of applying benefit-cost analysis (BCA) to prioritize both federal and state government actions, existing methods for identifying distributional effects, and areas within the BCA framework that could be improved to address social equity [1];
- *Guidance on Assessing Distributional Effects* (MTR210702), which focused on developing the methodology for assessing distributional effects [2];
- *Framework for Assessing Equity in Federal Programs* [3]; and
- *Improving Social Equity in Federal Financial Assistance.*

This work is expected to continue beyond this document, ideally building consensus on the methods that can be used to consider social equity within economic analyses, for program evaluation and throughout the planning process to prioritize investments in the communities that need the most support to lessen the impacts of climate change.

Executive Summary

Climate change and extreme weather hazards disproportionately impact communities and populations experiencing social inequities, including systemic racism and intergenerational poverty. Social equity in terms of climate resilience involves the fair and just inclusion and participation of communities to plan for and adapt positively to or thrive amid changing climate conditions and hazards. Government investments in climate resilience, such as federal funds distributed through discretionary grant programs, offer opportunities for improving social equity among communities and populations.

MITRE conducted research to understand, analyze, and document the quantitative accounting of social equity throughout the climate resilience planning process using metrics, indicators, indices and weights of inequity both within and external to economic analyses commonly used to assess cost effectiveness of proposed climate resilience investments. The purpose of this work is to identify the methods and data that contribute useful information to the formulation of plans, prioritization of funding, and tracking impact after implementation, while recognizing limitations and potential improvements. Our intention is to gather feedback and vet our recommendations with subject matter experts, practitioners, and government and community representatives to reach a consensus on a path towards greater understanding of how we might equitably and intentionally direct funding towards the communities who need it most. This report is intended for specialists with expertise in economics, climate resilience, social justice and equity and government agencies that administer or are planning to administer discretionary grant programs to fund climate resilience projects. This study builds upon and draws insights from various MITRE reports (see Preface) and is the third report in a series specifically exploring social equity in economic analyses.

The first, foundational step in accounting for and improving social equity in climate resilience planning and investment is the identification of communities and/or populations who are experiencing inequities. For this report, “disadvantaged communities,” “vulnerable populations,” and all similar designations of communities or populations are collectively referenced as “priority equity geographies (PEG).” This term highlights the importance of geography (both physical and human) in identifying priorities for climate resilience and social equity, and reduces detrimental population or community labels, which may perpetuate inequities.

MITRE recommends supplementing the traditional planning process by expanding the planning team to include representatives from PEGs for the identification and prioritization of projects. This requires understanding where PEGs are located within the planning area and identifying appropriate representatives that can advocate for these communities and/or populations. Further, defining equity for a proposed project or program requires understanding the challenges facing PEGs and their desired project outcome(s): it should include perspectives from the multiple lenses of equity including awareness, procedural and fairness (eligibility), access and distribution, output, outcome, quality, engagement, and temporal/intergenerational. After identifying the targeted project or program outcomes, planners can collaborate with PEGs to define criteria/requirements to successfully achieve them. These criteria/requirements then drive decision-making when developing and evaluating solutions.

After an equitable climate resilience planning process has been completed, federal funding through discretionary grant programs is necessary for many communities to implement a climate

resilience project. This report provides recommendations related to measuring equity themes (such as social vulnerability) and evaluating climate resilience investments that can support the Pre-Award phase of grant programs. Some of the same measurements during the Pre-Award phase may also be used in the Post-Award, Closeout and Post-Closeout phases to track performance of the funded projects and the overall grant program. To facilitate ongoing monitoring of selected measures, funding could cover data collection and reporting.

The report is divided into six major sections, namely: Quantitative Accounting of Social Equity using Metrics, Indicators, Indices and Screening Tools; Equity in Benefit-Cost Analysis (BCA); Equity in Cost-Effectiveness Analysis (CEA); Accounting for Social Capital; and Next Steps.

Quantitative Accounting of Social Equity using Metrics, Indicators, Indices and Screening Tools

Quantitative measures can be used to facilitate PEG investment prioritization, monitor project implementation and progress, and evaluate programmatic and investment effectiveness. In the literature, there is agreement that the communities and/or populations should define these measures. During the planning process for climate resilience projects, planners in collaboration with PEGs can define the criteria for successful outcome(s) that can inform the selection of indicators and metrics which could be used to measure performance. Within the federal grant program structure, consensus is needed between the applicant and the federal awarding agency for the selected measures and, therefore, requires more careful consideration of the myriad options and data biases.

MITRE identified criteria for selecting indicators based on scientific validity, utility, and practicality, as well as considerations and limitations of available data. We recommend additional existing and future climate-related hazards data that are not currently included in the National Risk Index (NRI), the *beta* Climate and Environmental Justice Screening Tool (CEJST), and the Climate Mapping for Resilience and Adaptation (CMRA) tool for consideration. Additionally, MITRE has created an Equity Indicator Catalog that can be used to facilitate the identification and selection of social equity indicators for climate resilience.

A list of national indices was screened based on MITRE-suggested criteria, categories of climate hazards, and equity domains and sub-domains, and gaps were identified. Further investigation of the CDC/ATSDR Social Vulnerability Index (SVI) led to recommended methods to balance the SVI scores with the accuracy and reliability of those scores. The strengths and limitations of *beta* CEJST were also briefly examined.

Equity in Benefit-Cost Analysis (BCA)

BCA has become a standard practice for evaluating the cost effectiveness of public investments; however, BCA is inherently indifferent to distributional concerns. Correcting for inherent bias in BCA by supplementing information traditionally provided to decision makers is imperative to supporting investments for populations who are disproportionately impacted by climate change and have fewer resources to adapt and respond to climate change effects. In addition to MITRE's recommendation and support for providing a distributional analysis in conjunction with BCA, we explored weighting within BCA as a sensitivity analysis, also known as equity weighting. Equity weighting in BCA has only been applied to income thus far, but the utilitarian equity weighting method could be used to derive other equity weights. Equity weighting should be approached cautiously and transparently since the inclusion of equity weighting in a BCA can significantly alter the conclusions.

While income is typically not specifically considered in climate resilience BCAs, property values could be considered a proxy for income. Generally, a large share of benefits for proposed climate resilience projects evaluated using BCA can be from avoiding property damages. Using a traditional BCA approach, BCA results will favor communities with higher property values because the net benefits would be greater than a similar project in communities with lower property values. Similar to the treatment of using an average Value of a Statistical Life (VSL) in transportation safety policy, MITRE recommends using a national average property value to evaluate climate resilience projects.

Due to the potential difficulties in addressing the limitations of BCA, MITRE recommends considering alternative approaches, such as multi-criteria decision analysis (MCDA) and cost-effectiveness analysis (CEA), depending on the objectives of the analysis. MCDA can consider more equity criteria and BCA can be part of the overall criteria. The MCDA approach requires decision makers to set weights for the evaluation criteria and does not require quantification or monetization.

Equity in Cost-Effectiveness Analysis (CEA)

CEA has been used to evaluate cost effectiveness when monetization of costs and/or benefits may be challenging or not possible. CEA is an economic analysis that allows an analyst to compare the relative costs of a project to its quantified “impacts” (costs or benefits) along various measures and dimensions. MITRE proposes potential CEA metrics and recommends the following for climate resilience discretionary grant programs:

- Use of CEA with explicit requirements for equity metrics to evaluate cost effectiveness to prioritize climate resilience projects over using BCA.
- Awarding agencies should consider an explicit weight for CEA, as compared to all other considerations in the application.
- In order to avoid difficult-to-distinguish differentiation between CEA metrics, awarding agencies should consider using CEA in an ordinal basis rather than using CEA metrics themselves.
- Awarding agencies can also consider setting aside funds from its authorization to establish technical assistance programs for PEGs to conduct climate risk modeling and economic analyses.
- Require continuous reporting to facilitate grant program evaluation.

Accounting for Social Capital

From a person or household-centric perspective, displacement due to disaster and climate conditions can incur major social costs that could be captured by a loss in the social capital of a person or household. Social capital can also predict an individual’s or community’s resilience to crisis, therefore building social capital can support recovery after disaster and the higher the social capital, the higher the cost of displacement. MITRE reviewed the measurement of social capital using indices and indicators and explored approaches to quantifying the social capital-related costs of displacement. Using existing social capital indices presents multiple challenges such as lack of universal applicability, predictors anticorrelated with other normative values, ideological bias, subject level (i.e., neighborhood vs. individual/household) and ambiguity over the normativity of social capital. Of the indices reviewed, we found one-to-one comparisons of the social capital of jurisdictions may be highly sensitive to differences in the definition of social capital, variation in the strength of social capital indicators for different communities, and availability in disaggregate form for different demographics. Three possible approaches to quantifying social capital-related costs of displacement were provided. For the purpose of quantifying social capital cost of climate-driven displacement, we recommend community-centered research on the most important services provided from social capital that displacement would disrupt and quantifying the costs (including barriers to access) of temporary replacement of those socially furnished services by paid services.

Next Steps

MITRE is planning to facilitate a working group session at the National Adaptation Forum conference to elicit feedback from the adaptation community on the proposed recommendations for using metrics, indicators, indices and weights both within and external to economic analyses commonly used to assess cost effectiveness to evaluate and prioritize climate resilience investments more equitably. The intention of the working group session is to gather feedback and move towards consensus on a path to greater understanding of how we might equitably and intentionally direct funding towards the communities who need it the most.

Following the working group session, it is intended that MITRE will incorporate feedback into a proposed approach that will be presented at a no-charge Technical Exchange Meeting hosted by MITRE to broaden the audience to any interested attendees.

Various use cases could be developed with government partners using the proposed approach for applicants of discretionary grant programs, as well as an overall evaluation of grant programs (assuming data is available) to understand the level of effort required (and subsequent support needed for PEGs), whether the intended outcomes materialized or if unintentional consequences exist, and the implications for social equity.

Acting on these recommendations will make it easier for the federal government to comply with Office of Management and Budget (OMB) requirements (Circular A-4) and six EOs dating back to the Clinton Administration (i.e., EO 12291, EO 12866, EO 13563, EO 13990, EO 13985 and EO 14008) that specify the need to demonstrate cost effectiveness while prioritizing investments in PEGs.

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1 Introduction

1.1 Background

Climate change hazards and risks present multidimensional challenges. For example, hazards can be single events or trends (sometimes spanning generations) with varying degrees of intensity and spatial/temporal impacts. Understanding climate change risks requires consideration beyond the traditional magnitude, likelihood, and severity characteristics, to include assessment of compounding and cascading effects in aggregate (e.g., heavy precipitation after wildfires, heat wave after severe storm).

Climate change and extreme weather hazards disproportionately impact communities and populations experiencing social inequities, including systemic racism and generational poverty. Investments in climate resilience using government funding, such as federal funds distributed through discretionary grant programs, offer opportunities for communities and populations experiencing social inequities, as long as funds are distributed fairly. In general, "climate resilience is the ability of communities to anticipate, accommodate and adapt positively to or thrive amid changing climate conditions or hazard events, and also to enhance quality of life, reliable systems, economic vitality, and conservation of resources for present and future generations [4]." However, climate resilience may be defined differently by communities and populations. For example, through a livelihood resilience lens [5], Tribal communities may define climate resilience based on local, subsistence food systems whereas non-Tribal communities may rely more on supply chains for food security in the context of climate resilience.

Pathways to achieving climate resilience are also varied with some improving social equity and some not. The concept of social equity is defined as "the fair and just inclusion in a society that allows all to participate and to prosper [4]." Social equity includes consideration of "intertemporal distributional consequences, particularly where intergenerational effects are concerned [6]." Temporal considerations can be reparative, restorative, and/or future focused. In addition to a temporal/intergenerational lens, social equity has multiple, additional perspectives to consider including awareness, procedural and eligibility, access and distribution, output, outcome, quality and process, and citizen engagement [3]. Social equity in terms of climate resilience, therefore, involves the fair and just inclusion and participation of communities to plan for and adapt positively to or thrive amid changing climate conditions and hazards.

Consideration of how social equity and climate resilience can be accounted for in federal funding and discretionary grant distributions is currently a topic of great discussion amongst climate adaptation professionals. According to initiatives aligned with Justice40, communities, cities and states applying for discretionary grant funds will need to describe how funding will be distributed to "disadvantaged communities" and federal agencies disbursing funds will need similar data to prioritize which areas receive funding [7].

Some federal agencies like the U.S. Department of Transportation (USDOT) and the Federal Emergency Management Agency (FEMA) are already specifying which data or screening tools to use for this identification in their Notice of Funding Opportunities (NOFOs). USDOT highlights several tools for use including Transportation Disadvantaged Census Tracts, EJScreen, and the Centers for Disease Control (CDC) and Agency for Toxic Substances and Disease

Registry (ATSDR) Social Vulnerability Index (SVI) [8]. The FEMA Building Resilient Infrastructure and Communities (BRIC) and the Flood Mitigation Assistance (FMA) grant programs are using the CDC/ATSDR SVI.

The sheer number of equity-related indices, indicators, and screening tools currently available and in development (the latest one to be released at the time of this report is the CDC/ATSDR Environmental Justice Index (EJI) [9]) is enough to raise concern and questions regarding which one to use and why. For example, the World Resources Institute recently identified key equity challenges cities face in accessing Infrastructure Investments and Job Act (IIJA) funds, which included the possible mismatch between the "right" data to measure equity and grant requirements "despite the number of equity screening tools and indicators currently available" [10]. One outstanding question is whether states and communities who have already spent time and resources, including community engagement, to develop their own climate and equity indicators, such as the Cincinnati Climate Equity Indicators [11] or the Minneapolis Green Zones [12], should be allowed to use these more localized measures for grant qualification and monitoring.

1.2 Purpose

MITRE conducted research to understand, analyze, and document the quantitative accounting of social equity using metrics, indicators, indices, and weights of inequity both within and external to economic analyses commonly used to assess cost effectiveness of proposed climate resilience investments. The purpose of this work is to identify the methods and data that contribute useful information to the formulation of plans, prioritization of funding, and tracking impact after implementation, while recognizing limitations and potential improvements. Our intention is to gather feedback and vet our recommendations with subject matter experts, practitioners, and government and community representatives to reach a consensus on a path towards greater understanding of how we might equitably and intentionally direct funding towards the communities who need it most. This report is intended for specialists with expertise in economics, climate resilience, social justice and equity and government agencies that administer or are planning to administer discretionary grant programs to fund climate resilience projects. This study builds upon and draws insights from various MITRE reports (see Preface) and is the third report in a series specifically exploring social equity in economic analyses.

1.3 Report Contents

This report begins by describing the context of climate resilience investments and suggested practices for evaluating equity in the planning process. Section 2 considers metrics, indicators, indices, and screening tools commonly used to facilitate equitable investments. Section 3 focuses on benefit-cost analysis (BCA) and how weighting of certain variables may be used as a sensitivity analysis to balance inherent biases. Section 4 discusses cost effectiveness analysis (CEA) as an alternative to BCA. Section 5 presents social capital and Section 6 details intended next steps.

Appendix A provides weather and climate-related hazards that are included in the National Risk Index (NRI) and the Climate and Economic Justice Screening Tool (CEJST), and also considers additional weather and climate-related hazards that are not included in NRI and CEJEST. Appendix B is a table of domains and sub-domains of equity indicators in the MITRE Social

Justice Platform (SJP) related to climate resilience. Appendix C offers a crosswalk of variables from select equity indices and screening tools with climate hazards. Appendix D is an alphabetical listing of all abbreviations (initialisms, and acronyms) listed in the report.

1.4 Priority Equity Geographies (PEG)

The first, foundational step in accounting for and improving social equity in climate resilience planning and investment is the identification of communities and/or populations who are experiencing inequities. The Justice40 initiative is giving renewed attention to the identification and definition of "disadvantaged communities," especially for funds disbursed to build resilience against climate change impacts that threaten to exacerbate existing inequities. The Office of Management and Budget (OMB) directs federal agencies to "consider appropriate data, indices, and screening tools" to determine whether a community or area is "disadvantaged" [13]. Yet, there are known challenges in the application of data, indices, and screening tools for identifying "disadvantaged communities."

First, there are multiple themes (i.e., frontline, marginalized, overburdened, socially vulnerable, underserved, etc.) within the definition of "disadvantaged," but combining themes of disadvantage may obscure community need. Therefore, community involvement is crucial to defining "disadvantage" for their area.

Within the themes of "disadvantage," populations who are disproportionately impacted by climate change and have less resources to adapt and respond to climate change effects may include those with one or more of the following attributes (among others defined by the community): [14], [15], [16], [17], [18], [19], [20], [21]

- Children
- Communities with low income, low social capital, and/or distressed neighborhoods
- Immigrants
- Lesbian, gay, bisexual, transgender, queer/questioning, intersex, asexual/aromantic/agender, plus (LGBTQIA+)
- Older adults
- People at risk of displacement
- People experiencing high poverty, homelessness, linguistic isolation, persistent poverty, segregation, unemployment, underemployment
- People experiencing a high-cost burden for housing, transportation, and/or energy
- People living in substandard housing, and/or with limited water and sanitation access
- People of racial, ethnic, and/or religious minority groups
- People who are pregnant, chronically ill, hospitalized, incarcerated, and/or working outdoors
- People with disabilities
- People with at-risk occupations (e.g., farmers, fishermen, etc.)
- People who lack risk awareness, or have limited education and/or limited access to healthcare, transportation, and/or energy

- Rural and/or frontline communities (e.g., coastal and wildland-urban interface)

As previously stated, we cannot rely solely on these attributes and available data to identify "disadvantaged communities." While data-based methods may initiate the identification of communities, community engagement is required to validate identification and add or adjust population attributes for which data may exhibit bias or may not be available.

One example of a national-level indicator validation effort for defining and identifying "disadvantaged communities" is seen in the White House Environmental Justice Advisory Council's recommendations to the White House Council on Environmental Quality for Justice40 and the CEJST. Among other recommendations, they suggested additional population and community attributes including: [22]

- High rate of health disparities
- Non-attainment of clean air and water standards
- Formerly redlined
- Food insecurity and child nutrition levels
- Children receiving school lunch program
- Numbers of superfund, waste, landfills and toxic facilities
- High maternal and infant mortality rates
- High asthma rates and deaths
- Lack of grocery stores, proliferation of bargain stores and fast-food restaurants

For this report, "disadvantaged communities," "vulnerable populations," and all similar designations of communities or populations are collectively referenced as "priority equity geographies (PEG)." We do this to highlight the importance of geography (both physical and human) in identifying priorities for climate resilience and social equity, and to reduce any detrimental population or community labels, which may perpetuate inequities.

In this report, we aim to address some of the challenges associated with the application of data, indices, and screening tools for identifying PEGs while providing recommendations for improved definitions, measures, and data-based methods that may complement community-based approaches.

1.5 Equity in Climate Resilience Planning and Process

The U.S. Army Corps of Engineers commonly uses (often iteratively) the following six-step planning process for climate resilience planning [23]:

1. Identify problems and opportunities
2. Inventory and forecast conditions
3. Formulate alternative plans
4. Evaluate alternative plans
5. Compare alternative plans
6. Select a plan

This traditional planning process can be improved to produce more equitable climate resilience projects. MITRE recommends supplementing this planning process, which combines insights from MITRE's Framework for Assessing Equity in Federal Programs (Figure 1) and the Ready-to-Fund Resilience toolkit [15] created through a partnership between the American Society of Adaptation Professionals (ASAP) and Climate Resilience Consulting and supported by a National Oceanic and Atmospheric Administration (NOAA) cooperative agreement with Climate Resilience Fund.

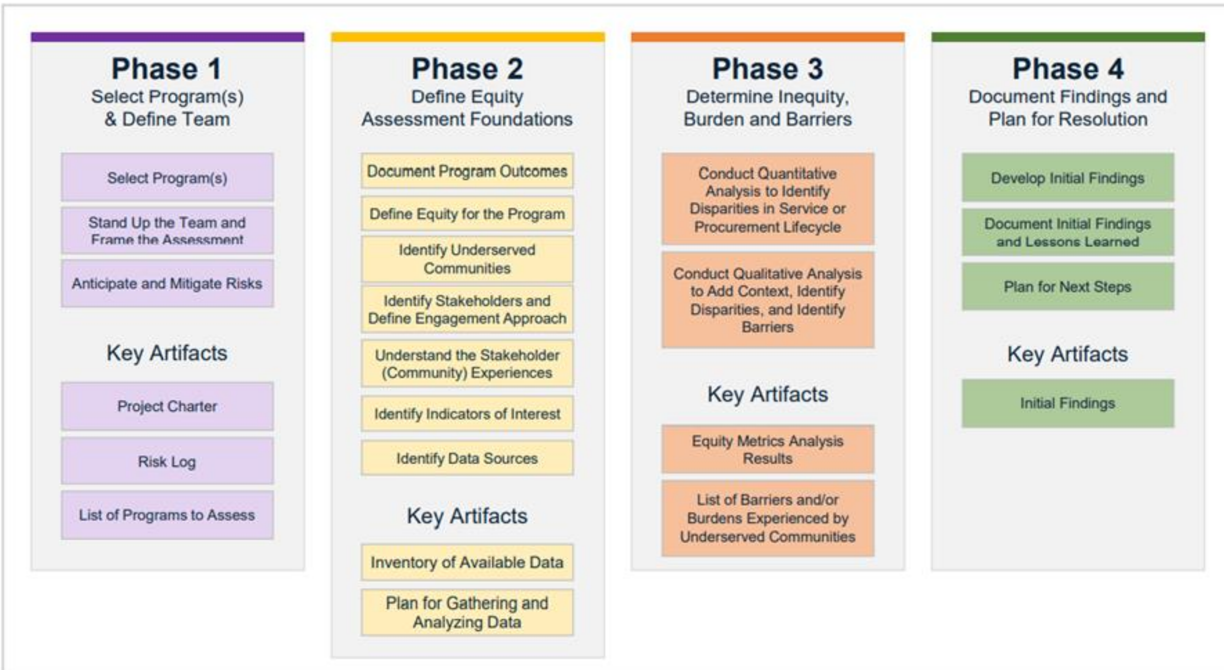

Figure 1. MITRE's Framework for Assessing Equity in Federal Programs

Prior to Step 1 of the planning process, MITRE recommends expanding the planning team to include PEG representatives for the identification and prioritization of projects. This approach is echoed in MITRE's Phase 1 (Figure 1) and requires understanding where PEGs are located within the planning area and identifying appropriate representatives that can advocate for these communities and/or populations. Section 2 discusses methods for identifying PEGs in more detail.

Supplementing Step 1 of the planning process by understanding the challenges facing PEGs and the desired project outcome(s) from the communities and/or populations is foundational to equity planning. Including a description of how social equity is being addressed as part of the desired outcome helps to frame project decisions and solutions. The description should include perspectives from the multiple lenses of equity outlined above (i.e., awareness, procedural and fairness (eligibility), access and distribution, output, outcome, quality, engagement, and temporal/intergenerational).

After identifying the targeted project or program outcomes, planners can collaborate with PEGs to define criteria/requirements to successfully achieve them. These criteria/requirements then drive decision-making when developing and evaluating solutions. Sections 3, 4 and 5 discuss incorporating equity into the evaluation (Steps 2 through 6) in more detail.

1.6 Climate Resilience Investment Prioritization Process

After an equitable climate resilience planning process has been completed, federal funding through discretionary grant programs is necessary for many communities to implement a climate resilience project. The discretionary grant process can be thought of in five steps of pre-award, award, post-award, closeout, and post-closeout as the U.S. Government Accountability Office illustrates in Figure 2 [24]. Discretionary grant programs differ from other grant programs in that grant applicants compete for funds, and federal awarding agencies review, assess, and evaluate the quality of the grant application to inform their funding decisions.

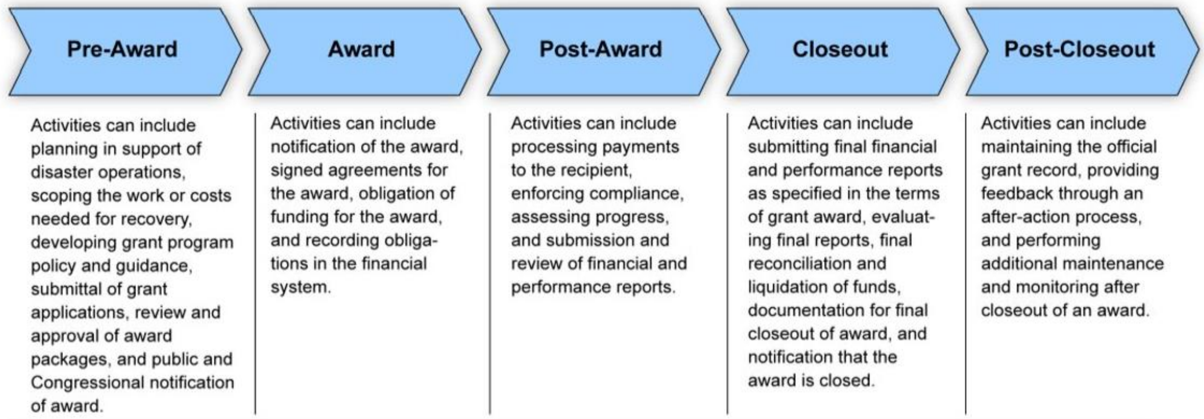

Figure 2. Discretionary Award Process from GAO (2019)

During the Pre-Award phase, federal awarding agencies announce a funding opportunity through a NOFO. The NOFO specifies the eligibility requirements for the grant opportunity and key steps of the application process. Federal awarding agencies can specify grant requirements and how applications will be evaluated in the NOFO. The Pre-Award phase aligns with the planning process (as described in Section 1.5) and in some cases communities may apply for funding to support planning activities and application development. After the application deadline, federal awarding agencies screen submitted applications for adherence to eligibility requirements. Eligible applications are then reviewed by a range of program decision partners[1] using the selection criteria outlined in the NOFO.

The Pre-Award phase offers opportunities for both the federal awarding agencies and applicants to incorporate equity into climate resilience planning and investments. The following sections provide recommendations related to measuring equity and evaluating climate resilience investments that can support the Pre-Award phase of grant programs. Some of the same measurements during the Pre-Award phase may also be used in the Post-Award, Closeout, and Post-Closeout phases to track performance of the funded projects and the overall grant program. To facilitate ongoing monitoring of selected measures, funding could cover data collection and reporting.

[1] Decision partners may include contributors, community, community members, community impacted, community affected, community of solution, coalition members, allies, colleagues, clients, Tribes, advocacy groups, interested parties/groups, implementing partners, working partners, and/or funders.

2 Quantitative Accounting of Social Equity using Metrics, Indicators, Indices, and Screening Tools

Quantitative measures can be used to facilitate PEG investment prioritization, monitor project implementation and progress, and evaluate programmatic and investment effectiveness. In the literature, there is agreement that the communities and/or populations should define these measures. The Resilience Metrics Toolkit suggests selecting indicators and metrics for six dimensions of the climate resilience building process: (1) adaptation planning process, (2) adaptation decision-making process, (3) the choice and implementation of adaptation actions, (4) the adaptive capacity of those involved, (5) the barriers to adaptation to overcome, and (6) the adaptation progress and outcomes achieved.

During the planning process for climate resilience projects, planners collaborate with PEGs to define the criteria for successful outcome(s) that can inform the selection of indicators and metrics which could be used to measure performance. It is important to consider indicators and metrics from data that capture each applicable social equity lens for a holistic perspective. Within the federal grant program structure, consensus is needed between the applicant and the federal awarding agency for the selected measures and, therefore, requires more careful consideration of the myriad options and data biases [25].

A recent National Academies of Sciences, Engineering and Medicine (NASEM) report, *Equitable and Resilient Infrastructure Investments*, found that an enabling factor for community climate resilience is the development of "a better understanding of resilience and equity gaps and related problems using data that are consistently available for analysis and metrics to track progress (or lack thereof)" [26]. Recent work exploring current understandings of community climate resilience includes the National Institute of Standards and Technology (NIST) Inventory of Community Resilience Indicators and Assessment Frameworks, which compiles existing quantitative resilience frameworks (n=57) and measures and indicators (n=7835) ranging from building to country levels of analysis [27], [28]. Review of these frameworks has shown lack of consensus in theoretical approaches, spatial scales, and indicators and measures used to operationalize concepts of climate resilience. The NASEM report further identified applied research questions echoing this lack of consensus and operationalization: "What measures and indicators are needed to help communities track progress toward improving resilience and equity and prioritize infrastructure plans and investments?" In the following sections, we explore this question and include assets beyond infrastructure (i.e., people and services) and potential solutions for improved climate resilience planning and investments.

2.1 Metric and Indicator Selection Criteria, Limitations and Recommendations

A broad approach, applicable across sectors and federal-to-local levels, for identifying key indicators for climate resilience and adaptation involves two key steps: (1) setting the goals of a climate resilience project, and (2) identifying the key process and outcome indicators for monitoring climate resilience/adaptation and equity [29]. To achieve these steps, grant applicants can ask and answer questions regarding: *Resilience of who/what? To what? For whom?* and *Over what time period?* They can also identify criteria for selecting the process and outcome indicators to effectively monitor progress toward climate resilience and equity goals. Likewise, federal agencies or grantors can follow similar criteria when selecting indicators for identifying PEGs and monitoring climate resilience project goals and outcomes.

Criteria for selecting indicators are often based on scientific validity, utility, and practicality. Such criteria may require that indicators are:

- SMART: Specific, Measurable and repeatable, Attainable, Relevant (including Spatially Relevant), Timely [30]
- Direct, Objective, Useful for Management, Attributable, Practical, Adequate, Disaggregated (as necessary) [31]
- Accepted in Practice, Applicable/Relevant in Different Settings, Available, Limiting the Burden of Data Collection on Participants, Unambiguous, Culturally Appropriate, Quality (Complete, Reliable, Valid), Transparent Regarding Investment of Resources for Data Collection and Use, Collected through Nondirectional Language, Able to Detect Unexpected or Unintended Findings, Transparent Regarding Intended Data Use and Users, Relevant to Evaluation Questions, Providing Evidence or Substantive Merit, Adding Value within a Set of Indicators [32]

While the previously mentioned criteria can be helpful in selecting appropriate indicators, we consider a few essential criteria that are necessary for maintaining the usefulness of indicators across all federal climate resilience and equity projects and investments. In narrowing these criteria, it should be noted that we have focused on federally collected and available data, which are more consistently available on a national level. We acknowledge that criteria for community-level and community-selected indicators may vary from these. Overall, when selecting indicators for federal discretionary grants programs, these key criteria must be met:

- **Measurable and repeatable; Objective:** transparent documentation for free, open data sources and methods (especially for missing data)
- **Timely; Practical; Available**: all data current at least through 2018 or newer (or less than five years old)**;** annual update frequency, or at least on a predictable schedule consistently into the foreseeable future
- **Spatially relevant:** Community-level spatial resolution (or at least Census tract for federal data)

Other criteria listed above that can improve equity considerations for selecting indicators at both the federal and community levels include whether data are: Relevant, Disaggregated (as necessary), Culturally Appropriate, Limiting the Burden of Data Collection on Participants, Transparent Regarding Investment of Resources for Data Collection and Use, and Transparent Regarding Intended Data Use and Users. In general, all the ways in which data for indicators are collected, managed, analyzed, and made available to decision makers and the public can impact equity in decision-making.

High data uncertainty is a key equity concern in the application of American Community Survey (ACS) data, often used to identify “disadvantaged communities,” and researchers and statisticians warn of possibilities for policy failures [33], [34]. For example, with the introduction of online responses for the 2020 Census, researchers and community activists raised concerns that unequal broadband coverage puts traditionally hard-to-count populations at an even greater disadvantage for the Census [35]. Other studies show consistent decline in response rates for mail-in surveys, subsequently calling into question the reliability and use of survey data overall [36].

Some other known limitations that restrict the effective implementation of social equity related indicators, whether utilizing ACS data or not, include:

- Lack of direct measures or data related to improving equity or increasing resilience, which may vary depending on the stressor or hazard
- Lack of appropriate justification of indicators included
- Infrequent and insufficient validation of indices [37], [38]
- Infrequent use of sensitivity and uncertainty analysis with indices

The lack of inclusion or availability of direct measures of climate resilience and equity for prioritizing and monitoring investments is certainly one of the biggest hurdles facing both federal and community decision-makers. The climate adaptation field is attempting to address this problem by increasing federal and community engagements around this issue to formulate solutions. In the meantime, federal discretionary grant programs can continue to support advancement in this area through clear expectations for data collection and reporting at the project level. To overcome some of the other limitations mentioned above, we considered work from scholars who have explored these issues and their recommendations:

- Rely on multiple sources to evaluate priority equity geographies [39]
- Consider whether area-based or population-based data are preferable, which may vary by geography (i.e., urban vs rural) [40]
- Reduce uncertainty or margin of error in the use of ACS through data-driven regionalization [33]. This recommendation must be weighed carefully with the need to show data at the "neighborhood" or Census tract level recommended above under spatially relevant criteria. If the Margin of Error (MOE) at the Census tract level is acceptable, moving to a coarser Census division, like County, may not be necessary.

The selection criteria, limitations and recommendations outlined thus far provide opportunities and challenges in deciding which climate resilience and equity metrics to use for the grant application process and monitoring of funded projects.

2.1.1 Climate and Weather Hazard Metrics

Common weather and climate-related hazards, that is "events that could result in damage to assets [people, places, and services]," are identified by the NOAA U.S. Climate Resilience Toolkit and include: avalanche, coastal flooding, cold wave, drought, hail, heat wave, hurricane, ice storm, landslide, riverine flooding, strong wind, tornado, wildfire, winter weather (see descriptions in Table A-1, Appendix A). These overlap with 14 of the 18 natural hazards in the FEMA NRI, which are also included in the *beta* version of the CEJST (Table A-2, Appendix A). Yet, there are opportunities to go beyond these hazards to include other climate-related hazards and future climate projections. The annual State of the Climate in 2021 report by the American Meteorological Society lists 24 climate variables that are fully monitored spatially and temporally on a global scale [41]. Some of these variables, such as sea surface temperature and river discharge, could be added for consideration in the NRI along with future climate projections when available. Based on a review of climate indicators and impact-drivers as listed by the Intergovernmental Panel on Climate Change (IPCC), the Environmental Protection Agency (EPA), the U.S. Global Change Research Program (USGCRP), and the U.S. Department of Agriculture (USDA), some additional hazards and the rationale for inclusion are found in Table A-2 (Appendix A). The Climate Mapping for Resilience and Adaptation (CMRA) tool developed in August 2022 through a federal interagency partnership includes both historical data and future projections for extreme heat, drought, wildfire, inland flooding, and coastal flooding [42]. Since this tool was created specifically for climate resilience planning and investments, including decision-making for grant funds, adding additional climate hazards to the CMRA platform instead of the NRI may be more beneficial for evaluating current and future local exposure to climate-hazard risks.

2.1.2 Equity Metrics

The MITRE Social Justice Platform is creating an Equity Indicator Catalog, where equity lenses may be aligned with the domains and sub-domains of equity indicators listed in Table 1 [3]. While these domains and sub-domains are reflective of those used across most equity-related indices and lists of indicators, an opportunity exists to add climate-related hazard data to complete the catalog of indicators for examination in climate resilient planning and investment.

Table 1. Excerpt of Domains and Sub-Domains of Equity Indicators in the MITRE Social Justice Platform with Examples of Equity Lenses

Equity Indicator Domain	Equity Indicator Sub-Domain	Equity Lens
Demographics	Age	Temporal/Intergenerational
Demographics	Citizenship	Procedural and Fairness
Economy	Poverty	Outcome
Education	Education Quality	Quality and Process
Environment	Disaster Preparedness	Quality and Process
Environment	Urbanization	Access and Distributional
Health	Health Insurance Status	Output
Justice	Crime	Outcome
Social Context	Civic Engagement	Citizen Engagement
Technology	Broadband	Access and Distributional
Transportation & Land Use	Housing	Access and Distributional

Note: Full table found in Appendix B, Table B-1.

2.2 Evaluating Indices and Screening Tools for Climate Resilience and Equity

Given the climate and equity metrics and indicators described in the previous section, we were interested in seeing which national indices or sets of indicators included climate hazards from Table A-1 in Appendix A and equity domains and sub-domains from Table B-1 in Appendix B. We considered Area Deprivation Index (ADI), Behavioral Risk Factor Surveillance System (BRFSS) – PLACES, CDC/ATSDR Social Vulnerability Index (SVI), CEJST, Child Opportunity Index, Community Need Index, County Health Rankings, Distressed Community Index, EJScreen, Gallup-Sharecare Community Well-being Index, Livability Index, Opportunity Index, USC Social Vulnerability Index (SoVI) as part of the NRI, and Vulnerable Populations Footprint. After applying the essential criteria in Section 2.1, the remaining CDC/ATSDR SVI, CEJST, NRI/SoVI, EJScreen, ADI, and the Livability Index (Table C-1 in Appendix C) were selected for a crosswalk with climate hazards and social equity sub-domains. CDC/ATSDR SVI, ADI and the Livability Index have an obvious gap of climate hazards. Therefore, these need to be supplemented with climate hazard data from other sources for use in the discretionary grant process for increasing climate resilience. Likewise, there are gaps in different aspects of social equity where applicants and grantors may need to carefully weigh options and select the appropriate index or set of indicators for the context of their project and their vision of climate resilience and equity success.

Across the U.S., the prevailing models for mapping social vulnerability – a key theme of "disadvantaged communities" and PEGs – on a county or Census tract level have been the SoVI created by the University of South Carolina [43], which is incorporated in the NRI, and the CDC/ATSDR SVI developed at the U.S. Centers for Disease Control [8]. The research literature regarding the practical application of social vulnerability indices and composite indicators questions their use [44], [37], [38]. Both SoVI and SVI have been found to have weak construct validity and explanatory power when examined against outcomes from Hurricane Sandy, for example [38]. SVI exhibited a negative relationship with housing damage, property loss, and number of renters affected by Hurricane Sandy. An analysis of SoVI has found theoretical shortcomings and internal consistency issues, where an increase in unemployment rates has been shown to correspond with a decrease in overall vulnerability in some areas, suggesting against its use [45]. As found in [44], using the single variable of poverty identified close to the same county and sub-county level as using SoVI and SVI, begging the question, "Should we simply use single measures of equity instead of complex indices that may confound outcomes?" And, if we continue to use complex indices such as SVI, "How can we apply them for equitable and reliable outcomes?"

In the following section, we evaluate the CDC/ATSDR SVI as one of the tools federal agencies recommend using when identifying PEGs for climate resilience planning and investments. Our analysis aims to better understand how data variability and bias in indices and screening tools that use ACS and Census data may contribute to identification of PEGs. Through this examination we illustrate issues of reliability and data clustering, which may inform recommendations for improving the application of indices and screening tools dependent on ACS and Census data.

2.2.1 Evaluation of the CDC/ATSDR Social Vulnerability Index (SVI)

Data used to construct the SVI developed at the U.S. Centers for Disease Control [8] was drawn from the ACS in 2018. The sampling methods and response rates mean there is differential reliability with the estimates for each variable in each county/Census tract. Since the SVI combines these different variables, this means not all SVI scores are created equally – some are more reliable than others.

The total uncertainty in the SVI is composed of the individual uncertainty in each of the variables as well as the errors in the joint behaviors of variables. We use the percentile rank transformed variable used to additively create the SVI to keep the variables on the same scale. To get an estimate of total uncertainty, we treat each variable independently to get rid of joint effects, square the MOE of each variable, sum them, and then take the square root to get the MOE of the SVI. This gives a lower bound of the total uncertainty. Since the total uncertainty of a county is tied to population size (generally, larger populations have better samples and more certainty), we normalize by county population size to have a per capita comparison of county MOEs. For this analysis, we looked at county level data because the ACS estimate error increases as we increase the geographic resolution.

In Figure 3, we map out the per capita uncertainty percentile rank of each county in the SVI and see where the SVI is more reliable and less reliable. Rural counties in the Great Plains and Mountain West have the least certainty in their scores. In addition, parts of the South and Gulf Coast have high uncertainty. This means it is more difficult to trust and compare the SVI scores of these areas. It’s important to note that due to area size of counties in the Midwest, their influence may be visually overstated in comparison to smaller counties in states like Delaware.

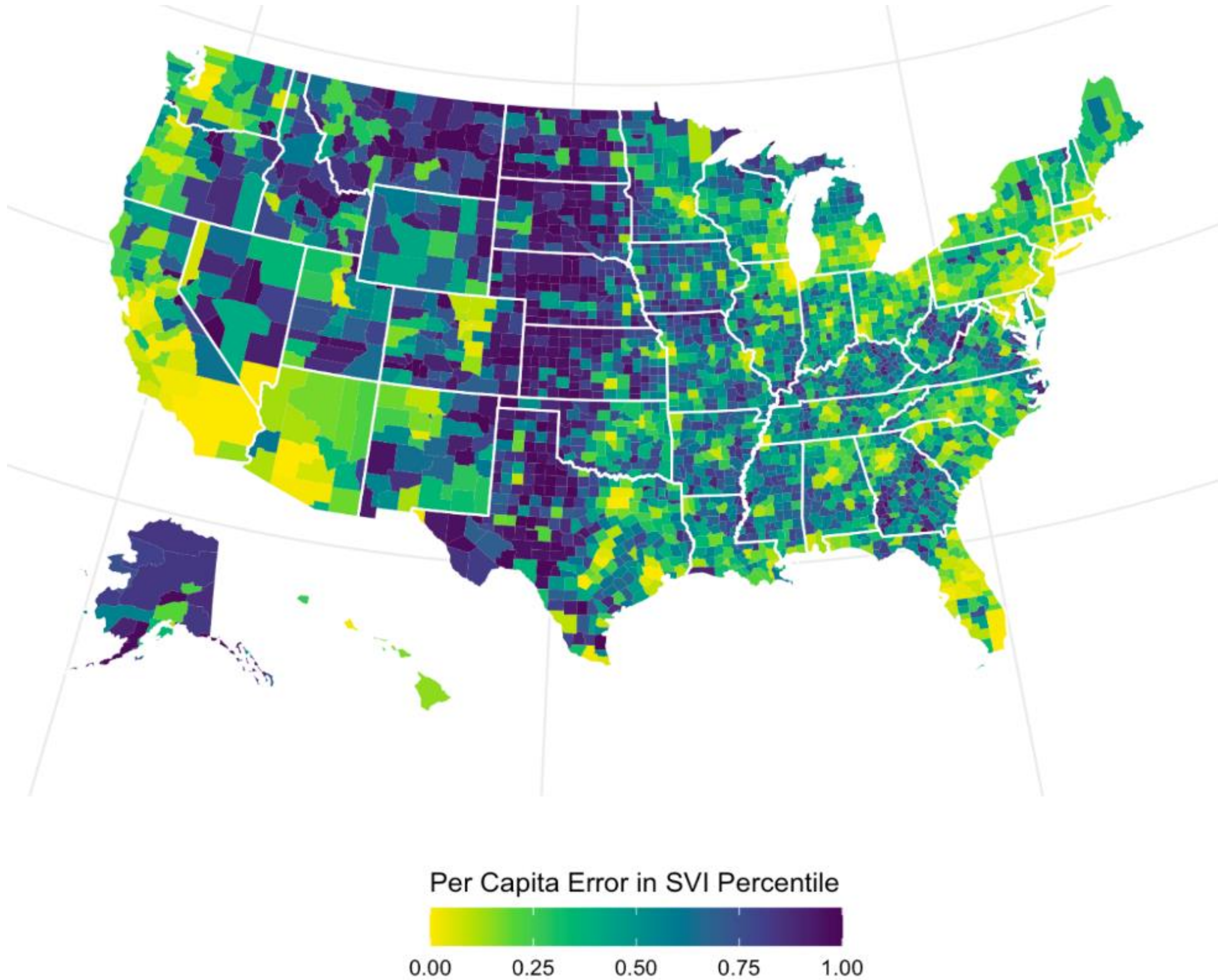

Figure 3. SVI Reliability Measured by Per Capita Error in Ranked SVI Percentile

To illustrate how total per capita error in SVI scores relates to reliability, we examine two communities/counties across the country. The Bronx is a vulnerable community in New York with a predominately Black and Hispanic populations. During Hurricane Sandy, this area received a lot of damage. It ranks in the top 1% of SVI scores and is precisely measured with a total error of 16.2 (measure of uncertainty). Jefferson County in Texas is located near the Gulf Coast and is also a highly vulnerable community that has experienced four large hurricanes since 2005. This area is also a predominately Black community. Its SVI score is in the top 15% but it is imprecisely measured and has a total error of about 24.7. The error propagated in calculating the SVI score for Jefferson County is 50% more than it is for Bronx County. This large difference in certainty makes it hard to rank the Bronx as more vulnerable than Jefferson County because the true vulnerability of Jefferson County may be much higher. In fact, assuming a normal distribution on the true value of SVI score for these counties given the error we calculated, there is a 45% chance that Jefferson County is more vulnerable than the Bronx even though the SVI scores would convey the opposite result. Similarly, since Jefferson County is imprecisely measured, there is a probability that it has a lower SVI score than a county which was scored lower but more precisely. Not having certainty one county is less vulnerable than the other jeopardizes informed decision making when allocating limited funds. The uncertainty in the SVI can lead one to neglect the needs of PEGs and lead one to allocate funding to counties which are not truly PEGs.

In addition to how reliable the SVI is in each county/Census tract, we are interested in what equity themes within the SVI can be used to group together different counties. While we have a direct formula to calculate SVI scores from the 15 variables, it is not clear if counties have similar profiles of those variables. To create those profiles, we fed all the percentile rank transformed variables used to calculate the SVI into a K-means algorithm. We identified four main clusters for all counties after testing multiple numbers of clusters. We then performed Principal Component Analysis (PCA) to visualize the SVI in two dimensions. We then performed Principal Component Analysis (PCA) to visualize the SVI in two dimensions.

According to the proportion of variance in the data, Dimension 1 explains 32.3% of the variance and Dimension 2 explains 22.1%. Dimension 1 is roughly 1.5 times as important as Dimension 2. To characterize each dimension, we look at the variables with an absolute weight of over 0.3 in the dimension. The first dimension is described by variables which correspond to *socioeconomic status* (i.e., per capita income estimate, persons below poverty estimate, persons (25+) without high school diploma, civilian (age 16+) unemployed estimate) and the variables in the second dimension correspond to *vulnerability* (i.e., minority (all persons except white, non-Hispanic) estimate, persons aged 65 and older estimate, civilian noninstitutionalized population with a disability estimate, persons (age 5+) who speak English "less than well" estimate, housing in structures with 10 or more units estimate, persons aged 17 and younger estimate). Note that other data and factors could be used to define socioeconomic status and vulnerability and the data included in these broad categories was limited to the data available in SVI.

As shown in Figure 4, we found the four identified clusters fall into the four quadrants of these dimensions. This allows for mathematical description of the counties as high/low socioeconomic status and high/low vulnerability, two different equity themes.

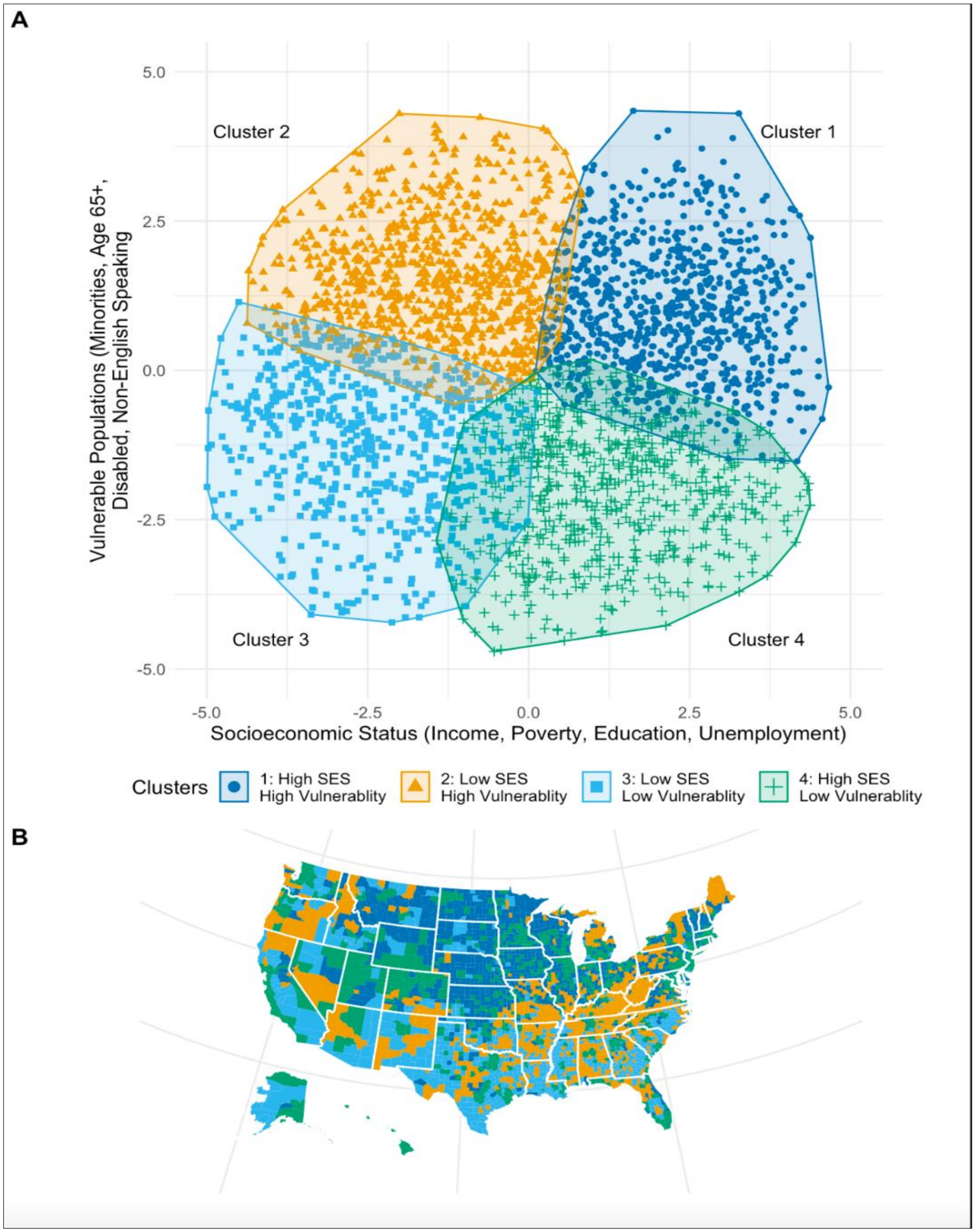

Figure 4. A. Map of SVI Clusters by Socioeconomic Status (SES) and Populations Characteristics of Vulnerability; B. Map of SVI Clusters

Cluster 1 is composed of high socioeconomic status (SES) and high vulnerability; Cluster 2 is composed of low SES and high vulnerability; Cluster 3 is composed of low SES and low vulnerability; and Cluster 4 is composed of high SES and low vulnerability. On average, Clusters 2 and 3 have the highest SVI scores while Cluster 1 has the lowest (Table 2). It would be expected that Cluster 2 (Low SES, High Vulnerability) would have the highest average SVI score, however Cluster 3 has the highest average SVI score. Cluster 1 is primarily in the Great Plains regions, Cluster 2 is in the South and parts of the West, Cluster 3 is also in the South and parts of California, and lastly Cluster 4 includes major U.S. cities. One way to make sense of why Cluster 3 has higher SVI scores than Cluster 2, is to note that Dimension 1 or SES is a stronger indicator of SVI and PCA gives it more weight. In addition, Cluster 2 may have more older adults, but Cluster 3 has more minority populations which correlates more strongly with the SES variables. Overall, SES status plays the most important role in determining SVI followed by vulnerability, and we identify communities in Clusters 2 and 3 as those with the highest average SVI scores.

Table 2. Cluster Breakdown by SVI Percentile Thresholds

Cluster (Average SVI Score)	Proportion ≥0.6 SVI	Proportion <0.6 SVI	Proportion ≥0.8 SVI	Proportion <0.8 SVI	(n)
1 (5.28)	.000	.469	.000	.352	883
2 (8.25)	.403	.201	.258	.288	885
3 (9.81)	.483	.020	.723	.076	645
4 (6.86)	.114	.310	.019	.285	728
(n)	1257	1884	629	2512	

The FEMA NOFO for the BRIC program that was released in August 2022 suggests using SVI scores in the top 40% (SVI Percentile Rank ≥0.6) or 20% (SVI Percentile Rank ≥0.8) in their application process. "Areas with CDC SVI greater than or equal to 0.6, as well as Economically Disadvantaged Rural Communities and geographic areas within Tribal jurisdictions are considered disadvantaged" [46]. FEMA will also review subapplications from Economically Disadvantaged Rural Community (EDRC), federally recognized Tribal government, or community with an SVI ≥ 0.80 unable to calculate a BCA at the time of application with the understanding that FEMA will assist those subapplicants with developing BCAs if they are down selected prior to award. The communities in areas with an SVI score of 0.6 or above would be identified as "disadvantaged" and conversely, the communities below that threshold could be considered "advantaged". To see how well that threshold identifies "disadvantaged" communities, we can check how it corresponds to Clusters 2 and 3. Conversely, we also want to make sure the threshold accurately identifies "advantaged" communities as Cluster 1 and 4 which have a lower SVI score on average.

In Table 2, when we look at the top 40% of SVI scores (≥0.6), we find that 1,257 counties would be identified as "disadvantaged" areas and that 88% of these counties fall into Clusters 2 (Low SES, High Vulnerability) and 3 (Low SES, Low Vulnerability) which is consistent with what we analytically found as a "disadvantaged" community. Table 2 also shows that none of the counties in Cluster 1 are in the top 40% of SVI scores, despite having high vulnerability groups. Looking below this threshold at the bottom 60% of SVI scores, we see 78% of counties are in Clusters 1 and 4, which corresponds to the "advantaged" counties. In comparison, when we look at the top 20% of SVI scores (0.8), there are 629 counties in consideration and 97% of them fall into

Clusters 2 (Low SES, High Vulnerability) and 3 (Low SES, Low Vulnerability). This adheres strongly with identifying the “disadvantaged” counties we found as well. However, of the counties below this threshold, 63% are in Clusters 1 and 4. This means a threshold of 0.8 will mislabel counties in Clusters 2 and 3 as “advantaged” counties 37% of the time while a threshold of 0.6 will only do so 21% of the time.

A threshold of 0.8 is less likely to identify a less “disadvantaged” county or community than a threshold of 0.6, and more likely to identify a vulnerable county as an “advantaged” community. Given the better balance of how communities of concern are distributed between clusters, we recommend using 0.6 as the threshold to provide assistance with developing economic analyses prior to award if grant applicants are down selected. Furthermore, assuming no changes to the calculation of SVI scores to account for reliability or MOEs, we recommend prioritizing communities that fall into Clusters 2 and 3, as they align more closely with the most “disadvantaged” communities according to the SVI.

When we combine the two branches of analyses: estimating reliability of SVI scores and equity themes clustering, we see that, on average, clusters have significantly different reliability from one another. Geographically, we see the clusters follow a clear pattern where Clusters 2 and 3 describe counties mostly in the South and rural areas of the U.S. as shown in Figure 4.B. This suggests not only are highly “disadvantaged” communities in the Midwest and South, but they are also the ones with the least reliable SVI scores as shown in Figure 5. Even when counties are like others in the dimensions of SES and/or vulnerability and have similar SVI scores, they may have very different reliability in their SVI scores. Overall, Cluster 2 (Low SES, High Vulnerability) has less reliability than Cluster 3 (Low SES, Low Vulnerability) as shown in Table 3. Cluster 4 (High SES, Low Vulnerability) has the least uncertainty associated with the SVI scores, demonstrating that SVI scores are more reliable for identifying the least “disadvantaged” communities. Note that earlier in the document we normalized the total error by the population and scaled it to fit in [0,1] to show trends in per capita error. However, in order to keep some measure of per capita error in an interpretable scale, we chose to normalize by the log of the population size in Table 3 and observe the same patterns described above with the clusters.

Table 3. SVI Total Errors by Cluster and Threshold

Cluster	Total Error Range: [3.54, 138.21]	Total Error / log(Population Size) Range: [0.33, 24.02]
1	43.32 ± 0.890	4.78 ± 0.141
2	40.25 ± 0.683	4.22 ± 0.104
3	37.27 ± 0.806	3.78 ± 0.112
4	30.99 ± 0.807	2.83 ± 0.122
Threshold		
Above .6	37.09 ± 0.589	3.74 ± 0.085
Below .6	39.22 ± 0.601	4.11 ± 0.094

As we demonstrated earlier, this has important implications for ranking communities according to SVI scores. Even if one community has a better SVI score than another, the MOE can be much larger making it unclear if that community is truly less socially vulnerable or just appears so because of the data sample. Caution must still be exercised while using a threshold to identify PEGs for this reason as well.

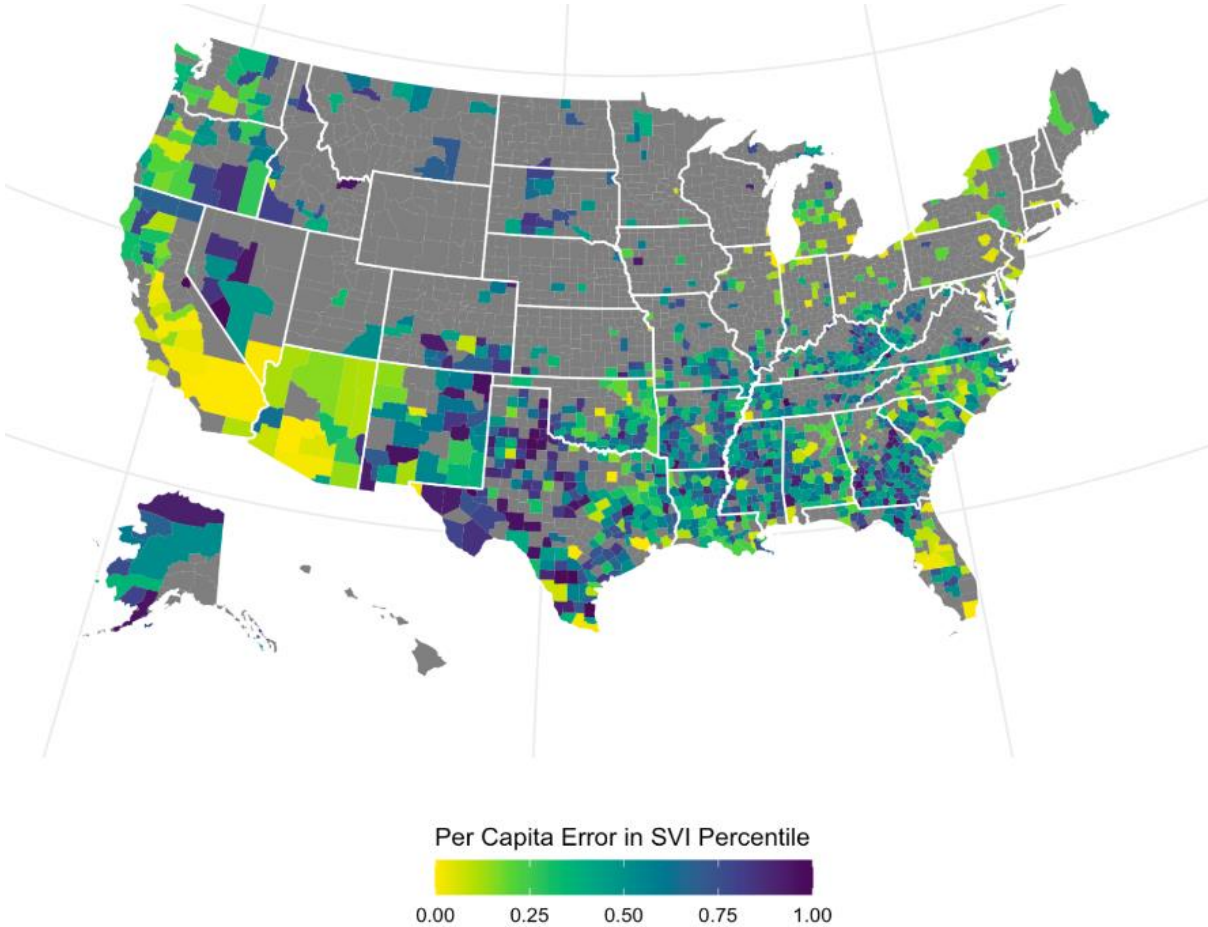

Figure 5: **Map of Percentile Per Capita Error in SVI for Counties in Top 40% of SVI Scores**

One way to take the differential reliability into account is to recalculate the SVI by weighting by the total error or each component error. Alternatively, we reweight the scores by population size, as a proxy for the total uncertainty. In addition, we can make fairer comparisons between counties by considering them within their local context rather than a national context. Because the SVI is constructed by percentile ranking and summing all of its variables, the rank of a county can differ greatly depending on the context of that to which it is being compared. A county may have low income compared to the rest of the nation but high income with respect to other counties in its state, or vice versa. Communities are subject to local dynamics of socioeconomics, policies, and other factors; consequently, in addition to national SVI scores, considering SVI scores with respect to fellow communities in an area, or region gives more context to a county's score and can help create fairer assessments. For example, state level SVI scores are already provided, but not the ability to compare multiple counties that are not within a state. The choice in the reference region can be informed by expert opinions. King County in Washington state, for example, worked with the Department of Homeland Security to create a cohort for defining an area for constructing SVI scores. The Urban Area Security Initiative

(UASI) designates a geographical area designed by DHS to demarcate the whole metropolitan area around many major American cities [47].

We can further enhance the SVI by decomposing some of its measures. The Minority Health SVI by the CDC and Department of Health and Human Services (HSS) does this by decomposing Minority and Linguistic Isolation into different races and different languages, and in doing so, acknowledges that the effects of threats to vulnerable communities are, on aggregate, experienced differently by people of different races. This version of the SVI also adds dimensions of Medical Vulnerability and Healthcare Infrastructure and Access. By doing so, they were able to understand which communities and racial/ethnic groups were at the greatest risk for COVID-19 [48].

2.2.1.1 Limitations of SVI in the Context of Climate Resilience Planning

The limitations of the CDC/ATDSR SVI in the context of climate resilience planning and investment include:

- SVI is designed for identification of PEGs based on geographic boundaries. That is, it does not address a geographically dispersed population (such as migrant workers or persons experiencing homelessness). Since SVI reflects traits of a Census population boundary (e.g., Census tract), it may not be useful in establishing project goals, estimating likely benefits/outcomes, and evaluating benefits/outcomes beyond those boundaries. Careful attention may be warranted when considering projects related to climate hazard displacement or planned relocation.
- SVI is a cumulative index. Its subthemes or individual variables may be better suited for identifying PEGs depending on project goals.
- SVI does not include any climate indicators or hazards, which calls into question its use for climate resilience planning and investments. A RAND report suggested Census variables from the SVI could be juxtaposed with climate variables from the NRI for these purposes [49].
- There are several measures that are negatively correlated with other measures in their respective themes and negatively correlated to the entire SVI score as a whole. For example, Housing in Structures with 10 or More Units Estimate is negatively correlated with the rest of the sub pillars and variables like Persons Age 65 and Older Estimate are negatively correlated with the whole SVI index.
- The SVI has coverage for all counties for all variables except for Rio Arriba County, New Mexico, in variables for per capita income estimate, persons below poverty estimate, civilian (age 16+) unemployed estimate.
- Data in SVI does not include key social equity variables from various equity domains and sub-domains as shown in Table B-1 in Appendix B.

2.2.1.2 Key Recommendations for Using SVI in the Context of Climate Resilience Planning

Based on our evaluation of SVI, we have the following recommendations for balancing the SVI scores with the accuracy and certainty of those scores. The following methods account for the

SVI score as calculated and make recommendations for alternative calculations if we are less certain about the original SVI score. It is important to note that the adjusted SVI scores from these calculations would mean PEGs with fewer people will get a larger boost in their SVI scores due to them having more error in their estimates. If funding allocation probability increases with SVI scores, implications of this include allocating funding towards populations who may or may not be more vulnerable than the SVI score indicates but also perhaps draw away funding from precisely measured communities with high SVI scores. The latter situation would likely apply to low income areas in large coastal cities as was exemplified with the Bronx but as we have seen, over 90% of FEMA BRIC funding in 2020 went to coastal communities leaving geographies in the Gulf, Midwest, and Mountain West underfunded. To balance the implications mentioned, a scaling factor for how much to weight the reliability may be chosen.

- We can use the MOE from the ACS data in the SVI to weight the variables/score through one of the following approaches which are ranked in terms of complexity.
  - Percentile rank each county's MOE for each variable, multiply/divide the variable percentile rank by the corresponding MOE.
    - Let X_{ij} be the percentile rank transformation of variable i for county $j$and let $MOE(X_{ij})$ be the margin of error of variable i for county j. Let a_i be some scaling factor for the margin of error of variable i. Then the new SVI score of county j is:

$$SVI_j^* = \sum_i X_i * a_i * MOE(X_i)$$

  - Percentile rank each county's total MOE and multiply/divide the overall SVI score/percentile rank by this rank.
    - Let SVI_j be the percentile rank transformation of the SVI score of county j and let $MOE(SVI_j)$ be the total estimated error in the SVI score of county j. Let a be some scaling factor. Then the new SVI score of county j is:

$$SVI_j^* = SVI_j * a * MOE(SVI_j)$$

  - Normalize SVI score by population size since the error tracks inversely with population size.
    - Let SVI_j be the SVI score of county j and let P_j be the estimated total population of county j. Then the new SVI score of county j is:

$$SVI_j^* = \frac{SVI_j}{\mathrm{P_j}}$$

- To increase specificity of vulnerability assessment of local communities, we can report SVI rankings according to smaller regional windows instead of the nation, e.g.:
  - Within the state
  - Within the region
  - Within the clusters of high or low socioeconomic status (poverty, income, education, unemployment rate) and high or low vulnerability (minority status, disability, linguistic isolation, age > 65)

- Within a community-defined area such as the Urban Area Security Initiative (UASI) in Washington State and King County.
    - Urban Area Security Initiative [50]
    - King County SVI [47]

- Minority Health SVI offered by HSS, OMH, and CDC extends the SVI by including Social Determinants of Health (SDOH) and two additional themes: medical vulnerability and healthcare infrastructure/access. This version of SVI draws data from non-ACS sources, and it expands the Minority Status and Language Dimensions to disaggregate by race. A threshold or flag variable for low income and Black, Indigenous, and People of Color (BIPOC) communities can show when/where a community falls into a cluster. Designating the threshold for a single variable or the total index value at 0.6 or 0.8, for example, could offer different advantages for different climate resilience planning and investment outcomes.

2.2.2 Climate and Environmental Justice Screening Tool (CEJST)

The Justice40 Initiative is an example of a program designed to incorporate social equity into environmental justice planning, investments, and solutions. The program is coordinated by the Council on Environmental Quality (CEQ), the White House OMB, and the White House Climate Policy Office (CPO). As stated in *Executive Order 14008, Tackling the Climate Crisis at Home and Abroad*, it is the policy of the "Administration to secure environmental justice and spur economic opportunity for disadvantaged communities… [Therefore] Agencies shall… [develop] programs, policies, and activities to address the disproportionately high and adverse human health, environmental, climate-related and other cumulative impacts on disadvantaged communities, as well as the accompanying economic challenges of such impacts" [51].

The Administration issued interim guidance on the definition of "disadvantaged" communities for development of the beta version of the CEJST, which is a "geospatial mapping tool [developed] to identify disadvantaged communities that are marginalized, underserved, and overburdened by pollution" [52]. To identify "disadvantaged" communities, agencies should consider appropriate data, indices, and screening tools to determine whether a specific community is "disadvantaged" based on a combination of variables that may include, but are not limited to, the attributes listed under Section 2.1 of this document. In determining which attributes to consider, agencies should consider the statutory authority for covered programs.

In the beta version of CEJST, "To be considered disadvantaged, a census tract must exceed the cutoff values for both (1) an environmental or climate indicator, and (2) the corresponding socioeconomic indicators" [52]. "The *beta* version of the CEJST uses thresholds rather than indexing, which enables the tool to account for regional, state, and other geographic differences across the U.S., including between urban and rural areas. Each threshold is measured independently, and the thresholds do not compete with each other. In other words, adding a new threshold to the methodology will add some communities to the definition of disadvantaged without having to remove other communities [52]." In addition, the threshold methodology is intended to address concerns that areas of the country that have less available data could be penalized in an index. Therefore, the use of thresholds of particular indicators for decision-making is an improvement over the combination of all indicators in an index or score.

2.2.2.1 Limitations of *Beta* CEJST in the Context of Climate Resilience Planning

Unlike the CDC/ATSDR SVI, *beta* CEJST does incorporate climate hazard data via three loss-rate indicators—agriculture, building and population—based on 14 of the 18 NRI climate and weather hazards. This addition creates a screening tool more capable of capturing the variability of climate hazards and resilience in relation to social equity. However, the limitations of *beta* CEJST are similar to those of the CDC/ATSDR SVI when it comes to the use of Census variables for quantifying equity and disadvantage themes. Some of these limitations include the following:

- CEJST is designed for identification of PEGs based on geographic boundaries. That is, it does not address a geographically dispersed or mobile set of individuals (such as migrant workers or persons experiencing homelessness) who experience common conditions. Since CEJST reflects traits of a Census population boundary (e.g., Census tract), it may not be very useful in establishing project goals, estimating likely benefits/outcomes, and evaluating benefits/outcomes beyond those boundaries. Careful attention may be warranted when considering projects related to climate hazard displacement or planned community-led relocation.
- Timescales of datasets and sources for *beta* CEJST vary. For example, the time scale for the CDC USALEEP data on low life expectancy is 2010-2015 and EPA EJScreen data on diesel PM exposure is from 2014, whereas most other datasets range from 2015-2021. Given the changes that can occur in population demographics and land use and land cover from rapidly evolving societal shocks and stressors such as the pandemic and climate change hazards, consistently including datasets within the last five years prior to the latest screening tool or indicator update is preferrable. If best-available data is outdated for a metric of interest, proxy data that have been collected or assessed more recently may be useful replacements.
- CEJST uses 'low income' as a socioeconomic indicator threshold in seven of eight categories. The eighth category uses 'education attainment' as a socioeconomic indicator threshold. There are many other valid indicators of equity that may be useful in identifying PEGs depending on the goals of an investment or project.
- CEJST has potentially important gaps in its climate category indicators, as it only includes 14 types of climate-related disasters. CEJST does not address several other relevant natural climate-impact drivers that affect society and cause shifts in marine, fresh water, and land ecosystems (see Table A-2 in Appendix A).
- CEJST leverages historical data but does not include future projections of climate change, population demographics, land use and land cover. The recently developed CMRA tool that includes both historical data and future projections for extreme heat, drought, wildfire, inland flooding, and coastal flooding is useful for evaluating current and future local exposure to climate-hazard risks. CMRA ties in the "disadvantaged community" classification based on CEJST, so combining both CMRA and CEJST may allow for a more comprehensive future view of climate resilience and social equity.

2.3 Summary of Recommendations

In addition to the specific recommendations outlined above in Section 2.2.1.1. for using the CDC/ATSDR SVI in climate resilience planning, we advise federal discretionary grant programs to consider other practices for improving equity in climate resilience planning and investments. Recommendations for the selection and use of climate resilience and social equity metrics, indicators, indices, and weights (external to economic analyses commonly used to assess cost effectiveness of proposed climate resilience investments) include the following:

- Define communities or populations who may experience disparities in climate resilience and social equity requiring increased planning and investments from discretionary grant programs as Priority Equity Geographies (PEGs). This term replaces more negative terms like "disadvantaged communities" and "vulnerable populations" while also serving as an umbrella term that can encompass multiple themes within definitions of social equity (i.e., frontline, marginalized, overburdened, socially vulnerable, underserved, etc.). PEGs also highlight the importance of geography (both physical and human) in identifying priorities for climate resilience and social equity.
- Merge federal (top-down) with community (bottom-up) frameworks and processes for selecting and validating indicators for identification of PEGs as well as monitoring and achieving discretionary grant program and funded project goals for a more equitable, climate resilient outcome. Federal-level frameworks, such as MITRE's Framework for Assessing Equity in Federal Programs (Figure 1), can be merged with more community-level ones like ASAP's Ready-to-Fund Resilience toolkit and the Resilience Metrics toolkit. Bringing together community and federal-level frameworks for the climate resilience investment prioritization process may require additional time in the Pre-Award phase (Figure 2) but may also lessen time needed in consecutive phases, such as the Award and Post-Award phases, when agreement between the grantor and grantee are beneficial for monitoring progress and enforcing compliance.
- Consider current, historic and future climate hazard data. Currently, the best tool to do this seems to be the CMRA. However, it only includes five climate hazards. Efforts should be made to incorporate additional climate hazards in updates of this tool. Other indices and screening tools evaluated in this report that do not include climate data need to work hand-in-hand with a tool that does, similar to how CMRA incorporates "disadvantaged communities" from CEJST.
- Acknowledge and account for the limitations of survey data, especially when they are applied when evaluating social equity themes. Error, uncertainty, and/or reliability of survey-based indicators need to be assessed and accounted for via weighting. Non-survey variables, such as broadband availability, may also be incorporated. To find other candidate measures that meet criteria and equity lenses, we recommend selection from existing databases such as the MITRE Social Justice Platform Equity Indicator Catalog.
- Finally, since changes in methods and weights for evaluating geographic data associated with climate resilience and social equity may result in identifying different PEGs, consider consulting a minimum of three indicators, indices or screening tools with different datasets and a combination of demographic and geophysical attributes. Selection of local or national-level indicators from a dashboard like the Building Environmental Justice Tool [53] may be one way forward.

3 Equity in Benefit-Cost Analysis (BCA)

Benefit-cost analysis (BCA) is a pragmatic framework designed to enable the formal comparison of disparate benefits and costs using the same metric—money. Methodologically, BCA sums all benefits that society accrues from an action and then subtracts all costs imposed by the action to derive net benefits (in dollars) to society. Maximizing net benefits is a measure of economic efficiency[2] and represents one of the fundamental criteria for evaluating proposed government actions. Positive net benefits indicate that the benefits of an action exceed the costs, therefore it can be considered an efficient use of resources. Various methods, based in economic theory, can be used to monetize goods and services not sold in traditional markets. Monetary valuations of these non-market goods and services are useful for measuring the extent individuals are willing to exchange income for specific outcomes if they could be directly bought and sold. BCA is limited in providing a full accounting of all the effects of a proposed action because some consequences may not be possible to monetize or quantify with a reasonable amount of certainty. BCAs have become a standard practice for evaluating the cost effectiveness of public investments and regulatory decisions.

Because BCA is inherently indifferent to distributional concerns, analyzing the distributional effects is imperative to understanding the significance of investments on social equity, meaning whether the distribution of the benefits and costs is “fair.” Although the OMB Circular A-4 directs federal agencies to provide an analysis of the distributional effects of a proposed government action [54], a comprehensive distributional analysis and subsequent assessment of social equity is rarely performed in practice [55].

MITRE found a lack of federal guidance and approved methodologies available for performing distributional analysis. As a result, MITRE developed Guidance on Assessing Distributional Effects (MTR210702), which provides a methodology for assessing distributional effects.

In addition to MITRE’s recommendation and support for providing a distributional analysis in conjunction with BCA, we explore weighting costs and benefits within BCA. In the accounting of social equity, the economic principle at play is the diminishing marginal value of income, meaning the value of an additional dollar is worth more to a poor person than a wealthy person. The choice of how to incorporate the differential value of benefits and costs between people of different incomes is sometimes referred to as “equity weighting” [56]. The inclusion of equity weighting in a BCA can significantly alter the conclusions, leading to identification of who to target, what to do, how much to invest, and how to share risks, with increased emphasis on resiliency measures for population segments with low-income and high-social vulnerability [57].

This effort to explore BCA weighting is a continuation of previous MITRE work, namely Benefit-Cost Analysis and Consideration of Distributional Effects and Social Equity (MP210978), which focused on current practices of applying BCA to prioritize both federal and state government actions, existing methods for identifying distributional effects, and areas within the BCA framework that could be improved to address social equity [1].

[2] Economic efficiency (or Pareto optimality) is the optimum allocation of resources, where no redistribution of resources can make someone better off without making someone else worse off.

The following sections cover how scholars have considered the use of weights and equity measures in BCA and where these measures have been used in the U.S. or abroad and whether in BCA or other policymaking, if at all. MITRE will continue to engage with federal, state, local, Tribal and territorial (SLTT) governments to reach consensus on tangible methods for including equity into BCA where current methods and guidelines may be lacking.

For those readers new to the concept of BCA, the appendices in [1] provide a primer that describes the basic steps of a BCA, details on the total economic value framework, and how economists estimate the monetary value of goods and services not traded in markets, as well as detail on discounting and specifically intergenerational discounting.

3.1 Equity Weighting in BCA

Social equity may be considered within BCA by applying weights and other functions in ways that provide additional information to supplement BCA results. As described more thoroughly in [1], equity weighting in BCA has only been applied to income thus far, based on the economic principle called the marginal utility of income. Utility is how economists operationalize an individual's well-being. The relationship between small changes in an individual's well-being (marginal utility) and small changes in income (marginal utility of income) is not linear but concave. A concave function indicates that the marginal utility of income decreases with increasing wealth. For example, $100 given to a person with lower income produces significantly more well-being than if a billionaire were to receive $100.

Scholars have suggested alternatives to using income, such as happiness surveys and measures that may better approximate utility rather than relying on theories of compensating variation in dollar terms [58]. Also, many scholars counter the use of distributional weights, often in formal terms and definitions of models, as discussed in the next section.

An influential policy advocacy paper, *Making Regulations Fair* from the Institute for Policy Integrity at the New York University School of Law [59], has practical suggestions for how regulatory agencies can incorporate equity more broadly, and in BCA, specifically. Table 4 summarizes five potential ways in which income weighting can be assessed as suggested by Lienke, et al (2021) [59].

Table 4. Quantitative Methods for Income Weighting, Adapted from Lienke, et al. (2021)

Method	Numerical Output	Description
Gini Coefficient	0 to 1 (a higher value denotes greater inequality)	A ratio representing the projected distribution of an impact (e.g., cost or benefit) in a given scenario compared to an equal distribution of said impact.
Atkinson Index (isoelastic weights)	0 to 1 (a higher value denotes greater inequality)	A ratio representing the projected distribution of an impact in a given scenario compared to an equal distribution of said impact, reflecting societal preferences about inequality. The greater the societal aversion to inequality, the more sensitive the ratio is to unequal distribution of outcomes.
Theil Index	0 to infinity (a higher value	A statistical measurement representing how far away a projected impact is from an ideal distribution.

Method	Numerical Output	Description
	denotes greater inequality)	
Utilitarian Weighted BCA	A dollar value for net benefits	Aggregate costs and benefits of a rule if willingness to pay for a specific impact of the rule is weighted to reflect the diminishing marginal utility of income.
Proletarian Weighted BCA	A dollar value for net benefits	Aggregate costs and benefits of a rule if willingness to pay for a specific impact of the rule is weighted so that improvements to the worst off are prioritized above other welfare impacts.

The **Gini Coefficient** is often a figure used to measure inequality across geographies, or income inequality within a state or country. The Gini Coefficient can be used as a supplemental BCA measure to assess the distributional impacts of a policy.

Atkinson Index is a similar coefficient to the Gini Coefficient but has parameters requiring some coefficient reflecting societal aversion to inequality. While Lienke, et al., do not discuss it in their review, the Atkinson Index can also be used as a method to drive weights within BCA [59]. Therefore, it can be used either alongside BCA as a policy evaluation measure, and/or as a compliment to BCA as a method to derive weights.

Thiel Index has similar properties to Gini and Atkinson but "lacks intuitive appeal" (it is an index without real-world units) despite its use in health and racial segregation measures. It would be most applicable alongside BCA in broader policymaking.

Utilitarian Weighted BCA would apply marginal-utility weights to benefit categories, as differentiated by income, to change the results of the BCA compared to a standard unweighted BCA that presumes a utility-income elasticity of zero.

Proletarian Weighted BCA functions like utilitarian weighted BCA but applies greater value judgements for favored groups. This approach has less economic basis in that it implies value judgements to apply weights to favored or disfavored social groups.

Lienke, et al. [59] provide a valuable summary of weights available to the BCA analyst. Utilitarian equity weighting emerges as a likely candidate for incorporation into BCA according to Lienke, et al. Together with using Atkinson indices to derive such weights, there emerges the possibility of a method for equity weighting.

The Atkinson index, further, is viewed as one of the more consistent measures that meets several criteria (i.e., able to be calculated, intuitive meaning, less subjective on values; see Leinke, et. al. [59]) for an appropriate weight and equity measure. Given this possibility, Lienke, et al., argue that OMB should recommend that agencies use equity weighting within BCA, at least as a sensitivity analysis in evaluating proposed government actions [59].

In the next section, we offer some detracting views against the use of any such weights in BCA. Later, we discuss some applications of governments and academics in the use of equity and social factors in BCA, with specific examples of programs at the federal and state level.

3.2 Equity Weighting Considerations

Unlike scholars who find BCA to be incompatible with social equity from the onset, and who argue outright against its use, there are others who are proponents of BCA but otherwise advise against the use of equity criteria or distributional weights because it would run counter to the classical economic-based objectivity of BCA.

Kaplow [60] and [61] suggests that any policy chosen in an unweighted BCA, with a proper taxation mechanism, is optimal to a policy using weighted BCA. His thinking rests on the notion that a federal policy, and a commensurate tax and redistribution scheme, can and would be made in tandem. A similar classical-economic approach against using distributional weights by Weisbach [62] suggests that weights violate the core principle of regulations compensating for economic market failures. To the extent that there is a market failure, and that there is a policy or regulation intended to redress it, then BCA, he argues, should merely follow market prices even when they appear morally perverse like higher values of life for rich people—and that distribution should be left to political mechanisms and tax and redistribution policy. Weisbach further emphasizes that only regulations that seek to redress a market failure should be subject to BCA as the appropriate evaluation tool, and that regulations attempting to achieve some other non-market goal should simply not use BCA to begin with [62].

Hemel [63] uses the Value of a Statistical Life (VSL) in U.S. transportation safety policy to underscore that traditional BCA methods, without weights, may be preferable to using distributional weights. The reason for this is because if income weights are introduced, then one must also accept that the VSL is subject to an income-elasticity. On the one hand, distributional weights would down-weight wealthier individuals, broadly. But VSL is usually expressed as a function of income, creating a math function pulling in two directions, with the income effect undoing the equity weights. In fact, this is underscored by empirical research throughout, including work that shows that global VSL can range between $45,000 per life in the poorest countries to $18.3 million in the richest ones [64]. Hemel concludes that a traditional unweighted analysis (using a constant VSL) of a safety program may yield greater results for people with less income because of these elasticity effects [63].

Hemel also notes the issues with respect to regulatory information burdens, the cognitive biases of the BCA analyst, and the possibility of illegitimate preferences and interest group pressures if weights begin to be regularly applied [63]. Of course, this assumes that the analyst determines the weighting. But even when given weights, there ultimately is one person or a group of people making those decisions, and those individuals are susceptible to cognitive bias.

3.3 Equity Weighting in Practice

In MITRE's literature review, equity and social justice criteria were not found to be incorporated within BCA for U.S. government actions. While agencies may often take the steps to measure appropriate benefits and costs and not overlook certain groups, and to abide by federal guidance recommending identification of distributional effects, there currently does not appear to be any overt use of advanced equity approaches incorporated within or supplemental to BCA at the federal or state level (i.e., any approach requiring more than just measuring equity-related items, such as negative externalities imposed on a certain community). Further, because BCA is increasingly part of federal rulemaking, Cecot and Kip Viscusi provide legal history and contend that it is subject to heightened judicial review [65]. By applying equity weights without full support, stronger federal rules, or legislation, courts may intervene to consider the weighted BCA as “arbitrary or capricious” (in the legal sense of the term). This is likely one of the reasons that we were unable to find any examples of equity weighting being applied by government agencies in the U.S.

Outside of the U.S., Little and Mirrlees point out that distributional weights were once adopted at the World Bank, although few examples can be found [66]. However, a recent World Bank staff reference paper [67] provides guidance of how one would apply equity weighting, suggesting a form of the Atkinson Index called the “survivor function” (one minus the cumulative distribution function (CDF) in the counterfactual state), and the Gini coefficient. The paper indicates that the use of marginal utility of income measures is consistent with the priority principle of the Social Welfare Functions (SWF) that requires resources go to the greatest claim: people with lower income and people most vulnerable to climate impacts.

The United Kingdom is one of the few governments that allows for and provides guidance in the use of equity weighting as current as the revised *Green Book* of 2022 [68]. The UK recommends an Atkinson Index that is a simple function of income or wealth, which provides a certain set of rules in the UK government decision-making. The guidance suggests that distributional weights should be used at the “shortlist stage” of policymaking. It goes on to suggest that distributional weights can be used in a distributional analysis (without mandating their use). And a third way to use them is in sensitivity analysis to identify how high the weights would have to be to change the preferred option. The report further advises that transparancy is paramount due to uncertainty of the weights and that such analyses should be presented with and without weights.

Farrow provides one of the most useful analyses of equity and distributional weights for BCA [69] (see also: Farrow (1998) [70]). Importantly, he derives and develops point estimates for weights that can be used in the application of BCA. In this work, Farrow highlights some key elements [69]. He notes the various types of weights in which one could apply, noting many of the same that Lienke, et al. [59] offer, but adding some others: the use of a Lorenz curve, simple variance, coefficient of variation, and revealed preference based on marginal income tax rates. The revealed preference from tax rates is notable to the extent that marginal tax rates reflect a democratic society’s revealed preference of the marginal utility of income, the ratio among the marginal tax rates can be used as an income distributional weight.

In Table 5, Farrow’s [69] derivation of income weights shows that the relative utility (the income weights) for any individual group is a function of that individual group’s income compared to the average and a coefficient that indicates a highly important inequality aversion parameter. He cites U.S. Census Bureau reports [71], [72] that use parameter values of 0.25, 0.50, and 0.75 for the parameter, e, that measures the coefficient of inequality aversion. By this measure, when e=0 the implied weights across all groups become 1.0 (no differences); when e=1 the marginal utility follows a function of 1/y (where y is income). Ultimately, he derives weights that suggest a ratio of weights between the lowest to highest quintiles to range from 1.4:0.7 to 4.3:0.3.

Table 5. Atkinson Distributional Weights Used by the U.S. Census Bureau and U.K. Treasury [69]

Population Quintile, Median, %	Mean US HH Income by Quintile: 2007	Default				
		$e = 0$	$e = 0.25$	$e = 0.5$	$e = 0.75$	$e = 1$
0-20	$11,551	1	1.4	2.1	3.0	4.3
20-40	$29,442	1	1.1	1.3	1.5	1.7
Median	$50,233	1	1.0	1.0	1.0	1.0
40-60	$49,968	1	1.0	1.0	1.0	1.0
60-80	$79,111	1	0.9	0.8	0.7	0.6
80-100	$167,971	1	0.7	0.5	0.4	0.3

Raucher, et al., use BCA to evaluate drinking water standards in small communities [73]. Their notable contribution to the literature isn't in weights, but in the way that they treat equity for an important public health investment topic. Raucher, et al. begin by defining an association between health risks and income with respect to arsenic poisoning above the maximum contaminant level (MCL) [73]. By using a risk approach, where the authors apply uncertainty and probabilities of different communities being impacted, they find that there is a 75 percent chance that the benefits of the risk reduction from arsenic would exceed the costs. Through this finding, they highlight an important method in BCA, which is to present BCA results as a range of uncertainty and risks rather than as a singular number. This presentation of results is especially appropriate given the broad latitude in sensitivity analysis for applying social equity factors.

In a flood risk example, Markanday, et al. [74] assessed adding employment effects, equity, and risk aversion to BCA in a climate change problem by comparing four different BCA approaches: (1) standard BCA; (2) standard BCA with equity; (3) standard BCA with equity and employment; and (4) standard BCA with equity, employment, and risk aversion. In other words, the researchers progressively added more considerations in each BCA to test sensitivity on the benefit-cost ratio. Markanday, et al.'s results show benefit-cost ratio changes slightly based on BCA approach [74]. An important equity test they employed was to set wages differentially for income groups, and they found that doing so (instead of an average across-group wage) can strengthen or weaken the case for action depending on the differentials. The authors also found that considering risk aversion (a core element in an Atkinson approach) can affect BCA results for climate change resilience investments because BCA is highly sensitive to discount rates.

Loomis adds to natural disaster research by assessing empirical methods for identifying the impact of household income or race on differentiating property values related to national forest fire suppression policies [75]. Using Hispanic persons and households with incomes below the federal poverty level, they find that hedonic price modeling can reveal the implicit price gradients across income and ethnicity instead of using a simple property-based assessment. Loomis finds important regression-based evidence that there is an implicit income-elasticity to risk aversion from forest fires: neighborhoods with predominantly White people see a higher drop of 3.3 percent in property next to a forest fire, and thus a higher value for reducing risk, than homes with predominantly Hispanic people, which fell only 2 percent [75]. This is an example of how to employ empirical research to derive appropriate point estimates, but it ultimately lands in the classical economic approach: willingness to pay increases with income and thus benefits (in a utilitarian sense) would be greatest by reducing risk to the highest income people. This strict utilitarian approach underscores how BCA can perpetuate prioritization of investments in areas where White people live over areas where other ethnic groups live because the property values (and risk of loss) is higher. This intent was a more equitable outcome but instead, the results favored the majority ethnic group.

Similar counterintuitions also exist in transportation literature. Travel time is a well-thought of topic in equity because, like the VSL, the value of travel time savings (VTTS) is a function of income. Again, not because the rich are more deserving of free time or that their time is morally superior, but simply their opportunity cost to working is greater, and this reflects in VTTS being a strict function of income. One way the USDOT recommends to mitigate this is an across-the-nation VTTS with distinctions made only between higher-value work-related trips, and lower-value non-work related trips [76]. Additionally, recent guidance has allowed for different VTTS for cycling and walking to account for the differences of using these modes [77]. If VTTS were merely a function of income, then USDOT would possibly be in the position of consistently favoring projects in high-income regions versus lower-income regions. For example, incomes in urban New York City tend to be much higher than in rural Manhattan, Kansas.

In the case of VTTS, Martens and Di Ciommo [78] highlight this counterintuition by showing that a full analysis of a transportation project has varying implications for sub-populations. While applying diminishing returns to the VTSS can help push a project towards a particular sub-population, the distribution or costs and benefits may have other unintended implications. Other effects like the income effect (income-elasticities), geometry effect (higher-income people are more likely to have cars and a larger space-time map), and the group size effect (the majority group tends to be larger in number than the most marginal group) can impact results. Not that Martens and Di Ciommo [78] are arguing against inclusion of equity as such, and in fact they are proponents, but they are simply pointing out that income-weighting and distributional distinctions can cause different parts of a BCA to move in different directions.

3.4 Critical Arguments Against the Use of Benefit-Cost Analysis

BCA is currently, firmly established in the U.S. Code of Federal Regulations and commonly used across many federal agencies. However, we note that critics argue against the influence and use of BCA. Some of the most contrarian views against the use of BCA, broadly, come from Critical Theory scholars who stipulate that such a numerically driven procedure is liable to have inherent problems regarding race and class. The Center for Progressive Reform, for example, has launched an initiative titled, *Beyond 12866: A Progressive Plan for Reforming the Regulatory System*, referring to EO 12866, that establishes the current use of BCA, and squarely takes aim against that directive [79]. Goodwin, a senior researcher at the Center, advances that BCA is problematic from the onset because the baseline conditions used to compare with proposed actions is always the status quo, which can lead to inequities becoming sanctioned in policy instead of subject to criticism [80]. Secondly, he contends that the monetization and objectivity of BCA assigns inappropriate moral equality to competing interests, such as a polluting corporation versus a vulnerable community.

In 1981, Kelman [81] noted that BCA is incapable of accounting for the utility of “doing the right thing” even if he may disagree with Goodwin [80] about what that right thing would be. “We believe that some acts whose costs are greater than their benefits may be morally right and, contrariwise, some acts whose benefits are greater than their costs may be morally wrong,” Kelman writes, illustrating a commonality with other critics that there is something inherent with the quantifying nature of BCA that causes it to fail at certain accounting like that of human rights, commonly held moral beliefs, and duties [81]. Though it may appear metaphysical, this point is important to address because the attempt to imbue social equity into BCA is precisely an attempt to try and account for some sense of justice.

As a practical matter, some empirical work has suggested that BCA tends towards favoring powerful interests rather than regulation. Driesen, at the Center for Progressive Reform, assessed OMB examinations of 25 federal rules on major health, environmental, and safety agencies during the George W. Bush administration (2001–2002) and found that in all 25 cases the OMB supported changes that would benefit the regulated entity. And where OMB sought these changes, it wanted to weaken regulations rather than strengthen them in 24 of 25 cases [82]. He specifically highlighted data gaps and the inability of BCA to quantify some health and environmental effects, as attributable to that outcome. Other empirical work by Flyvbjerg and Bester shows a challenge with cost and benefit estimates of public investments being biased and seriously impacting efficient resource allocation [83].

Often the criticisms against the use of BCA generally amount to an argument against the use of economic theory in federal policymaking. Because BCA requires monetizing all benefits and costs to the extent possible—and to do so relies on finding market prices or shadow prices—some uncomfortable findings abound. A commonly cited example is a 2010 BCA conducted by the U.S. Department of Justice (USDOJ) applying BCA to the question of sexual assault and rape in federal prisons and whether the cost of preventing these horrible incidents outweighed the benefits [84]. Here, the DOJ was in the uncomfortable position of quantifying the market value of preventing a rape and further breaking down rape into several categories in order to compare those benefits against the cost of the program. Heinzerling, a law professor at Georgetown University, points out the uncomfortable use of BCA in evaluating wheelchair users' willingness to pay for accessibility, noting that "even to ask the question is to strip the context of its rights-based foundations; an underlying premise of cost-benefit analysis is that there are no rights, only preferences" [85].

While it is beyond the scope of this report to fully rebut the arguments against BCA, these views are worth noting. In cases where BCA may not be the most appropriate economic analysis, other approaches such as multi-criteria decision analysis (MCDA) or CEA should be considered. MCDA is discussed in Section 3.5 and CEA is discussed more thoroughly in Section 4.

3.5 Alternative Approaches

OMB Circular A-94 [86] together with OMB Circular A-4 [6] guide federal agencies on BCA methods. Interestingly, the circular provides a warning in the use of BCA, "When important benefits and costs cannot be expressed in monetary units, BCA is less useful, and it can even be misleading, because the calculation of net benefits in such cases does not provide a full evaluation of all relevant benefits and costs." This underscores the importance of unquantifiable benefits that are germain to equity analysis and the limitations of BCA in accounting for non-monetized costs and benefits.

CEA and MCDA are alternative analyses to using BCA depending on the objectives of the analysis. CEA, in simply measuring the impacts of a proposed action against costs, doesn't have the same kind of technical rigor as BCA. CEA requires quantification but not monetization, costs can be compared with units of measure, such as habitat units.

The similarity between BCA and CEA is slightly deceiving because both divide some type of outcome by costs, they both provide some type of ratio. However, the similarities generally end there. BCA, stemming from a social welfare analytical modeling approach, requires significantly more constraints. The first and most challenging constraint is that BCA requires the analyst to translate any outcome into monetized terms so that costs and benefits are in equal dollars. Second, it requires a more substantial understanding of the *timing* of projects as in when the dollars are spent and when the monetized benefits are incurred. Third, BCA imposes several requirements on many benefit calculations that may limit their counting, and some may seem unintuitive to non-economists. As an example, a transit agency may be very interested in how adding a new train station increases value of nearby properties; however, this benefit is severely curtailed in BCA because those benefits may be considered "transfers" of economic activity from one part of town to another; or they might be considered an expression of travel time savings into real estate value, and thus considered "double counting" benefits (the travel time and the real estate). There are many more requirements to BCA and practitioners must be specially trained to conduct one, or at least be diligent in following guidelines.

One outcome of BCA is a benefit-cost ratio, but we should emphasize that it requires quantification in "net present value" terms, which is the value of dollars considering the time value of money. Hence, *when* dollars are spent and benefits are incurred, *combined* with the discount rate used, has a large impact on the result. As a contrast, CEA uses *incremental* costs, which are costs incurred for gain one unit of output. CEA is most often used to assess health and environmental restoration outcomes but has a strong foundation that could be applied to climate resilience outcomes. In the next section, CEA is discussed in much greater detail.

MCDA is increasingly proposed as a method to include equity in decision-making [87]. This is because MCDA as a decision-making strategy in the rulemaking process can consider far more equity criteria than, perhaps, BCA alone. Further, MCDA can allow for BCA as part of its overall criteria.

While MCDA bears parallels to traditional policymaking processes (see: Weimer and Vining [88], [89]), MCDA has its own explicit approach for preferences and interests. This decision approach is divided into five parts: (1) the goal; (2) the decision makers with preferences; (3) a set of decision alternatives; (4) a set of evaluation criteria; and (5) outcomes or consequences associated with alternative/interest combination [90]. Here, the decision makers can be any set of decision partners with decision-making power, from legislatures to citizens groups. Multiple criteria can be given weights depending on decision-maker preferences and this is accomplished, often, through rank-order preference surveys and analytical techniques [91] or proprietary software and tools like *Decision Lens* [92]. Such techniques allow broad criteria like "safety versus mobility" or "economic growth versus security" to be evaluated, ranked, and weighed for final decision-making.

The Ministry of Health in Ghana explored the quantification of equity to prioritize health interventions leading Ghana to become the first country to use MCDA for priority setting in health according to one study by Jehu-Appiah, et al. [93]. The authors assisted the government by assessing tradeoffs between equity, efficiency, and social concerns in health. They deployed MCDA by convening 63 policymakers to participate in discrete choice experiments to weigh the relative importance of health interventions. Results showed that the policymakers considered targeting vulnerable populations as most important, followed by disease severity, number of beneficiaries, and diseases of the poor. When the government selected a certain criteria set, the resulting policy resulted in prioritizing interventions in child health, reproductive health, and communicable diseases [93].

Roy and Kar [94] show that MCDA would be beneficial in assessing hospital accessibility during the Covid-19 pandemic. They noted that Covid-19 infections were higher for socially vulnerable populations and that access to hospitals diminishes due to barriers stemming from socioeconomic disadvantages. In this study of ways to increase access, MCDA was beneficial because it “accounted for the underlying social, environmental, and geographic context that adds to the overall cost of access” [94].

3.6 BCA Recommendations

Understanding how climate change resiliency investments are prioritized and correcting for inherent bias in BCA by supplementing information traditionally provided to decision makers is imperative to supporting investments for populations who are disproportionately impacted by climate change and have less resources to adapt and respond to climate change effects. MITRE continues to recommend an analysis of distributive effects in conjunction with BCA.

There are various methods for weighting income within BCA. Utilitarian equity weighting along with using Atkinson indices to derive such weights are the preferred methods for equity weighting. It is proposed that income weighting would be used as a sensitivity analysis of BCA to provide additional information to decision makers on the impacts of proposed public investments in climate resilience. However, income-weighting and distributional distinctions can cause different parts of a BCA to move in different directions, sometimes counterintuitively. Whenever weighting is performed, it should be a separate sensitivity analysis in addition to the BCA, and transparency is paramount due to uncertainty of the weights.

While typically income is not specifically considered in climate resilience BCAs, property values could be considered a proxy for income. Generally, a large share of benefits for proposed climate resilience projects evaluated using BCA can be from avoiding property damages. Using a traditional BCA approach, BCA results will favor communities with higher property values because the net benefits would be greater than a similar project in communities with lower property values. Similar to the treatment of using an average VSL in transportation safety policy, MITRE recommends using a national average property value by property type to evaluate climate resilience projects. Alternatively, discretionary grant programs may develop eligibility criteria that limit projects in areas where property values exceed a certain threshold.

Due to the potential difficulties in addressing the limitations of BCA, alternative approaches may be considered to evaluate cost effectiveness of climate resilience investments. MCDA or CEA should be considered as alternatives to BCA.

4 Equity in Cost-Effectiveness Analysis (CEA)

OMB Circular A-94 [86] has served as the broad U.S. foundation for BCA and cost-effectiveness analysis since 1992 in combination with Circular A-4 issued in 2003 [6]. Where BCA evaluates benefits and costs, CEA seeks to evaluate the costs of an alternative against the environmental or social impacts (e.g., cost per life saved or cost per endangered animal saved). CEA has been used when monetization of costs and/or benefits may be challenging or not possible.

CEA is one of many forms of economic analysis that allow an analyst to compare the relative costs of a project to its quantified "impacts" along various measures and dimensions. During the discretionary grant pre-award phase, federal agencies are tasked with considering applications from communities around the country, each with a different project, and finding ways to systematically and fairly decide where to distribute limited funds. During that process, agencies can use many quantitative and qualitative approaches, like CEA, to contribute to evaluation, filtering, and ranking projects.

In Section 4.1 we define and expand on the various types of CEA. Section 4.2 has examples of applying CEA. Finally, by considering the overall process, and combining our understanding of CEA, we arrive at Section 4.3, which is a set of recommendations to federal grant awarding agencies on where and how they can add CEA to the decision-making process to provide for more systematic decision-making, and to consider important metrics along social equity dimensions.

4.1 Typology of CEA

CEA can be considered an efficiency measure: the analyst first identifies the cost of a proposed project or program, and then identifies one or many quantifiable impacts. Those impacts, for example, can be things like "number of habitat units created" or "tons of carbon dioxide emissions avoided." By dividing the impacts by the cost, the analyst develops a cost effectiveness measure that can provide understanding of the cost effectiveness of certain outcomes for comparison with other plans or projects. CEA results can be used to filter projects based on some pre-determined threshold or to rank and compare cost effectiveness across projects.

In more formal terms, CEA seeks to maximize the primary outcome by comparing the costs (including opportunity costs) and outcomes of two or more mutually exclusive options [95], [96] [6], [97], [98]. Traditional CEA does not explicitly take equity weighting into consideration (e.g., individual gains and losses are treated and weighted equally), nor does it consider tradeoffs between cost-effectiveness and equity [98]. However, outcome measures that have important equity implications can be used in CEA.

To contrast, there are several other analytical approaches that bear some similarities to CEA but differ in key ways. Economic impact analysis (EIA) is often used by regional analysts to consider the long-term jobs and regional economic output impacts of a proposed investment, and it can be used to explore local economic impacts of major investments. For example, the Council of Economic Advisors during the American Recovery and Reinvestment Act of 2009 estimated that for every $92,000 spent, one job would be created [99]. While this bears similarity to CEA in that it focuses on some impact per dollar (jobs for every dollar spent) it is unique in that the methods and outcomes of EIA focus heavily on job creation, economic value-added, economic output, and regional multipliers. It might be considered a unique form of CEA, but its emphasis is necessarily defined by a specified set of outcomes.

There are generally three types of CEA that one can conduct. The first is the previously discussed traditional CEA, which compares monetized costs against any outcome of interest at the margin. CEA can be particularly useful for comparing cost impacts of different interventions affecting the same outcome but is more challenging when considering different outcomes and may require other techniques discussed later. CEA is also useful for understanding the impact of an intervention on cost compared to an alternative outcome, however the key to CEA is that the outcome of each compared intervention must be the same.

A second form of CEA is the Extended Cost-Effectiveness Analysis (ECEA). This approach extends the conventional CEA "typically through the evaluation of a policy's ability to provide financial risk protection (FRP)" [98] (see also: Cookson, et al. [96]; Verguet et al. [100]). "ECEA does not always have to be concerned with FRP, with other dimensions encompassing, for example, educational, agricultural, or environmental benefits. [98]" Here, FRP are other benefits that are outside of the scope of the initial inquiry: for example, for a health program, FRP would be many of the non-health benefits accrued by the program. Likewise, it can consider equity considerations in the evaluation of policies, projects, or programs.

To illustrate a contrast, one can think of traditional CEA as one dimensional as it evaluates a project along the single dimension of cost effectiveness. However, we know that projects have many trade-offs. Figure 6 provides an example where a health program is considered along two axes: health outcomes and non-health outcomes, each having a presumed tradeoff [101]. As a policy moves up and to the left, it can be considered more cost effective because it optimizes the two tradeoffs. Using ECEA is "novel in that it includes equity and non-health benefits…[and] allows policy makers to take both health and non-health outcomes into account when making decisions and thus to target scarce health care resources more effectively toward specific policy objectives" [102]. While the literature focuses on public health, the same concepts are transferrable to climate resilience, environmental sustainability, or disaster risk.

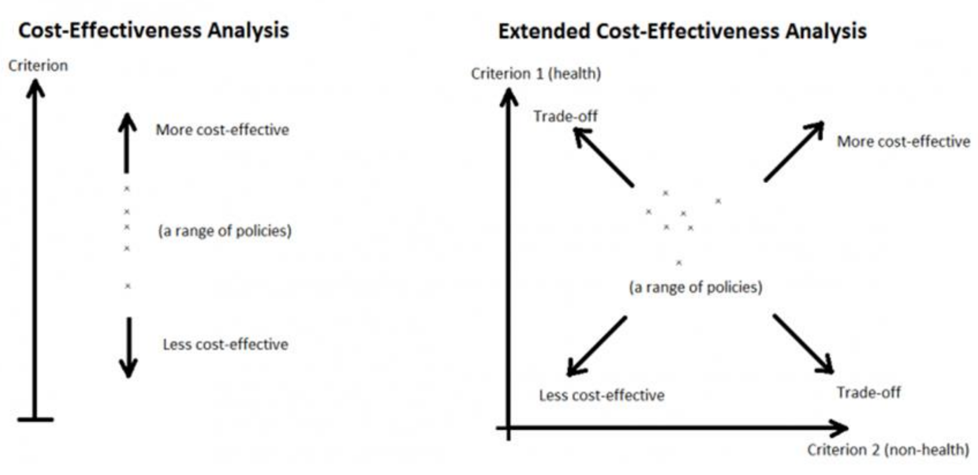

Figure 6. Cost-Effectiveness Analysis and Extended-Cost Effectiveness Analysis [102]

A third variety of CEA is the Distributional Cost-Effectiveness Analysis (DCEA). This form of CEA measures "the change in the distribution of costs and benefits before and after the introduction of a new intervention or policy to identify those that benefit and those that lose out as a function of displaced programs" [98]. DCEA may incorporate multiple equity impacts on social groups into one analysis through the use of SWF. Costs (including opportunity costs) and effects are presented in aggregate and in disaggregate form [96], [103], [98]. "The 2 key stages in DCEA are 1) modeling social distributions … associated with different interventions, and 2) evaluating social distributions … with respect to the dual objectives of improving [primary outcomes] and reducing … inequality. [104]" DCEA may also include equity weights and associated sensitivity analysis of them [96].

In simpler terms DCEA allows the analyst to consider either, or both, the equity and distributional effects as well as the economic and efficiency effects. Through this approach there are equity or distributional considerations alongside those that primarily measure aggregate outcomes. An applied example comes from Asaria, et. al. [105] who considered the equity impacts of different bowel screening programs in the UK for colon cancer prevention. The researchers compared two programs: one public health reminder program that targeted screening in ethnically diverse neighborhoods, and a more universal public health reminder program aimed at the whole population. This was possible through coordination with the UK Department of Health Policy Research Program, which enabled the marketing and data to be collected in this manner. Comparing across both total and equity dimensions, the analysts found that the former program was best at minimizing unfair variation in public health outcomes, while the latter general program maximized population health.

DCEA, then, allows an analyst to consider equity alongside efficiency considerations. Unlike ECEA, it isn't imposing a slightly more analytically challenging multidimensional tradeoff analysis. DCEA simply creates an opportunity to consider traditional efficiency outcomes at the aggregate level against equity and distributional outcomes. In mathematical terms, it could be comparing costs against average effects or comparing costs against the variance in effects across certain populations. In tangible terms, one lens looks at everyone in the population and the second compares specific populations and how the intervention increased or reduced disparities.

Some researchers may not even consider DCEA a unique term and simply consider it CEA as applied with equity, which is an important consideration because, traditionally, the focus of CEA is efficiency at the average. CEAs that include equity can quantify the impacts of interventions on included criteria, as DCEA applications show. Most literature in this area for equity-focused CEAs have often been used to solve public health problems despite being applicable in any domain. The concern over applying equity is salient as the public demands more and more of these considerations, and this is supported by researchers. Avanceña and Prosser [95] analyzed the use of equity in CEA across a survey of scholarly articles and found that equity considerations were frequent in the literature, with equity-informative criteria appearing in 56 percent of the articles they screened and equity impacts with consideration for financial protection analysis in another 30 percent of the articles. DCEA is becoming increasingly common and can be applicable to evaluating climate resilience investments and discretionary grant programs.

An important consideration of any equity analysis, whether in public health or in climate resilience, is tradeoffs in cost-effectiveness and equity outcomes. As shown in Figure 7, Cookson, et at. [96] provide a "Win-Lose" typology to consider how such tradeoffs can be applied, with the "Win-Win" quadrant being those projects or programs that are both cost-effective in the aggregate and improve equity. The “Win-Lose” and “Lose-Win” quadrants would be tradeoffs, while the “Lose-Lose” quadrant would be programs likely not suitable for consideration.

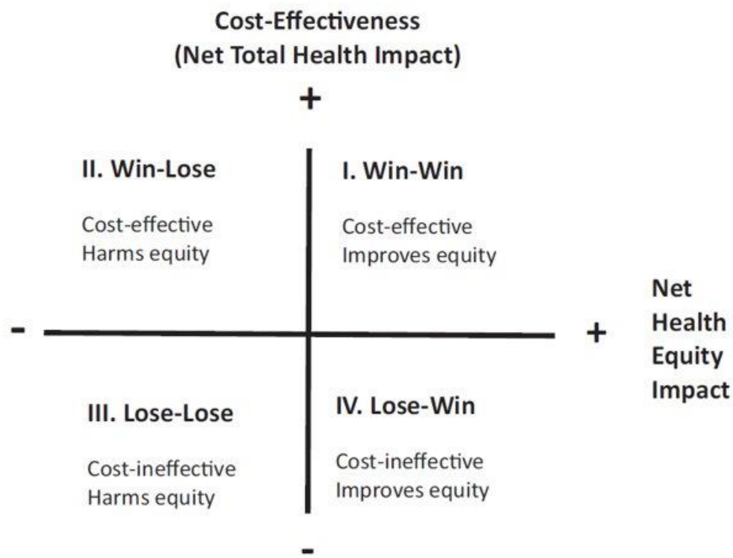

Figure 7. Cost-Effectiveness and Equity in a Win-Lose Typology [96]

4.2 CEA in Practice

In addition to some of the literature previously mentioned, CEA has been used in various applications by scholars and government agencies. The technique has origins in public health, and its applications are most common there, but it is a technique general enough to apply to many other applications, like climate resilience.

One of the largest examples of the use of CEA in the federal government is the Federal Transit Administration’s (FTA) New Starts and Small Starts programs [106]. This program provides for large federal grants to states and local agencies to implement new transit expansions, usually heavy rail transit, light-rail transit, or bus rapid transit. In the Small Starts programs, applicants with smaller capital requirements are eligible. Bus expansion programs are also eligible. (see also: 49 U.S. Code Section 5309 [107]).

Since 2010, FTA has used CEA as a portion of scoring criteria, as shown in Figure 8, to evaluate proposed New Starts programs [108] (see also: 49 CFR Part 611 [109]). While FTA includes many ratings in their evaluation process, CEA is invaluable to comparing the relative costs of potential programs. To evaluate cost effectiveness of New Starts and Small Starts programs, FTA uses a measure of the “incremental cost per hour of transportation system user benefits in the forecast year.”

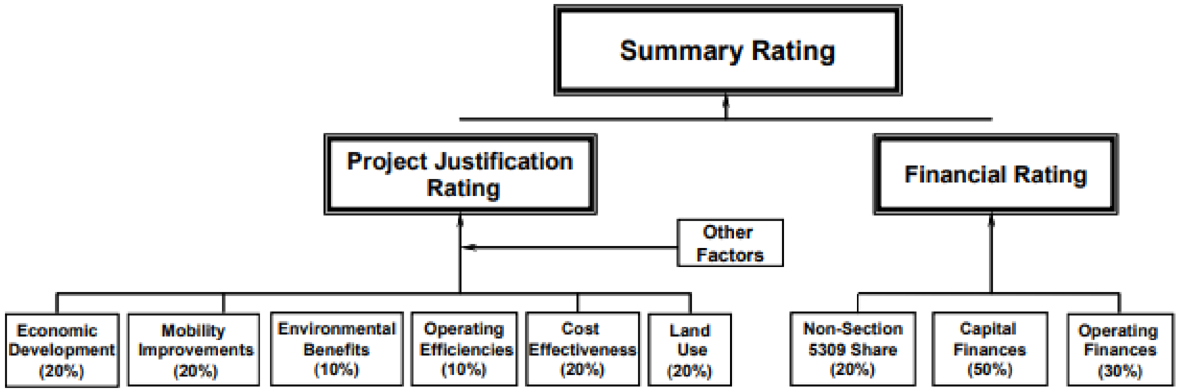

Figure 8. Federal Transit Administration New Starts Evaluation Process [108]

The CEA Breakpoints outlined in Table 6 help FTA objectively compare different programs based on program benefits. These Cost-Effective Breakpoints have been used since 2002 and are updated periodically (the most recent are from 2016 [110]). In 2010, FTA aimed to improve the process by considering both mobility and non-mobility benefits. Additionally, using this process, all "Very Small Starts" receive a medium rating for cost-effectiveness.

Table 6. Cost Effectiveness Breakpoints in FTA New Starts (cost per annual passenger trip)

Rating	Range
High	<$4.00
Medium-High	Between $4.00 and $5.99
Medium	Between $6.00 and $9.99
Medium-Low	Between $10.00 and $14.99
Low	>$15.00

Source: Adapted from Federal Transit Administration (2016)

FTA uses CEA to compare and prioritize dozens of applications for federal funds in a given year. The agency assigns CEA a specific place among other project justification ratings. Here it is 20 percent as compared to other considerations like economic development and mobility improvements. Thus, CEA is not a be-all and end-all method to compare or filter programs; it is one of many factors. However, among the slice that CEA constitutes, there are certain evaluative considerations and cutoffs. Projects with a "cost per passenger trip" of transportation services of $4.00 or lower are considered "High." These cutoffs also illustrate how CEA figures can be converted from a continuous figure (the cost effectiveness figure) to an ordinal category based on agency considerations (such as "High" to "Low").

Literature suggests that CEA is applicable in the analysis of other programs or projects related to climate resilience and emergency response. Results show that deployments of search and rescue (SAR) and Emergency Medical Teams (EMT) are highly expensive, and success is related to the time needed for the team to become operational [111]. Activities of the SAR teams involve the location, extrication, and initial medical treatment of victims trapped in structural collapse, while EMTs focus on providing treatment to patients affected by an emergency or disaster. When analyzing deployments, SAR deployments are characterized by limited outcomes in terms of lives saved and EMTs by insufficient data and lack of detailed assessment. BCAs of SAR deployments exist; however, they are rarely part of the decision process when there is a need to save lives because many find it inappropriate to quantify human life in these scenarios.

The researcher's comparative review concludes that data reporting should be mandatory for humanitarian response agencies for CEA to be used effectively. Local resources should be used, and local response plans implemented, supported by the regional and international systems. Increasing local adaptive and absorptive capacity is perhaps the most cost-effective way for the affected government to meet their responsibility.

In the area of evaluating relief operations, Hallam [112] offers that CEA is used in situations where benefits and costs cannot be reasonably measured in monetary terms, and it is a potentially valuable tool for evaluating relief operations with the aim to save lives and reduce suffering. Due to finite aid resources, the inefficient use of funds in one operation can reduce the availability of funds for other operations where needs are equally critical. Relief agency personnel tend to feel unease towards CEA because many believe that the level of suffering and need for assistance is so urgent that financial considerations are irrelevant or immoral. Additionally, people who aren't familiar with economic analyses often face confusion between BCA and CEA, so they may reject CEA due to concerns about BCA.

Hallam [112] outlines two CEA approaches: Least-Cost Combination (also known as constant effects method) and Constant Cost. The former method seeks to determine the least expensive combination of tangible costs that will result in the same level of benefits. For example, Least-Cost Combination examines whether the same number of lives can be saved for a lower cost by buying up flood plain property and relocating residents or by constructing dikes and levees. Least-Cost Combination can only be used to compare different approaches aimed at the same goal, but no absolute judgements can be made. The Constant Cost method quantifies benefits without attaching a monetary or economic value to the benefits. Often Quality Adjusted Life-Years (QALYs), Disability-Adjusted Life-Years (DALYs), or Couple-Years of Protection (CYPs, especially in fertility-based applications) are used for this method.

Theoretically, the Constant Cost method can be used to see where the expenditure of a single dollar would have the greatest impact. The research concludes by acknowledging that when assessing approaches to relief operations, many organizations should work together to complete joint evaluations rather than having organizations complete CEAs for their own organization.

4.3 CEA Recommendations

To effectively implement CEA into federal discretionary grants programs, the federal grant awarding agencies need to determine what unit of outcome they are looking to optimize that is consistent across the applications; this also involves buy-in on the outcome the agency selects from impacted communities and populations.

4.3.1 CEA Recommendations for Grant Programs

In this section we discuss CEA recommendations and how CEA can be applied within the various phases of the grantmaking process. In a broader sense, the grantmaking process can be thought of as five steps of pre-award, award, post-award, closeout, and post-closeout as discussed in Section 1.6. We recommend applying CEA in the pre-award, post-award, close-out, and post-closeout stages.

Recommendation 1 (Pre-Award): Use CEA to evaluate cost-effectiveness instead of BCA

To the extent that awarding agencies have issued guidance urging or requiring the use of BCA, consider rescinding that guidance and begin a new rulemaking process to replace BCA with CEA. During this phase, awarding agencies can use their regulatory authority to replace BCA requirements in the NOFO with CEA requirements, if applicable. Awarding agencies can further use ECEA and DCEA concepts to include equity requirements. New CEA guidelines should incorporate explicit requirements for equity metrics that align with intended outcomes (see potential metrics for consideration in Section 4.3.2).

During the rule-making process, awarding agencies will have the opportunity to consider the comments received during the comment period, as well as solicit feedback from relevant decision partners. This process should solicit maximum input from relevant decision partners (e.g., the public, state emergency administrators, and local government leaders), NGOs, and other entities with expertise in disaster mitigation and emergency management. During this process, it will be incumbent on awarding agencies to define CEA for the program and establish toolkits to assist applicants in conducting appropriate CEAs.

Recommendation 2 (Pre-Award): Establish CEA's weight compared to other grantmaking considerations

Awarding agencies should consider an explicit weight for CEA for each grant program, as compared to all other considerations in the application process. This should, again, be made in consultation with relevant decision partners and can be done using various community planning and decision weighting methods.

Recommendation 3 (Pre-Award): Consider CEA breakpoints for a rating system

To avoid difficult-to-distinguish differentiation between CEA metrics, awarding agencies should consider using CEA in an ordinal basis rather than using CEA metrics themselves. For example, awarding agencies could consider converting metrics into a "high-to-low" five-tier rating system. This affords applicants more leeway and clarity in how their application will be evaluated. Such breakpoints should be updated periodically and use data from previous grant cycles as information to reevaluate which levels are high, low, and in-between.

Recommendation 4 (Pre-Award): Provide funded technical guidance and technical assistance

Many communities—especially smaller ones and communities with less resources—face challenges in acquiring data or proper modeling techniques to conduct climate risk modeling and economic analyses. The awarding agency should consider setting aside funds from its authorization to establish technical assistance programs in both areas. One program could provide funds to assist applicants in establishing models that forecast potential disaster and weather event risk. A second program could provide for toolkits and technical assistance in conducting a CEA.

Recommendation 5 (Post-Award, Closeout, and Post-Closeout): Require continuous reporting to facilitate grant program evaluation

Awarding agencies could assess current and former grant awards to identify if previous grantees are meeting proposed metrics. Awarding agencies can use final CEA results (post-implementation) using actual data rather than projected data when possible. In some situations, especially as the effects of resilience are based on modeled disasters, this type of post-project analysis likely will focus on the implementation of the project, and whether assumptions in the model remain the same.

This would require that awarding agencies mandate applicants collect data that will help determine cost-effective breakpoints and program evaluation going forward. This will ensure that the cost-effective breakpoints are reasonable and realistic and allow awarding agencies to tailor their technical assistance programs accordingly. Breakpoints can be developed using formal statistical methods (such as breakpoint tests or other distribution tests); or derived by consensus from federal agency leadership and staff.

Further, projects should be evaluated against the defined cost-effectiveness metrics, and awarding agencies can use this data to conduct a program-level program evaluation. Awarding agencies can monitor CEA results against projections and consider a broad program evaluation, or "meta-CEA" by aggregating the various projects for which federal funds were awarded.

4.3.2 Potential Metrics

MITRE examined the Building Resilient Infrastructure and Communities (BRIC) program FY 2021 awardees [113] and considered how CEA metrics could have been applied to those projects. Particularly, the team examined the types of projects that were funded, what kinds of outcomes the funded projects sought to attain, and what kinds of metrics would be most applicable to those projects. Based on an overall synthesis of the projects, as well as prior experience conducting BCA for numerous climate resilience projects, we developed the following possible performance metrics (for CEA) that are most generalizable.

Some projects were awarded on specific bases that had outcomes that were not generalizable. For example, many projects involved flood and hazard mitigation, and those types of measurements can be applied across many applications. However, some projects focused on resilience to emergency response services (such as preventing flooding and power-outages at a 911 call center). In those situations, some other measures (like cost per life saved) could be applicable.

We also stress that these recommended measures are not exhaustive, but a strong starting point. Further, we note that many metrics are in the hypothetical. Resilience projects, for example, save lives and avert property damage compared to a hypothetical disaster scenario. As a result, many of the suggested metrics are "modeled"; future evaluations will compare whether there have been major changes to the modeling assumptions.

Although CEA metrics are typically the cost per outcome, we recommend using "investment" per outcome. In the metrics discussed below, "investment" is used in place of the total cost of a proposed climate resilience project because the cost of the project could be considered an investment for the community. It is expected that cost includes the initial capital costs, as well as ongoing operation, maintenance, repair, replacement and rehabilitation for the life of the project.

In some cases, the community that would benefit from a project may not be the same community that would be impacted by the construction of the project. In these situations, it should be transparently communicated in the grant application how the community will be negatively impacted (including the duration) and whether they have been effectively engaged in the planning process and any intended reparations or accommodations.

The following metrics are associated with climate resilience projects and are based on the inputs that are typically used to in economic analyses to evaluate cost effectiveness. These inputs can be used to evaluate ancillary benefits, such as improvements to water quality and air quality. While the ancillary benefits are not specifically measured by the proposed metrics, it is expected that these ancillary benefits are captured by accounting for the inputs that would be used to calculate them. In cases where double-counting may be a concern, correlation coefficients between metrics could be used to weight them overall. These metrics are not intended to address capability and capacity building projects.

4.3.2.1 Property Damages Avoided

In general, a large share of benefits for climate resilience projects are derived from damages avoided to structures (residential and non-residential, such as commercial, industrial and utilities) and contents. To avoid biasing results towards communities with the highest property values, we recommend using the number of properties by category instead of the depreciated replacement value of properties. The categories could align with the applicable depth-damage function, such as those used by the U.S. Army Corps of Engineers, approved for use by the federal awarding agency. For example, residential structures may be classified as house with basement, house without basement, bi-level and split-level homes, apartment on slab, apartment with first floor 4 feet below grade.

Various ordinal categories could be developed based on national depth-damage functions to sort structures by category and by the percentage of structure and content damage. For example, low structure damage for a residential structure without a basement may be greater than zero up to 20% damage, low-medium structure damage may be 21% to 40%, medium structure damage may be 41% to 60%, medium-high structure damage may be 61% to 80% and high structure damage may be 81% to total loss. Further study is needed to recommend specific ordinal categories for each structure type. A similar approach could be used for other damages that have an established depth-damage function, such as automobiles.

4.3.2.2 Population Served

Because information about property owners and occupants is not likely to be available by structure, the population served should be evaluated separately from property damages avoided. The total investment for the project could be distributed by the equity indicators that have been established by the grant program and the community served by the proposed project. The population served may expand beyond the project area, considering public resources, and critical and public facilities within the project area may serve populations outside of the project area. Multiple metrics could be established, depending on whether different outcomes have different associated populations. Some of the damages avoided are a function of the population impacted, such as costs associated with loss of services (e.g., utilities, public services), evacuation and subsistence, disruption, displacement and reoccupation. Additionally, the total investment for the project per capita could be another metric used for comparison.

For example, an equity indicator could be Low- and Moderate Income (LMI) households, meaning household income lower than 80% of the area median income (AMI). Then metrics could be the share of the total investment per LMI household and the remaining investment per non-LMI households. If the total cost of a proposed resilience project is $5 million serving 100,000 people and 40% of the population qualifies as LMI households, the estimated investment directed towards LMI households would be $2 million.

4.3.2.3 Loss of Life and Injuries

Natural hazards linked to climate change can cause physical impacts during and/or after the event as a direct or indirect consequence. A suggested metric for consideration is the investment per the number of lives saved (both direct and indirect, including acute and chronic diseases) by a proposed resilience project. For injuries, we suggest investment per the number of injuries avoided by severity of injury and investment per number of avoided workdays lost due to injury. Further study is needed to recommend specific loss functions and ordinal categories for each type of disease or injury. While county-level hazard data like those from SHELDUS incorporated in FEMA’s NRI are often used for evaluating loss of life and injuries associated with climate hazards, there are known issues of underreporting especially when it comes to indirect or uninsured losses and events resulting in small or moderate damage [114] [115].

Penning-Rowsell et al. [116] along with the Reclamation Consequence Estimating Methodology (RCEM) from the U.S. Department of the Interior Bureau of Reclamation [117] suggest approaches that can be used for estimating direct loss of life and injuries during and the immediate aftermath of flood events. Approaches for other climate hazards would need to be investigated further. For consistency, the grant awarding agency should specify the approved approach for estimating loss of life and injuries from climate-related events for the grant program.

When a life-threatening situation occurs, timely emergency care is a key factor that affects the chances of survival. When critical facilities such as fire departments and other emergency medical services providers are delayed, there may be lives lost. Climate hazard events may increase the response time of critical services or cause a critical facility to temporarily shut down. FEMA suggests an approach to estimate mortality and emergency medical services (EMS) response time based on critical facilities/EMS providers located within the project area, the population served by those EMS providers and the nearest substitution (in miles) [118]. This approach can be used to estimate the indirect lives saved by a proposed project and could either be combined with or separated from the direct lives saved metric.

4.3.2.4 Mental Health

Mental health impacts associated with exposure to a disaster can include stress associated with evacuations, losing a home and possessions, physical injuries and illness of family and friends. Mental stress can also be a secondary response to other direct impacts, such as being displaced from home and community, loss of electricity and heat in the home for extended periods of time, inability to receive regular counseling or treatment as the result of closure or lack of transportation, or inability to obtain needed medication. Mental health issues can lead to sleep disorders, drug/alcohol use and inability to work, and can last for months or years following a disaster. Productivity losses can occur from lost labor and production for those affected by mental health issues and those who provide care for affected people.

FEMA provides guidance on the prevalence and course (rate of reduction of symptoms over time) of mental health impacts following a disaster [119]. FEMA categorizes mental health impacts as mild/moderate and severe and provides suggested prevalence rates by the time after disaster, as shown in Table 7. By associating these impacts with the costs of treatment and lost productivity, it effectively weights the mental health impacts. As an alternative to monetizing the mental health impacts, the number of people by duration and category can be used to understand the avoided mental health impacts of a proposed climate resilience project.

Table 7. Mental Health Prevalence Percentages with Effect and Course

Time after Disaster	Mild/Moderate	Severe
7-12 months	26%	6%
13-18 months	19%	7%
19-24 months	14%	7%
25-30 months	9%	6%

FEMA used 2009 and 2010 studies as the basis for the monetized value of lost productivity from people suffering from a severe mental illness. Further study is needed to leverage more recent data (within the past 5 years) to understand how to estimate the number of productive days that would be lost from mental health impacts associated with climate hazards.

4.3.2.5 Business Interruptions Avoided

Economic recovery is the ability to return economic and business activities to the level of service provided pre-disaster. The speed and effectiveness of recovery depends on the ability to adapt to changed market conditions and reopening businesses or establishing new businesses. FEMA accounts for commercial, industrial, agricultural, religious/non-profit, government and education displacement and disruption costs based on the defined occupancy class (e.g., retail trade, wholesale trade, banks, hospital, schools/libraries) and square footage [120]. This is limited to the estimated costs of temporary quarters and the time associated with displacement. In some cases, businesses may close permanently after a disaster or lose a portion of business because customers may switch to a different establishment permanently during the business interruption. Estimating the costs associated with business interruptions is difficult to generalize since losses are specific to the business, location and market conditions. This challenge can be compounded by the challenge of obtaining data that may be considered proprietary in some cases. Further study is needed to establish metrics for avoided business interruptions.

4.3.2.6 Agricultural Damages Avoided

Climate hazards, such as flooding and drought, can have significant impacts to agricultural lands. These impacts can be widespread and vary, but often can cause reduced crop yields, adverse impacts to livestock, and damage to farming structures and equipment. Evaluating agricultural damages can be complex depending on the land use, types of crops and distribution, time of year, commodity markets, and the intensity and duration of climate hazard events. Commensurate with the complexity is the uncertainty of damage estimates. As a simplification, the number of acres of pasture land and number of acres of crop land that would avoid damages from a proposed resilience project could be considered.

4.3.2.7 Transportation Delays Avoided

A climate hazard event can have potentially significant impacts on a transportation network. The impacts may include impediment of traffic flow between origin and destination, increased travel times, road closures and corresponding detours. USDOT has well established guidance for estimating costs associated with transportation delays [121]. Instead of monetizing the costs, the methods can be used to identify the delay time, number of vehicles impacted, number of miles, number of people impacted (based on occupancy rate for vehicles or ridership for other modes) and associated fatalities and injuries. Any of these impacts become a benefit when a proposed project would avoid them from occurring. Suggested metrics for consideration could include investment per travel time savings (in hours), which can be used to capture all modes of travel. When considering the safety benefits, it is important that these are not captured elsewhere to avoid double counting. If these are not accounted for already, additional metrics could include investment per fatality avoided and investment per injury avoided.

4.3.2.8 Nature-Based Solutions

Nature-based solutions, as defined by The Nature Conservancy, are “project solutions that are motivated and supported by nature and that may also offer environmental, economic, and social benefits, while increasing resilience. Nature-based solutions include both green and natural infrastructure [122].” Defined by FEMA as, “sustainable planning, design, environmental management, and engineering practices that weave natural features or processes into the built environment to build more resilient communities.” The benefits of nature-based solutions can include ecosystem services and ancillary benefits, such as recreation benefits, reduced urban heat island effects, appreciating property values, reduced energy use and improved human health [123]. The value of these benefits is highly context specific and related to the location and type of habitat created (or restored).

The ecosystem services can be categorized as provisioning, regulating, supporting, and cultural services [124]. Provisioning services may include food, raw materials, and medicinal resources that can be used by people. Regulating services are services provided by ecosystems that act as regulators, such as regulating air quality, water quality, moderating extreme events, erosion prevention, and biological control. Supporting services can also be described as the habitats that provide for flora and fauna to survive, such as food water, and shelter. Supporting services may also include the maintenance of genetic and species diversity. Cultural services can include the recreational value of the ecosystem, aesthetics, tourism, and the spiritual experience provided by the ecosystem.

When ecosystem services benefits are monetized, there is a high degree of uncertainty. The suggested metrics below reduce uncertainty by focusing on the quantity and quality of the habitat created (or restored). Further study is needed to define ordinal ranking for the quality of the habitat by type of habitat (e.g., maturity of tree at time of planting and whether it is native to the habitat), therefore this was not included in the suggested metrics. Suggested metrics for consideration are listed here and are not intended to be exhaustive:

- Investment per acre of urban/rural green space created or restored given ecoregion or ecozone
- Investment per acre of riparian land created or restored
- Investment per acre of shellfish/coral reefs created or restored
- Investment per acre of coastal/inland wetlands created or restored
- Investment per acre of coastal forests created or restored
- Investment per acre of mangroves created or restored
- Investment per acre of prairies created or restored
- Investment per acre of seagrass created or restored
- Investment per acre of beaches and dunes created or restored
- Investment per number of trees planted given ecoregion or ecozone

5 Accounting for Social Capital

Social capital – the goods of individuals' social connection, "social networks and the norms of reciprocity and trustworthiness that arise from them," through both personal relationships and more formal associations – is a relevant concept to climate resilience and hazard mitigation in several ways [125]. First, in defining the social costs of disaster to a community: disaster to homes, neighborhood resources, and community institutions can disrupt relationships, reduce access to neighborhood interaction, and depending on the level of preparation and the perceived efficacy and fairness of the disaster management, may reduce local trust in institutions. The Australian Business Roundtable for Disaster Resilience & Safer Communities found that social impacts–effects on health and wellbeing, employment, education, and community ties–constitute half or more of the total economic cost of recent natural disasters [126].

From a person or household-centric perspective, displacement due to disaster and climate conditions can incur major social costs that could be captured by a loss in the social capital of a person or household. For example, while evacuees from low-opportunity zones may eventually find better jobs in their new locations [127], a relocated disaster refugee may no longer have access to the same level of social support, amounting to a loss as uncertain and long-term as loss of opportunity networks for social, professional, and spiritual flourishing (and their associated health and well-being outcomes) as concrete and immediate as a loss of access to nearby family or friend-provided childcare.

In addition to capturing costs of disaster and displacement, social capital can also predict an individual's or community's resilience to crisis, beyond the effect of income and education [128], from natural disaster to the COVID-19 pandemic [129]. The greater the social capital, the more likely a community will make group decisions about evacuation, coordinate recovery, and commit to rebuilding [130]. In this sense, building social capital can support disaster recovery. This recent body of literature makes the case for building social capital to "create a culture of resilience" in the face of climate change, whether through creating programs with social capital as their primary goal or investing in programs with social capital as a desirable byproduct.

Certain traditional resilience-building investments may build social capital as a byproduct, when they, for example, provide or fortify community gathering spaces or run disaster management training programs that also build trust among neighbors. This level of social trust, further, can be measured as general trust, perceived fairness of others, and perceived helpfulness of others. When done so, empirical research shows that natural disasters tend to decrease the level of social capital in individuals impacted by the event [131].

These relationships between social capital and community resilience motivate the consideration of social capital in climate resilience grant selection and prioritization. For example, an examination of BCA use in FEMA's Flood-Mitigation programs by the University of Chicago Law Review argues that the current method "neglect[s] the long-term intangible social costs incurred by vulnerable communities" by flood disasters [132]. To readily consider social capital in existing climate resilience grant program decision-making, whether a program uses BCA or CEA, we must be able to quantify it. To this end, we review measurement of social capital for the climate resilience grant context and explore approaches to quantifying the social capital-related costs to disaster displacement.

5.1 Measuring Social Capital

Sociologists quantify social capital via the properties of the structure and quality of social connections [133]. Structure can be observed or self-reported: network analysis properties such as the size of one's social network, its density (interconnectedness among one's connections), and its connection frequency. Theoretically, quality (e.g., levels of trust and reciprocity of those connections) could be observed as well, but generally is expressed via one's beliefs about the social behaviors of their network. Surveys on this topic may focus on the quality of neighborhood social connections in general, collecting Likert-scale responses to statements such as "people around here are willing to help their neighbors" (measuring "social cohesion") and "neighbors would intervene if a fight broke out in front of their street" (measuring "informal social control"), conceiving social capital as the combination of those two social quantities [134].

While those methods best measure social capital, they are likely prohibitive in resources, time, and cost for programs looking to evaluate many proposals nationwide on an ongoing basis. Similar to the consideration of social vulnerability in grant prioritization via social vulnerability indices (such as SVI and SoVI), policy-oriented researchers have proposed several social capital indices aggregating social capital indicators based on regularly collected, publicly available nationwide data, such as the ACS. Individual indicators may be proximal—quantities assumed to be components or immediate outcomes of social capital, such as membership rates in clubs—or distal, quantities hypothesized to be effects of possessing or lacking social capital, such as rate of suicide [133]. Table 8 presents several commonly used social capital indices, along with their data sources and data availability.

Table 8: Commonly Used Indices of Social Capital

Name	Level	Years available	Data Source
Joint Economic Committee Republicans Social Capital Project – Social Capital Index **[135]**	County	2018	ACS, IRS, Association of Religious Data archives, multiple sources
Opportunity Insights Social Capital Atlas **[136]**	Zip Code	2022	Proprietary Meta/Facebook data, ACS, Penn State Index, Social Capital Project's Local Trust Index
Data Science for the Public Good Initiative's Advancing Economic Mobility Project (OSU, ISU, VT, UV, VSU) Community Engagement and Isolation Indicators **[137]**	County	Annual	ACS
Penn State University Northeast Regional Center for Rural Development, by Anil	County	1990, 1997, 2005,	Number of Establishments: County Business Patterns

Name	Level	Years available	Data Source
Rupasingha, Stephan Goetz, and David Freshwater **[138]**		2009, 2014	Population size: U.S. Census, Population and Housing Unit Estimates Voter Turnout: Dave Leip's Atlas of U.S. Presidential Elections Census participation: U.S. Census 2010 Number of non-profit organizations: National Center for Charitable Statistics
Kyne, Aldrich, Fraser, Page-Tan: Bonding, Bridging, Linking **[129]**	Bonding: Census tract, Bridging: county; Linking: county	Mostly annual, some aspects every decade	U.S. Census, ESRI
Alesina and La Ferrara **[139]**	State	N/A	General Social Survey (however, not meant to be representative by state)
Civic Health Index TM	custom for national, state, city	level-specific	U.S. Census and additional local sources
Legatum Prosperity Index TM Social Capital subindex	National	2008	Gallup Data

Note: N/A = not available

5.2 Challenges in Leveraging Existing Social Capital Indices

Using existing social capital indices presents multiple challenges, such as lack of universal applicability, predictors anticorrelated with other normative values, ideological bias, subject level (i.e., neighborhood vs. individual/household), and ambiguity over the normativity of social capital. We touch on each of these issues in this section.

5.2.1 Lack of universal applicability

Some indicators in social capital indices may globally correlate with social capital and serve the purpose for examining causal effects of social capital over a national population, but there is enough regional and demographic variation in that relationship that would make county-to-county comparison—which may be necessary in grant selection—inaccurate, as we show here.

The role of formal religious congregations (included in many indices) in social capital, for example, differs by region and demographics. Some research has found a weak inverse correlation between religious social capital and neighborhood social capital overall, yet if there is religious homogeneity within a given county, religious capital translates into neighborhood social capital. Currently proposed indices do not capture this conditional nature of religious involvement as an indicator for social capital. Similarly, the strength of the correlation between voter registration rates and social capital varies by demographic, where historical and ongoing voter disenfranchisement, such as the case for many Black Americans, modulates the community-involvement measure [140].

For example, the Social Capital Index includes the indicator, "Share of adults reporting some or great confidence in corporations to do what is right" [135], while PSU's index includes, "Number of establishments in Labor organization" [138]. A close-knit socialist-leaning community may score low on the corporation-confidence metric, while a close-knit free market capitalist-leaning community may score low on the union involvement metric. The variation in the relevance of the indicators by community or region complicates the ability to use the indices for climate resilience investment prioritization.

5.2.2 Predictors anticorrelated with other normative values

Some of the indices include predictors of social capital that may introduce contradictions in objectives if decision-making bodies adopt said indicators in prioritization. For example, a climate resilience grant program may want to prioritize physical infrastructure investment to communities with low levels of physical resources but high levels of social capital, since the high level of social capital might magnify the effect of the physical resource intervention. However, a predictor of social capital included in Kyne et al.'s index is racial and ethnic similarity, where greater diversity reduces the Social Capital Index score [130]. While this may be an accurate predictor given current racial tensions in the U.S., the government has a stated interest in promoting racial and ethnic integration, and this objective may conflict with the directionality preference of the index.

5.2.3 Ideological bias

The decision to include or exclude the above indicators—to consider religious capital a subset of social capital versus an indicator of social capital; whether to include or exclude union membership, trust of corporations, or rate of government employment—may relate to ideological differences in the index-proposers' conception of social capital as well.

5.2.4 Subject level: Neighborhood vs. individual/household

Most indices measure the social capital of a region (county, city, state etc.) instead of a person, family, or demographic. Therefore, they do not lend themselves to quantifying an individual/family's loss in social capital when displaced, or disparities in social capital by identity or socioeconomic status within the same location.

5.2.5 Ambiguity over the normativity of social capital

Should programs view social capital as a public good that, all things being equal, the program has an interest in reducing inequality in this resource by prioritizing communities with little social capital? Or should the program think of social capital as an effect-multiplier of their intervention, and therefore prioritize communities with low external investment yet high social capital? Alternatively, if social capital is understood as an achieved level that the programs have an interest in increasing, should programs prioritize communities with the greatest growth in social capital? These questions may also have different answers for whether the proposed intervention has a logical causal link to building social capital. But even assuming a causal link to social capital: should programs prioritize neighborhoods with greater climate hazards to increase their resilience via increased social capital, or neighborhoods with fewer climate hazards so that the social capital benefit is less likely to be disrupted by displacement? Whether government has a mandate in equalizing levels of social capital, outside of the process of reducing other disparities, may inspire debate as well.

5.3 Quantifying Social Capital Costs of Climate-Driven Displacement

The previously mentioned challenges motivate care when incorporating social capital indices into equitable climate resilience grant evaluation.

Grant evaluators can consider the hypothesized social capital benefits of the programs or projects proposed in a grant application, especially by accounting for the likely reduction in social capital caused by the disaster fallout the grant application attempts to prevent. Evidence for such effects may make use of social capital indices.

In the following subsections, we explore three possible approaches to quantifying social capital-related costs of displacement.

5.3.1 Using the difference in social capital indices

If the likely location of an individual's or a family's resettlement is known, from location A to B, the social capital cost of resettlement could be approximated by the difference in social capital

$$sc(x', B) - sc(x, A)$$

where x' is a demographic profile similar to x, the individual/family potentially displaced, except in duration of residence: x would include the duration of residence in A, while x' would reflect recent arrivals to B. This difference represents the likely loss (or, in some occasions, gain) in social capital (as distinct from job opportunity) by moving to a new location for a given profile and assumes the social harm of the *involuntariness* and *suddenness* of displacement versus a planned move are accounted for elsewhere.

However, this data is not currently available disaggregated to the individual, family, or parcel level in existing social capital indices because the data is not available at that granular level.

5.3.2 Traditional approach to quantifying total cost of displacement

One could avoid specifying social capital costs altogether by quantifying the total cost of displacement via monetized Willingness to Accept (WTA) displacement or Willingness to Pay (WTP) to avoid displacement, with all the relevant adjustments to inequity in resources that affect WTA/WTP. If direct surveys of residents are unavailable, a model of rent differentials could potentially approximate the value to residents of different demographics of staying put in their current location, though this would require further research into its prediction power for surveyed WTA/WTP.

5.3.3 Directly accounting for major social costs of displacement

Much of the motivation to consider social capital loss in displacement is that social networks are resources for some basic human services and needs, from informal childcare and healthcare to emotional support, job coaching, exchanges of goods, and social connection [141]. While not a replacement for socially-provided care, these needs can also be served by paid professional services—day care centers, urgent care centers, therapists and social workers, job agencies, discount stores, and recreational programs at a higher cost. Community-centered research could identify the primary, formerly socially-provided needs of those displaced by climate disaster. Publicly available data on the local costs and accessibility of these services could be paired with data on the rates of use of those professional services by socioeconomic status (via sources like the Bureau of Labor Statistics Consumer Expenditure Survey) to estimate the additional cost burden to displacement by socioeconomic status.

5.4 Conclusion & Further Work

The concept of social capital helps pinpoint the social harms of climate-related disaster to communities and climate-based displacement. It also provides a factor for community resilience to climate disaster and an additional benefit to some community resilience interventions. Researchers have proposed several social capital indices when more direct measurement of social capital is unavailable. While these indices are appropriate for national social capital studies and assessments, one-to-one comparisons of the social capital of jurisdictions may be highly sensitive to differences in the definition of social capital, variation in the strength of social capital indicators for different communities, and availability in disaggregate form for different demographics. For the purpose of quantifying social capital cost of climate-driven displacement, we recommend community-centered research on the most important services provided from social capital that displacement would disrupt and quantifying the costs (including barriers to access) of temporary replacement of those socially-furnished services by paid services.

6 Next Steps

MITRE plans to facilitate a working group session at the National Adaptation Forum conference in October 2022 to elicit feedback from the adaptation community on the proposed recommendations for using metrics, indicators, indices, and weights both within and external to economic analyses commonly used to assess cost effectiveness to evaluate and prioritize climate resilience investments more equitably. The intention of the working group session is to gather feedback and move toward consensus on a path to greater understanding of how we might equitably and intentionally direct funding toward the communities who need it the most.

Following the working group session, MITRE intends to incorporate feedback into a proposed approach to present at a no-charge Technical Exchange Meeting hosted by MITRE to broaden the audience to any interested attendees.

Various use cases could be developed with government partners using the proposed approach for applicants of discretionary grant programs, as well as an overall evaluation of grant programs (assuming data is available) to understand the level of effort required (and subsequent support needed for PEGs), whether the intended outcomes materialized or if unintentional consequences exist, and the implications for social equity.

Acting on these recommendations will make it easier for the federal government to comply with OMB requirements (Circular A-4) and six EOs dating back to the Clinton Administration (i.e., EO 12291, EO 12866, EO 13563, EO 13990, EO 13985 and EO 14008) that specify the need to demonstrate cost effectiveness while prioritizing investments in PEGs.

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Appendix A Weather and Climate Hazards

Table A-1 presents weather and climate-related hazards that are included in the NRI and CEJST.

Table A-1. NRI/CEJST Natural Hazards Linked to Climate Change

Hazard Type	Description
Avalanche	An Avalanche is a mass of snow in swift motion traveling down a mountainside.
Coastal Flooding	Coastal Flooding is when water inundates or covers normally dry coastal land as a result of high or rising tides or storm surges.
Cold Wave	A Cold Wave is a rapid fall in temperature within 24 hours and extreme low temperatures for an extended period. The temperatures classified as a Cold Wave are dependent on the location and defined by the local NWS weather forecast office.
Drought	A Drought is a deficiency of precipitation over an extended period of time resulting in a water shortage.
Hail	Hail is a form of precipitation that occurs during thunderstorms when raindrops, in extremely cold areas of the atmosphere, freeze into balls of ice before falling towards the earth's surface.
Heat Wave	A Heat Wave is a period of abnormally and uncomfortably hot and unusually humid weather typically lasting two or more days with temperatures outside the historical averages for a given area. The temperatures classified as a Heat Wave are dependent on the location and defined by the local NWS weather forecast office.
Hurricane	A Hurricane is a tropical cyclone or localized, low-pressure weather system that has organized thunderstorms but no front (a boundary separating two air masses of different densities) and maximum sustained winds of at least 74 miles per hour (mph). The Hurricane data also include tropical storms for which wind speeds range from 39 to 74 mph.
Ice Storm	An Ice Storm is a freezing rain situation (rain that freezes on surface contact) with significant ice accumulations of 0.25 inches or greater.
Landslide	A Landslide is the movement of a mass of rock, debris, or earth down a slope.
Riverine Flooding	Riverine Flooding is when streams and rivers exceed the capacity of their natural or constructed channels to accommodate water flow and water overflows the banks, spilling into adjacent low-lying, dry land.
Strong Wind	Strong Wind consists of damaging winds (often originating from thunderstorms) that are classified as exceeding 58 mph.
Tornado	A Tornado is a narrow, violently rotating column of air that extends from the base of a thunderstorm to the ground and is visible only if it forms a condensation funnel made up of water droplets, dust, and debris.
Wildfire	A Wildfire is an unplanned fire burning in natural or wildland areas, such as forest, shrub lands, grasslands, or prairies.
Winter Weather	Winter Weather consists of winter storm events in which the main types of precipitation are snow, sleet, or freezing rain.

Note: NRI also includes four other natural hazards that are not associated with climate change. They are earthquake, lightning, tsunami, and volcanic activity.

Additional weather and climate-related hazards that are currently not included in NRI and CEJEST are provided in Table A-2 for consideration.

Table A-2. Additional Natural Hazards Linked to Climate Change for Consideration

Hazard Type	Description, Rationale and Example Data
Coastal Erosion	Long-term or episodic change in shoreline position caused by relative sea level rise, nearshore currents, waves, and storm surge. Hazardous to built infrastructure, ecosystems, and livelihoods. Example data: Coastal Erosion Hazard Mapping Project – ARDC; Coastal Topobathy Lidar (noaa.gov)
Marine Heatwave	Episodic extreme ocean temperatures. "Water temperature spikes in Hawaii have also been linked to coral disease outbreaks [142]" impacting tourism, ecosystems, and livelihoods. Example data: Marine Heatwaves: NOAA Physical Sciences Laboratory
Ocean Acidification	Profile of ocean water pH levels and accompanying concentrations of carbonate and bicarbonate ions. "Ocean acidification is currently affecting the entire ocean, including coastal estuaries and waterways. Many jobs and economies in the U.S. depend on the fish and shellfish that live in the ocean [143]." Example data: Ocean Carbon and Acidification Data Set: NCEI Accession 0219960 (noaa.gov)
Air Pollution (weather)	Atmospheric conditions that increase the likelihood of high particulate matter or ozone concentrations or chemical processes generating air pollutants. Note: distinct from aerosol emissions or air pollution concentrations themselves. Some examples include the increase in ground-level ozone from sunny, hot weather or the dispersal of wildfire pollutants through wind patterns and across large distances. Example data: Air Data: Air Quality Data Collected at Outdoor Monitors Across the U.S. | U.S. EPA
Low Streamflow	Trends in the amount of water carried by streams across the United States, as well as the timing of runoff associated with snowmelt. Example data: USGS Surface-Water Data for the Nation
Lake and Stream Water Quality	"Changing climate is likely to harm water quality in Lake Erie and Lake Michigan. Warmer water tends to cause more algal blooms, which can be unsightly, harm fish, and degrade water quality. During August 2014, an algal bloom in Lake Erie prompted the Monroe County Health Department to advise residents in four townships to avoid using tap water for cooking and drinking [144]." Example data: USGS Water-Quality Data for the Nation
Low Lake, River and Sea Ice	For Alaska's native communities, "The loss of sea ice restricts the subsistence lifestyle of groups such as the Yup'ik, Iñupiat, and Inuit by limiting hunting grounds and reducing habitat for traditional food sources such as walrus [145]." Example data: Data at NSIDC | National Snow and Ice Data Center
Thawing Permafrost	Permanently frozen deep soil layers, their ice characteristics, and the characteristics of seasonally frozen soils above. Hazardous to built infrastructure, ecosystems, and livelihoods. Example data: Data at NSIDC | National Snow and Ice Data Center
Growing Degree Days	Changes in growing degree days signal changes in the timing and length of growing seasons and pollen seasons in the United States. Example data: Explore Data | USA National Phenology Network (usanpn.org); Accumulated Growing Degree Day Products | USA National Phenology Network (usanpn.org)

Note: Not all climate-related hazards are included here.

Appendix B MITRE Social Justice Platform Equity Indicators

Table B-1. Domains & Sub-Domains of Equity Indicators in the MITRE Social Justice Platform as of September 2022

Equity Indicator Domain	Equity Indicator Sub-Domain	Equity Lens
Demographics	Age	Temporal/Intergenerational
Demographics	Citizenship	Procedural and Fairness
Demographics	Disability	Procedural and Fairness
Demographics	Gender	Procedural and Fairness
Demographics	Language	Awareness
Demographics	Population Distribution	Access and Distributional
Demographics	Race/Ethnicity	Citizen Engagement
Economy	Businesses	Quality and Process
Economy	Consumer	Output
Economy	Credit	Procedural and Fairness (Eligibility)
Economy	Income	Outcome
Economy	Poverty	Outcome
Economy	Retirement	Temporal/Intergenerational
Economy	Workforce/Employment	Outcome
Education	Education Access	Access and Distributional
Education	Education Quality	Quality and Process
Education	Educational Attainment	Outcome
Education	Educational Enrollment	Output
Education	School Discipline	Procedural and Fairness
Education	Security and Violence	Outcome
Education	Student Debt	Access and Distributional
Environment	Disaster Preparedness	Quality and Process
Environment	Emissions and Pollution	Quality and Process
Environment	Energy Use	Outcome
Environment	Urbanization	Access and Distributional
Environment	Water	Procedural and Fairness
Health	Food Access & Nutrition	Access and Distributional
Health	Health Insurance Status	Output
Health	Health Status	Outcome
Health	Healthcare Access	Access and Distributional

Equity Indicator Domain	Equity Indicator Sub-Domain	Equity Lens
Health	Healthcare System Characteristics	Quality and Process
Health	Mortality	Outcome
Justice	Crime	Outcome
Justice	Public Safety	Procedural and Fairness
Social Context	Civic Engagement	Citizen Engagement
Social Context	Community	Awareness
Social Context	Public Administration	Procedural and Fairness
Technology	Technology	Access and Distributional
Transportation & Land Use	Housing	Access and Distributional
Transportation & Land Use	Transportation	Access and Distributional

Appendix C Equity Indices & Screening Tool Variables Cross Walked with Climate Hazards

Table C-1. Variables from select equity indices and screening tools cross walked with Table A-1 (blue) and equity sub-domains from Table B-1 (orange). Blank cells without information denote a gap in coverage of climate hazards or equity sub-domains

Parameter/Domain		CEJST	NRI (SoVI)	EJ Screen	ADI	Livability Index
Avalanche		Yes (avalanche)	Yes (avalanche)			
Coastal flooding		Yes (coastal flooding)	Yes (coastal flooding)	Yes (Coastal Flood Hazard)		
Cold		Yes (cold wave)	Yes (cold wave)			
Agricultural/ecological drought		Yes (drought)	Yes (drought)	Yes (Drought)		
Hydrological drought		Yes (drought)	Yes (drought)	Yes (Drought)		
Hail		Yes (hail)	Yes (hail)			
Heat		Yes (heat wave)	Yes (heat wave)			
Hurricane/tropical cyclone		Yes (hurricane)	Yes (hurricane)			
Ice storm		Yes (ice storm)	Yes (ice storm)			
Landslide		Yes (landslide)	Yes (landslide)			
Pluvial flood, heavy precipitation		Yes (flash floods included in riverine flooding)	Yes (flash floods included in riverine flooding)			
Riverine flooding		Yes (riverine flooding)	Yes (riverine flooding)	Yes (Estimated 100-year floodplains)		

Parameter/Domain		CEJST	NRI (SoVI)	EJ Screen	ADI	Livability Index
Sea level rise		Yes (included in coastal flooding)	Yes (included in coastal flooding)	Yes (Sea level rise)		
Strong wind		Yes (strong wind)	Yes (strong wind)			
Tornado		Yes (tornado)	Yes (tornado)			
Wildfire, fire weather		Yes (wildfire)	Yes (wildfire)	Yes (Wildfire Hazard Potential)		
Winter weather, heavy snow		Yes (winter weather)	Yes (winter weather)			
Age			Yes (Median age, Percent population under five years or age 65 and over)	Yes (Percent under age 5, Percent over age 65)		Yes (Multi-generational communities: Age diversity)
Citizenship						
Gender			Yes (Percent female)			Yes (Equal rights: Municipal LGBTQ+ anti-discrimination laws)
Language		Yes (linguistic isolation)	Yes (Percent population speaking English as second language (with limited	Yes (Percent linguistic isolation)		

Parameter/Domain	CEJST	NRI (SoVI)	EJ Screen	ADI	Livability Index
		English proficiency))			
Population Distribution	Yes (Population loss rate)				Yes (Mixed-use neighborhoods, Diversity of destinations; Compact neighborhoods, Activity density)
Race/Ethnicity		Yes (Percent Asian population, Percent African American (Black) population, Percent Hispanic population, Percent Native American population)	Yes (Percent people of color, Demographic index)		
Businesses					
Consumer					
Credit					Yes (Local fiscal health: Local government creditworthiness)

Parameter/Domain		CEJST	NRI (SoVI)	EJ Screen	ADI	Livability Index
Income		Yes (low income, low median income)	Yes (Per capita income, Percent families earning more than $200,000 income per year)	Yes (Percent low income, Demographic index)	Yes (Median family income, Income disparity)	
Poverty		Yes (poverty)	Yes (Percent persons living in poverty)		Yes (Percent of families below poverty level, Percent of population below 150% of the poverty threshold)	Yes (Equal opportunity: Income inequality, State expansion of the Family and Medical Leave Act)
Retirement						
Workforce/Employment		Yes (unemployment rate)	Yes (Percent civilian labor force unemployed, Percent female participation in the labor force, Percent employment in service occupations, Percent	Yes (Unemployment)	Yes (Percent of employed persons >=16 years of age in white-collar occupations, Civilian labor force population aged ≥16 y unemployed (unemployment rate)	Yes (Economic opportunity: Jobs per worker, State and local minimum wage increase)

Parameter/Domain		CEJST	NRI (SoVI)	EJ Screen	ADI	Livability Index
			employment in extractive industries (e.g., farming))			
Education Access						
Education Quality						
Educational Attainment		Yes (high school degree non-attainment)	Yes (Percent population over 25 with <12 years of education)	Yes (Percent less than high school education)	Yes (Percent of population aged >= 25 years with < 9 years of education, Percent of population aged >= 25 years with < a high school diploma)	Yes (Educational opportunity: High school graduation rate)
Educational Enrollment		Yes (Higher Ed non-enrollment)				
School Discipline						
Security and Violence						
Student Debt						
Disaster Preparedness						Yes (Local multi-hazard mitigation plans)

Parameter/Domain		CEJST	NRI (SoVI)	EJ Screen	ADI	Livability Index
Emissions and Pollution		Yes (Traffic proximity and volume, Diesel PM exposure, PM 2.5 in air, Proximity to Superfund/RMP facilities, Proximity to hazardous waste facilities)		Yes (Particulate Matter 2.5 (level in air), Ozone (level in air), Diesel Particulate Matter (level in air), Air Toxics Cancer Risk, Air Toxics Respiratory Hazard Index, Traffic Proximity and Volume, Lead Paint (% pre-1960 housing), Superfund Proximity, Risk Management Plan (RMP) Facility Proximity, Hazardous Waste Proximity, Underground Storage Tanks (UST) and Leaking UST (LUST), Wastewater Dischargers		Yes (Air quality: Regional air quality, Near-roadway pollution, Local industrial pollution

Parameter/Domain		CEJST	NRI (SoVI)	EJ Screen	ADI	Livability Index
				Indicator (Stream Proximity and Toxic Concentration), Nonattainment areas (PM2.5, PM10, SO2, Ozone, CO, NO2, Lead), RSEI score)		
Energy Use		Yes (energy burden)				Yes (State utility disconnection policies, State energy efficiency scorecard)
Urbanization						
Water		Yes (wastewater discharge)		Yes (Impaired Water Points, Impaired streams, Impaired water bodies, Impaired catchments, Streams, Water	Yes (Percent of occupied housing units without complete plumbing)	Yes (Drinking water quality)

Parameter/Domain		CEJST	NRI (SoVI)	EJ Screen	ADI	Livability Index
				bodies, Sole source aquifers)		
Food Access & Nutrition		Yes (Agricultural value loss rate)		Yes (Food desert)		Yes (Proximity to destinations: Access to grocery stores and farmers markets)
Health Insurance Status			Yes (Percent population without health insurance)			Yes (Access to health care, Healthcare professional shortage areas)
Health Status		Yes (asthma, diabetes, heart disease, low life expectancy)		Yes (asthma, heart disease, low life expectancy)		Yes (Healthy behaviors: Smoking prevalence, State and local smoke-free laws, Obesity prevalence, Access to exercise opportunities)
Healthcare Access						Yes (Quality of health care: Patient satisfaction)

Parameter/Domain		CEJST	NRI (SoVI)	EJ Screen	ADI	Livability Index
Healthcare System Characteristics			Yes (Community hospitals per capita)	Yes (Medically underserved, Hospitals)		Yes (Quality of health care: Preventable hospitalization rate)
Disability						Yes (Housing accessibility (Zero-step entrances); Housing accessibility, State and local inclusive design laws; ADA accessible transit)
Mortality		Yes (low life expectancy)				
Crime						Yes (Crime rate)
Public Safety						Yes (Safe streets: State and local Complete Streets policies, Speed limits, Crash rate)
Civic Engagement						Yes (Civic engagement: Opportunity for civic involvement, Voting rate, Early, absentee, or mail-in state

Parameter/Domain		CEJST	NRI (SoVI)	EJ Screen	ADI	Livability Index
						voting laws; Equal rights: Local human rights commissions)
Community		Yes (Building value loss rate)	Yes (Percent children living in married couple families, Percent households receiving Social Security benefits, Percent families with female-headed households with no spouse present, Percent population living in nursing facilities)	Yes (Places of worship, Schools, Parks, Tribal areas, Prisons)	Yes (Percent of single-parent households with children aged < 18 y)	Yes (Proximity to destinations: Access to parks, Access to Libraries; Social engagement, Social involvement index, Cultural, arts, and entertainment institutions; Comprehensive livability commitment: State and local plans to create age-friendly communities)
Public Administration						

Parameter/Domain		CEJST	NRI (SoVI)	EJ Screen	ADI	Livability Index
Technology				Yes (Broadband access)	Yes (Percent of households without a phone)	Yes (Internet access: Broadband cost and speed, State barriers to community broadband)
Housing		Yes (Housing burden, Low median home value, Percent of housing units built before 1960 - Lead paint proxy)	Yes (Median gross rent for renter-occupied housing units, Median dollar value of owner-occupied housing units, Average number of people per household, Percent unoccupied housing units, Percent population living in mobile homes, Percent	Yes (Public housing)	Yes (Median home value, Median gross rent, Median monthly mortgage, Owner-occupied housing units (home ownership rate), Percent of households with more than 1 person per room (crowding))	Yes (Housing options, Availability of multi-family housing; Housing affordability, Housing costs; Housing affordability, Housing cost burden; Housing affordability, Availability of subsidized housing; Housing options, State manufactured housing protections; Housing affordability, State foreclosure prevention and protection);

Parameter/Domain		CEJST	NRI (SoVI)	EJ Screen	ADI	Livability Index
			renter-occupied housing units)			Housing options, State accessory dwelling unit support; Vacancy rate)

Parameter/Domain		CEJST	NRI (SoVI)	EJ Screen	ADI	Livability Index
Transportation		Yes (Traffic proximity and volume)	Yes (Percent housing units with no car available)	Yes (Airport points and polygons, Railroads)	Yes (Percent of households without a motor vehicle)	Yes (Proximity to destinations, Access to jobs by transit; Convenient transportation options: Frequency of local transit service, Walk trips, Congestion; Accessible system design, ADA-accessible stations and vehicles; Transportation costs, Household transportation costs; Convenient transportation options: State human services transportation coordination, State volunteer driver policies; Safe streets: State and local Complete Streets policies, Speed

Parameter/Domain		CEJST	NRI (SoVI)	EJ Screen	ADI	Livability Index
						limits, Crash rate; Convenient transportation options: State human services transportation coordination, State volunteer driver policies)

Appendix D Abbreviations and Acronyms

This is an alphabetical listing of all abbreviations (initialisms, and acronyms) listed in the document.

Term	Definition
ACS	American Community Survey
ADI	Area Deprivation Index
AMI	Area Median Income
ASAP	American Society of Adaptation Professionals
ATSDR	Agency for Toxic Substances and Disease Registry
BCA	Benefit-Cost Analysis
BIPOC	Black, Indigenous, and People of Color
BRFSS	Behavioral Risk Factor Surveillance System
BRIC	Building Resilient Infrastructure and Communities
CARES	Center for Applied Research and Engagement Systems
CDC	Centers for Disease Control
CDF	Cumulative Distribution Function
CEA	Cost-Effectiveness Analysis
CEJST	Climate and Economic Justice Screening Tool
CEQ	Council on Environmental Quality
CMRA	Climate Mapping for Resilience and Adaptation
CPO	White House Climate Policy Office
CYP	Couple-Years of Protection
DALY	Disability-Adjusted Life-Year
DCEA	Distributional Cost-Effectiveness Analysis
ECEA	Extended Cost-Effectiveness Analysis
EDRC	Economically Disadvantaged Rural Community
EJI	Environmental Justice Index
EMT	Emergency Medical Team
EPA	Environmental Protection Agency
FEMA	Federal Emergency Management Agency
FMA	Flood Mitigation Assistance
FRP	Financial Risk Protection
FTA	Federal Transit Administration
IEA	Economic Impact Analysis
IIJA	Infrastructure Investments and Job Act
IPCC	Intergovernmental Panel on Climate Change
LGBTQIA+	Lesbian, gay, bisexual, transgender, queer/questioning, intersex, asexual/aromantic/agender, plus
MCDA	Multi-Criteria Decision Analysis
MOE	Margin of Error
NASEM	National Academies of Sciences, Engineering and Medicine
NIST	National Institute of Standards and Technology
NOAA	National Oceanic and Atmospheric Administration
NOFO	Notice of Funding Opportunities

NRI	National Risk Index
OMB	White House Office of Management and Budget
PCA	Principal Component Analysis
PEG	Priority Equity Geographies
QALY	Quality Adjusted Life-Year
SAR	Search and Rescue
SJP	MITRE Social Justice Platform
SLTT	State, Local, Tribal and Territorial
SoVI	USC Social Vulnerability Index
SVI	Social Vulnerability Index
SWF	Social Welfare Functions
UASI	Urban Areas Security Initiative
USDA	US Department of Agriculture
USDOJ	U.S. Department of Justice
USDOT	U.S. Department of Transportation
USGCRP	US Global Change Research Program
VSL	Value of a Statistical Life
VTTS	Value of Travel Time Savings
WTA	Willingness to Accept
WTP	Willingness to Pay