INTEGRATING PUBLIC HEALTH INTO CAPITAL PLANNING FOR CLIMATE CHANGE:

An Exploration of Public Health Measures and Their Use in Capital and Climate Planning

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A thesis
submitted in partial fulfillment of the
requirements for the degrees of

Master of Urban Planning
and
Master of Public Health

University of Washington
2023

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Programs Authorized to Offer Degrees:

Department of Urban Planning and Design
and
Department of Health Systems and Population Health

University of Washington

Abstract

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Climate change's adverse impacts, including increasing heat, flooding risks, and wildfires, pose growing threats to human health, disproportionately affecting vulnerable populations and communities. With the majority of the global population residing in urban areas, cities play a central role in emissions reduction and climate adaptation efforts. Therefore, local government-led infrastructure projects provide opportunities to support these efforts. Despite known co-benefits, incorporating health and climate information into infrastructure decision-making processes is not yet common practice. This study aims to 1) review approaches for identifying and selecting measures of vulnerability, 2) explore the availability of measures and tools for infrastructure decision-making, and 3) examine how data and assessments are used in practice. Information was collected through a multi-method approach, including a comparative analysis of eight national and state spatial health or vulnerability data tools and interviews with local government and utility department staff. The findings reveal that despite limited consensus in the literature, there is agreement among tools and interviewees on common measurement categories, although variations persist in the use of specific measures. In practice, implementation of these measures is limited due to barriers such as resource constraints, complex processes, and competing priorities. However, this research confirms the opportunity and impact of vulnerability assessment in infrastructure planning, particularly in addressing social equity and health in the context of climate change. It highlights the need for further implementation-focused support and research to bolster its use in planning practice.

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INTRODUCTION

Climate change poses many risks to human health and well-being, and evidence is clear that climate change is already contributing to the global burden of disease and premature death (Buse & Patrick, 2020; Ebi et al., 2006; Intergovernmental Panel on Climate Change, 2022; Mailloux et al., 2021; Proust et al., 2012; Smith, K.R et al., 2014). Population health is impacted by climate change through a variety of pathways, with health impacts that are directly causal, mediated by biophysical and ecological conditions, or manifest from other more diffuse effects (Buse & Patrick, 2020; Ebi et al., 2006; Remais et al., 2014; Romanello et al., 2021; Younger et al., 2008).

Detrimental impacts on human health and well-being are expected to grow over time as continued warming of the planet creates increasingly extreme weather events (such as heat waves, floods, droughts, and wildfires), causes sea level rise, and impacts ecosystems and natural resources (Buse & Patrick, 2020; Ebi et al., 2006; Remais et al., 2014; Romanello et al., 2021; Younger et al., 2008). As ecosystem changes are already occurring across the globe due to warming global temperatures, addressing climate change health impacts is becoming more urgent (Ebi et al., 2006; Intergovernmental Panel on Climate Change, 2022)

The changes needed to address climate change will require actions that include cultural, political, technological, and economic shifts (Mailloux et al., 2021). Actions are typically grouped under two main categories: mitigation and adaptation (Bikomeye et al., 2021; Buse & Patrick, 2020; Intergovernmental Panel on Climate Change, 2001). Mitigation includes activities that limit or remove greenhouse gas emissions, and adaptation includes activities undertaken to cope or adjust to changing climate conditions.

In the context of human health, mitigation can reduce or prevent long-term risks of climate change on human life by reducing sources of climate change (Bikomeye et al., 2021). Comparatively, adaptation in the context of human health typically focuses on reducing the vulnerability of populations to the impacts of climate change and climate-related risks so that individuals and communities can better cope with, manage, or adjust to changing conditions, stressors, and hazards (Bikomeye et al., 2021; Smit & Wandel, 2006).

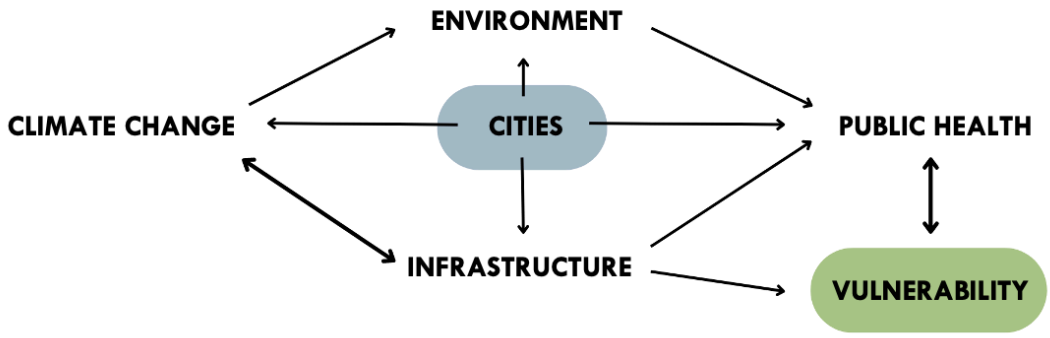
With the majority of the world's population living in urban areas, cities are at the center of the climate crisis. Urban areas are central to mitigation and adaptation efforts; they account for more than 70 percent of global greenhouse gas emissions and are locations of concentrated people, infrastructure, and investment (Coalition for Urban Transitions, 2019). As cities look to mitigate emissions and adapt to climate change, the design and development of infrastructure

projects can support these efforts while supporting resiliency and improving environmental and public health (Cutter et al., 2014; Intergovernmental Panel on Climate Change, 2022). Government-owned infrastructure, in particular, is a major source of emissions for urban areas and has the potential to be a major component of local infrastructure-based adaptation efforts (Whittington & Lynch, 2015; World Bank, 2021). For this reason, capital project investment is a key opportunity for actionable incorporation of climate and public health considerations into city planning practices.

Infrastructure policy and delivery that supports climate mitigation and adaptation can provide many opportunities, often called co-benefits (Bikomeye et al., 2021; Younger et al., 2008). However, it can also create unintended negative consequences when it occurs without consideration of the consequences for health and well-being (Harris et al., 2020). In particular, a lack of health considerations in infrastructure planning can exacerbate existing health inequities (Northridge & Freeman, 2011). Additionally, vulnerable populations, particularly low-income individuals and people of color who are already more likely to be negatively impacted by our current built environment, also are expected to face disproportionately larger impacts of climate change (Anguelovski et al., 2016; Intergovernmental Panel on Climate Change, 2022; Younger et al., 2008).

Based on the literature, this project proposes that an approach to prioritizing or designing infrastructure investments that include considerations of social vulnerability within the context of climate change and public health presents an opportunity to create climate and health co-benefits while advancing equity and social justice (Anguelovski et al., 2016; Bikomeye et al., 2021; Buse & Patrick, 2020; Hughes, 2020). Figure 1 illustrates the proposed connections of climate change, health and well-being, capital infrastructure, and vulnerability; arrows illustrate the directionality of impact.

Figure 1. Connecting Climate Change, Public Health, Infrastructure, and Vulnerability



The goal of this research is to understand how public health data can support local governments in identifying and understanding who in their communities may be more sensitive or vulnerable to climate impacts as they seek to implement new capital projects. The research was structured around two main objectives: 1) understanding available data at the intersection of capital investment choices, climate change, and public health, particularly related to measuring community vulnerability, and 2) determining the facilitators and barriers in practice to using public health data in infrastructure decision-making policy processes.

The following questions guided the research:

- What measures belong at the foundational intersection of capital investment choices, climate change, and public health?
- Do we use different measures to understand the relationship between infrastructure, health, and vulnerability when climate change is added as a consideration?
- How do you define vulnerability, and what measures can be used to determine vulnerability?
- How can city planners, policymakers, and utility staff leverage the identified measures within capital investment planning to support more equitable and resilient infrastructure?
- What are the current barriers to using public health data in infrastructure decision-making processes?

The research questions were explored through a literature review, a scan of existing data tools used to measure social vulnerability or public health, and a set of interviews with staff of city and county government agencies and utility departments.

Section I reviews the literature regarding the linkages between climate, infrastructure, and health, including a discussion of definitions and existing approaches for operationalizing the concept of vulnerability, and a review of current related planning efforts linking public health, climate, and capital planning. Section II provides an overview of the project's study design including the processes for the scan of data tools and semi-structured interviews. Section III presents the results from the scan of data tools and semi-structured interviews through highlighting the comparative similarities and differences between data tools, and the key themes and takeaways identified from the interviewees. Section IV explores the implications of these findings in relation to how measures are selected and used in planning practice. It also discusses limitations and areas for potential future research. Section V provides final remarks and notes that while research confirms the opportunities and impact of vulnerability assessments in infrastructure planning for climate change, it also highlights the need for further implementation-focused support and research to bolster its use in planning practice.

I. REVIEW OF THE LITERATURE

Despite a wide variety of literature that discusses the relationship between the health impacts of climate events, as well as literature that reviews the relationship between health and the built environment, there is a lack of consensus on how to measure this relationship, particularly in relation to capital infrastructure projects (Ebi et al., 2006; Hernández, 2013; Pineo, Glonti, et al., 2020; Remais et al., 2014; Rider, 2020; Romanello et al., 2021; Younger et al., 2008).

This need for standardization of health measures related to infrastructure is still a topic of ongoing debate; the addition of climate considerations results in even less agreement. A 2018 review by Pineo et al. identified only three studies that had completed systematic reviews of urban health metrics related to the built environment. All three of these studies identified common themes of a general lack of data, underdeveloped data, and a lack of information on applying available data to inform policy and practice (Pineo et al., 2018).

In general, using health or climate information, data, and tools in planning, capital improvement processes, and infrastructure standards and guidelines is not yet common practice (Pineo, Glonti, et al., 2020; Whittington & Lynch, 2015; World Bank, 2021). Yet mainstreaming these data and tools is crucial to ensure that future climate conditions and their health impacts are major elements of the local community and infrastructure planning process. Understanding the application of the data in practice is a core component of successfully implementing them into policy and practice. However, studies on this topic acknowledge that much of the existing knowledge and evidence related to health indicators and measures have often focused on their development and validation rather than application (Pineo, Glonti, et al., 2020; Pineo, Zimmermann, et al., 2020)

Current literature highlights two key gaps for additional knowledge generation: 1) further exploration of what health measures apply to capital planning for climate change, particularly related to measuring community vulnerability, and 2) a better understanding of how to improve the use of data in practice by policymakers, planners, and decision-makers to identify and fund more equitable and resilient infrastructure.

The following literature review explores existing theoretical perspectives, definitions, and applications of these concepts across existing research on climate change, hazard mitigation, urban planning, urban finance, and public health.

The first section presents the linkages between the disciplines of climate change, infrastructure, and health, including the health co-benefits and potential for maladaptation in infrastructure projects. The following section discusses the lack of theoretical or definitional

agreement related to the concepts of vulnerability and resilience and their use in planning practice; it also highlights the importance of linking these definitions to theories of justice. The third section of the literature review explores the challenges of measuring social vulnerability through explorations of the approaches for operationalizing and selecting data for social vulnerability measurement. Finally, the last section provides an overview of current planning efforts incorporating health and social vulnerability data and concludes by identifying the capital investment plan (CIP) as a crucial tool to address the positive or negative health impacts of climate-related infrastructure decisions.

LINKING CLIMATE CHANGE, INFRASTRUCTURE, AND HEALTH

The Role of Place

Climate change impacts are fundamentally tied to place. The natural ecosystems and built environments in which populations reside are inherently linked to the outcomes they will experience as a result of climate change (Rosen, 2016). Place is impacted by local planning decisions, which shape land uses and travel patterns, influence lifestyles and environmental exposures, and impact human health and environmental sustainability (Lowe et al., 2019). Urban planning decisions, therefore, play a key role in helping cities and communities mitigate and adapt to climate change and its related environmental, ecosystem, and human health impacts (Rosen, 2016).

Urban areas account for 70 percent of all carbon emissions and are already a significant focus of global attention in efforts related to climate change mitigation (Rashidi et al., 2017). In addition, the Intergovernmental Panel on Climate Change (IPCC) estimates that approximately 3.3 to 3.6 billion people live in highly vulnerable environments, many of which are tied to urbanized cities and their infrastructure (Intergovernmental Panel on Climate Change, 2022). While needed across all communities, mitigation and adaptation efforts will likely be centralized in urbanized areas and cities due to their concentration of infrastructure, its outsized impact on emissions, and expansive potential for adaptive opportunity (Coalition for Urban Transitions, 2019; World Bank, 2021).

City planning policies provide wide-ranging impacts on the built environment, including the specification of land uses through zoning and building codes, the funding and provision of infrastructure and other public services (i.e., transportation, drinking water, and wastewater services), and regulation of taxes and fees, among other activities (Lowe et al., 2019). Infrastructure is also linked with a community's capacity to maintain high levels of public health and well-being (Hendricks, 2022; Northridge & Freeman, 2011).

In the face of climate change, infrastructure is a key avenue for both mitigation and adaptation efforts (Sharifi et al., 2021). Adequate transportation can reduce reliance on single occupancy vehicles and reduce greenhouse gas emissions; stormwater infrastructure can reduce flooding in the event of a hazard, and electricity grid updates can reduce emissions and support long-term adaptation (Rashidi et al., 2017).

In conjunction with mitigation and adaptation opportunities within the infrastructure sector, existing literature outlines three additional reasons why focusing on infrastructure as a climate change response is imperative. First, the life span of physical infrastructure lasts for decades, and when well-designed and implemented, it can provide opportunities for long-term resilience. Second, infrastructure can enhance public health and well-being, providing crucial co-benefits that can advance population health and address inequities in health outcomes. Third, comparatively, when inadequate or poorly designed and implemented, infrastructure can amplify the impacts of climate change and exacerbate existing inequities (Sharifi et al., 2021).

The Inequity of Place: Infrastructure's Impact on Climate Vulnerability

Existing inequities due to the built environment are not by happenstance. Historic planning practices such as residential segregation through redlining and patterns of racialized economic distribution through comprehensive planning have impacted urban spaces, physical environments, and the health status of residents for decades. Evidence shows that zoning practices and redlining in the early 1900s are linked with disproportionate exposure to locations of polluting industries or hazardous materials and increased vulnerability to extreme heat (Bikomeye et al., 2021; Hendricks, 2022; Hendricks & Van Zandt, 2021).

Decisions around infrastructure funding, siting, and development continue to exacerbate social inequities, particularly among low-income communities and communities of color. Today, many of these same communities, which faced historical discrimination and investment, still experience poorly maintained infrastructure and elevated pollutant exposure, which reduces neighborhood quality of life and increases stress levels, particularly among low-income people of color (Hendricks, 2022).

The growing priority of climate mitigation and adaptation in urban areas has emerged against this historical backdrop of urban segregation, redlining, spatial inequality, and uneven planning prioritization and infrastructure investment (Anguelovski et al., 2016). Therefore, attempting to address climate change impacts through urban planning decisions without consideration of pre-existing vulnerability can exacerbate socio-spatial inequities and existing health disparities (Anguelovski et al., 2016; Hendricks, 2022; Hendricks & Van Zandt, 2021).

Infrastructure's Impact on Health: An Opportunity for Co-benefits or Maladaptation?

The built environment, including infrastructure, has always been a fundamental driver of public health outcomes, both positive and negative (Hendricks, 2022). A wealth of literature exists linking built environmental policies and projects to public health co-benefits (Hernández, 2013; Mailloux et al., 2021; Mayrhofer & Gupta, 2016; Rashidi et al., 2017; Remais et al., 2014; Sharifi et al., 2021; F. Thomas et al., 2014; von Grafenstein & Gao, 2021; Younger et al., 2008). While the primary goal of mitigation and adaptation strategies is to combat climate change, these health co-benefits or positive externalities are a growing focus within climate change literature as original research on health and climate has increased 11-fold from 2007 to 2020 (Mailloux et al., 2021). Primary literature summarizing these co-benefits includes Younger et al.'s (2008) review of health co-benefits of climate mitigation strategies and Sharifi et al.'s (2021) systematic review of the health co-benefits of urban climate-change adaptation strategies.

Within the literature, co-benefits are often described as "win-win" opportunities, or according to the IPCC, "positive effects that a policy or measure aimed at one objective might have on other objectives, irrespective of the net effect on overall social welfare" (Mayrhofer & Gupta, 2016; Smith, K.R et al., 2014). The concept of co-benefits has grown in part because it offers an approach for policymakers to identify solutions that can integrate diverse concerns and bring additional stakeholders to the table in discussions of climate mitigation and adaptation solutions. The concept has gained enough traction that the IPCC now features co-benefits as a central theme within their working group reports (Intergovernmental Panel on Climate Change, 2022; Mayrhofer & Gupta, 2016; Smith, K.R et al., 2014).

Despite the promise of co-benefits, they are often ignored in policy design. The identified limitations of application include a lack of multi-sector awareness in policymaking, difficulty monetizing the social costs/benefits which is often needed to guide policy decisions, and challenges in identifying measures to support policy development or evaluation (Mayrhofer & Gupta, 2016; Sharifi, 2016; von Grafenstein & Gao, 2021).

When ignored in policy design and infrastructure investment and management, there is an increasing potential for what is described as planning maladaptation or scenarios in which planning or infrastructure investment and management lead to negative health outcomes or exacerbate existing inequities (Anguelovski et al., 2016; Bikomeye et al., 2021; Burton et al., 2015). Part of this risk stems from the reality that efforts to mitigate or adapt to climate change are often embedded in the institutions and development processes that create and reproduce uneven risk exposure or socioeconomic vulnerability. Instances of maladaptive infrastructure frequently occur under two scenarios: through climate mitigation or adaptation investments that

disproportionally affect or displace disadvantaged groups or that prioritize economic considerations (including the protection of economically valuable areas) over social considerations (including public health and/or the needs of low-income or minority neighborhoods) (Anguelovski et al., 2016; K. Thomas et al., 2019).

Angueloveski et al. (2016) note the "double injustice" of these experiences; disadvantaged groups contribute the least to global carbon emissions and bear significant climate change impacts and experience the brunt of the social costs of adaptation, yet they are being excluded from many of the benefits of climate mitigation and adaptation action. In addition, these same groups often also face a third injustice, due to historical imbalances in privilege, power, and representation that often leave them excluded from decision-making (Kuehn, 2000). This triple injustice disproportionately affects communities with increased vulnerability and limited capacity to adapt to changing climate conditions. The literature identifies these vulnerable communities as including low-income individuals, communities of color, immigrant groups, indigenous peoples, children, pregnant women, older adults, vulnerable occupational groups (i.e., outdoor workers), and others with underlying health conditions or disabilities (Anguelovski et al., 2016; Bikomeye et al., 2021; Rosen, 2016; Smith, K.R et al., 2014).

Urban planning decisions, particularly those related to infrastructure, are linked with a community's capacity to address health and well-being. Therefore, an approach to climate-centered infrastructure investments that is inclusive of public health considerations presents an opportunity not only to mitigate and/or adapt to climate change but also to advance health equity and climate justice (Anguelovski et al., 2016; Bikomeye et al., 2021; Buse & Patrick, 2020; Hughes, 2020). However, without consideration of the needs of vulnerable populations, common land use planning strategies such as infrastructure investment and management, land use regulations, participatory planning processes, and private sector engagement can exacerbate existing inequities (Anguelovski et al., 2016; Hughes, 2020). Therefore, as cities look to mitigate emissions and adapt to climate impacts, planners must investigate if current efforts are effectively addressing the needs of vulnerable populations or if they are continuing business-as-usual practices that have so often created or exacerbated inequities (Rosen, 2016; von Grafenstein & Gao, 2021).

INEQUITABLE IMPACTS: UNDERSTANDING VULNERABILITY

As the impacts of climate change continue to increase in scale and scope, there is a growing need to understand and assess social and population vulnerabilities to these impacts

and identify cost-effective strategies to incorporate co-benefits and address and mitigate these adverse impacts (Haines et al., 2006).

However, it is well understood that the impacts of climate change (both on the ecosystem and human health) will not be evenly distributed. Urban vulnerabilities are highly variable and depend on specific geographic, demographic, health, and social contexts (Bambrick et al., 2011). Therefore, understanding the health consequences of climate change and the mitigation and adaptation strategies that seek to potentially provide co-benefits is a matter of social justice and equity.

Existing studies recognize that low-income populations, communities of color, and other vulnerable groups such as children, pregnant women, older adults, and individuals with disabilities already experience inequitable health outcomes. Additionally, socioeconomic and/or racial inequities experienced by these groups are likely to limit their ability to adapt to climate impacts (Bambrick et al., 2011; Rosen, 2016; F. Thomas et al., 2014).

It is important to position this work within the concepts of justice and vulnerability, as these scholarly research areas have converged frequently on the issue of inequities in environmental health threats (Alvarez & Evans, 2021).

Vulnerability and Resilience

As a concept, vulnerability is not new; it emerged alongside the concepts of resilience and adaptive capacity in the literature relating to risk hazards and food security (Adger, 2006). However, since the late 20th century, the concept of vulnerability has been expanded and integrated into the discourse specifically related to global climate change (Luers, 2005).

Vulnerability to environmental impacts results from a range of social, economic, historical, and political factors, all of which operate at multiple scales (Adger, 2006; Luers, 2005; Smit & Wandel, 2006; K. Thomas et al., 2019, 2019; Turner et al., 2003). Analyses of these concepts also range by both the stressor of interest (biological, economic, social, environmental) and by scale (geographic and time) (Smit & Wandel, 2006).

The literature provides several conceptual frameworks to view vulnerability (Adger, 2006; Gallopín, 2006; Luers, 2005; Smit & Wandel, 2006; K. Thomas et al., 2019, 2019; Turner et al., 2003). Across disciplines, the literature has yet to coalesce around a universally common definition; therefore, existing frameworks can assist in characterizing the multiple dimensions of vulnerability and its interactions with both resilience, exposure, and adaptive capacity (Adger, 2006; Colburn & Seara, n.d.; Katz et al., 2020; Turner et al., 2003). Depending on the framework,

which is often selected based on discipline or personal preference, there can be impacts on how approaches to policy and decision-making occur (Colburn & Seara, n.d.).

The relationship between vulnerability, exposure, and adaptive capacity frequently defines them as components of one another, whereas vulnerability and resilience are often seen as two ends of a spectrum (Adger, 2006; Buse & Patrick, 2020; Colburn & Seara, n.d.; Intergovernmental Panel on Climate Change, 2022). This spectrum of vulnerability to resilience stems originally from hazard mitigation literature but is now commonly utilized in research and practice related to environmental health, environmental stressors, and climate change (Flanagan et al., 2018; Hendricks & Van Zandt, 2021).

Within the literature on environmental stressors, vulnerability is widely considered to be a state of susceptibility to harm from exposures to stressors associated with change and from the absence of the capacity to adapt (Adger, 2006). Additional literature builds on this definition to characterize vulnerability. Factors used to characterize the level of vulnerability include sensitivity or potential exposure of a system (people or place) to shocks, stressors, or disturbances, the state of the system relative to a threshold of damage, and the system's ability to adapt to changing conditions (Adger, 2006; Luers, 2005; Smit & Wandel, 2006; Turner et al., 2003, 2003).

The IPCC's Framework for Vulnerability and Resilience

Due to the intersection of multiple disciplines within climate change research, this study will center on the Intergovernmental Panel on Climate Change's (IPCC) approach, which is frequently utilized as the standard of practice. As the United Nations body tasked with assessing the science related to climate change, the IPCC is a neutral group of international experts that completes assessments and writes reports to provide policymakers with information on climate change, its implications, potential future risks, and options for adaptation and mitigation. IPCC reports are science-driven and utilize a rigorous peer review process to ensure transparency and objectivity, leading to its role as an agreed-upon international standard (Intergovernmental Panel on Climate Change, n.d.).

In its most recent 2022 report, the IPCC defines **vulnerability** as "the propensity or predisposition to be adversely affected; vulnerability encompasses a variety of concepts and elements, including sensitivity or susceptibility to harm and lack of capacity to cope and adapt" (Intergovernmental Panel on Climate Change, 2022).

Vulnerability is widely understood to differ within communities and across societies, regions, and countries, also changing through time. The IPCC definition of vulnerability acknowledges this variation in 'what is considered vulnerable.' However, it also notes that

vulnerability is inherently driven by patterns of "socioeconomic development, unsustainable ocean and land use, inequity, marginalization, and historical and ongoing patterns of inequity such as colonization and governance" (Intergovernmental Panel on Climate Change, 2022).

Additionally, it is important to note that approaches to analyzing and assessing vulnerability have evolved since previous IPCC assessments. The updated 2022 IPCC definition has incorporated an increasing focus on social factors that drive vulnerability; however, it still centers on three main characteristics to explain variation in vulnerability: exposure, sensitivity, and adaptive capacity.

Exposure refers to the degree, duration, or extent to which a person, population, or community comes into contact with or is subject to climate-related harms (Buse & Patrick, 2020; Gallopín, 2006).

Sensitivity refers to the extent to which a person, population, or community is affected by climate change (Adger, 2006; Intergovernmental Panel on Climate Change, 2001). Effects may be direct or indirect and are often mitigated or exacerbated by certain social, cultural, political, and economic forces (Buse & Patrick, 2020; Smit & Wandel, 2006).

Adaptive capacity is consistently defined in the literature as the ability to *adjust* to an external disturbance or stressor and its consequences (Buse & Patrick, 2020; Gallopín, 2006; Intergovernmental Panel on Climate Change, 2001). Within climate scholarship, adaptive capacity is the ability of a system or community to adjust to climate change and its effects (Intergovernmental Panel on Climate Change, 2001). Therefore, adaptive capacity is based on the presence or absence of key adaptive resources and/or behaviors at the individual or population level (Buse & Patrick, 2020).

Comparatively, the IPCC defines **resilience** as the "capacity of social, economic and ecosystems to cope with a hazardous event or trend or disturbance, responding or reorganizing in ways that maintain their essential function, identity and structure, while maintaining the capacity for adaptation, learning, and transformation" (Intergovernmental Panel on Climate Change, 2022). Due to the focus on the ability to cope, resilience implies stability. When considering resilience within the concept of stability, it can be measured by the magnitude of disturbance that can be absorbed by a system or community (Gallopín, 2006). Adaptation efforts are frequently organized around resilience due to their focus on maintaining key functions, protecting identity and structures, and providing capacity for transformation to achieve those goals in the face of climate change.

A visual representation of the interactions of different key concepts across climate, ecosystems, and human society as outlined by the IPCC can be seen in Figure 2 below.

Figure 2. Climate, Ecosystems, and Human Society as Coupled Systems (Intergovernmental Panel on Climate Change, 2022).

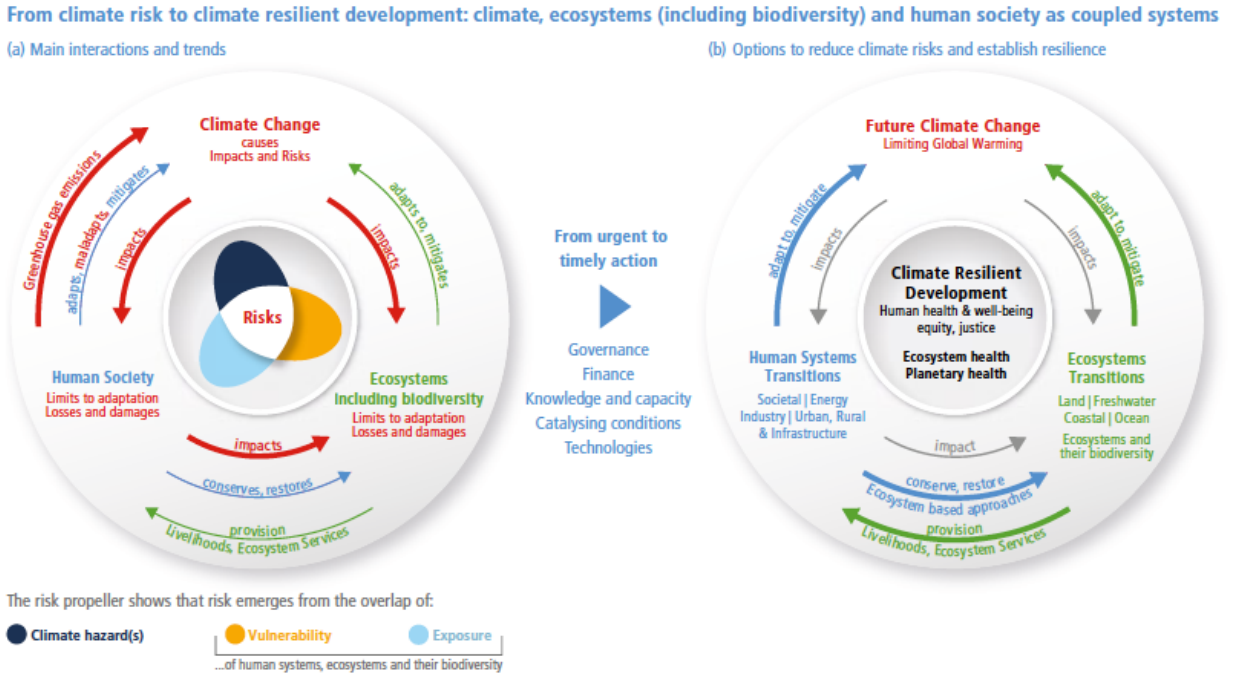


Figure SPM.1 | This report has a strong focus on the interactions among the coupled systems climate, ecosystems (including their biodiversity) and human society. These interactions are the basis of emerging risks from climate change, ecosystem degradation and biodiversity loss and, at the same time, offer opportunities for the future.

(a) Human society causes climate change. Climate change, through hazards, exposure and vulnerability generates impacts and risks that can surpass limits to adaptation and result in losses and damages. Human society can adapt to, maladapt and mitigate climate change, ecosystems can adapt and mitigate within limits. Ecosystems and their biodiversity provision livelihoods and ecosystem services. Human society impacts ecosystems and can restore and conserve them.

(b) Meeting the objectives of climate resilient development thereby supporting human, ecosystem and planetary health, as well as human well-being, requires society and ecosystems to move over (transition) to a more resilient state. The recognition of climate risks can strengthen adaptation and mitigation actions and transitions that reduce risks. Taking action is enabled by governance, finance, knowledge and capacity building, technology and catalysing conditions. Transformation entails system transitions strengthening the resilience of ecosystems and society (Section D). In a) arrow colours represent principle human society interactions (blue), ecosystem (including biodiversity) interactions (green) and the impacts of climate change and human activities, including losses and damages, under continued climate change (red). In b) arrow colours represent human system interactions (blue), ecosystem (including biodiversity) interactions (green) and reduced impacts from climate change and human activities (grey). {1.2, Figure 1.2, Figure TS. 2}

Incorporating Principles of Justice

Historically, initial definitions and frameworks of vulnerability and resilience have focused primarily on exposure issues and often offered little to no analysis of the social drivers of vulnerability or reasons for the unequal distribution of risk. Often scientific and technical approaches dominate policy development and decision-making related to climate change adaptation and mitigation, leaving many underlying social factors unaddressed (K. Thomas et al., 2019).

As climate mitigation and adaptation efforts seek to address vulnerability, it is also crucial to explore and understand theories and applications of justice. Applications of justice are relevant for several reasons, including the ability to address the disparate impacts of climate change across space, time, and populations, the unequal burdens of negative impacts, and power inequalities between different social groups (Jafino et al., 2021). Acknowledging current injustices

and designing interventions to correct them is crucial to achieving equitable opportunities for resilience (Buse & Patrick, 2020).

There are two main characterizations or categories of justice: procedural and distributive. Understanding these approaches is crucial as most climate initiatives focused on addressing vulnerability are framed as responses to either procedural and/or distributive injustices that have contributed to disparities in exposure to environmental and climate hazards (Min et al., 2019).

Procedural justice refers to the perceived fairness within decision-making processes and rules used to determine outcomes (Intergovernmental Panel on Climate Change, 2022; Jafino et al., 2021; Kuehn, 2000; Lucas et al., 2016; Min et al., 2019). Procedural justice seeks to address historical imbalances in privilege, power, and representation that result in the exclusion of certain populations from influencing decisions (Min et al., 2019). In the context of vulnerability, this requires changing political dynamics and decision-making power so that all groups are treated fairly and are provided a voice within the processes and procedures regarding how funding and opportunities are distributed (Kuehn, 2000).

Distributive justice refers to the right to equal treatment or the perceived fairness of outcomes or resource allocations (Intergovernmental Panel on Climate Change, 2001; Jafino et al., 2021; Kuehn, 2000; Lucas et al., 2016). Distributive justice seeks to address the inequitable distribution of either resources or impacts across communities. In the context of vulnerability, distributive justice approaches look at issues such as determining which communities are prioritized for climate mitigation and adaptation efforts and which communities bear the largest burdens (Min et al., 2019).

On top of the different types of justice, it is also crucial to note that as a concept on a pragmatic and emotional level, concepts of justice mean different things to different people (Kuehn, 2000). For communities overburdened by environmental hazards and left out of decision-making processes, it can capture these experiences. For government officials who address these burdens, it can feel like either an implication of bias and/or an opportunity to identify and address the problem. Both these individual emotional factors and the above theoretical factors align to create an environment where it is difficult to determine a consistent and common definition of justice and, thus, vulnerability.

These challenges have resulted in concepts of justice not yet becoming fully embedded in public health, climate change, and planning discourse (Buse & Patrick, 2020). Despite this, concepts of procedural and distributive justice provide frameworks through which future climate-centered infrastructure planning can seek to reduce inequities related to climate impacts through the distribution of resources and decision-making processes. Justice-oriented climate-centered

infrastructure is critical for addressing the needs of vulnerable urban communities and ensuring climate action reduces, rather than enhances, existing inequities (Hughes, 2020).

OPERATIONALIZING VULNERABILITY: THE ROLE OF MEASUREMENT

Importance of Data-driven Decision-making

The identified interest in measuring vulnerability is increasingly tied to environmental and climate justice and the movement toward data-driven decision-making within urban planning and government. The literature identifies one of the main rationales for data-driven decision-making in government is increased accountability, which can support procedural and distributive justice within governmental investment decisions (Hughes et al., 2020).

In the context of climate governance and climate-centered planning, data-driven approaches can facilitate and incentivize a focus and use of metrics within broader urban transformations. For example, city governments are increasingly developing greenhouse gas inventories and emissions reporting protocols, the data from which become core components of effective urban climate change policy and planning (Hughes et al., 2020). Measures focused on assessing social vulnerability are an additional data-centric tool that can be utilized to ensure that data-driven decision-making leverages considerations of justice, equity, and health.

Vulnerability Measurement as a Planning Tool

To support infrastructure decision-making processes, there is a need to identify the most relevant variables that link social vulnerabilities with infrastructure planning and management and to understand how the former is linked to the latter. Identifying vulnerable populations can help planners identify and understand the potential impacts of different strategies and select infrastructure investments and policies that promote health-benefiting outcomes and reduce negative health impacts.

Vulnerability assessments can be found in several research paradigms, including risk assessment, natural disaster management, hazard mitigation, environmental justice, and urban planning (Ahmed & Kelman, 2018; de Oliveira Mendes, 2009; Flanagan et al., 2018; Lee, 2014; Levison et al., 2018; Mendes et al., 2020; Tonmoy et al., 2014). Similar to the lack of consensus around the definition of vulnerability, the wide range of assessment paradigms make it difficult to identify agreed-upon directions or methodologies for assessing vulnerability (Tonmoy et al., 2014).

However, even on an ad hoc basis, efforts to assess vulnerability can support policymakers, urban planners, and infrastructure decision-makers in identifying vulnerable

groups, allocating climate adaptation resources, and understanding what makes a group or community vulnerable. In addition, measurements allow for increased transparency, monitoring and evaluation of the impacts of infrastructure projects, and improved communication of risk and justification of policies and projects to the public (Tonmoy et al., 2014).

The measurements of vulnerability can highlight the cumulative and complex impacts of climate change. These complex interactions include the fact that existing health inequities between groups based on biological (e.g., age) or socioeconomic factors (e.g., poverty) are significant and persistent; and, that there are spatial inequities in exposure to environmental hazards (e.g., lack of urban greenery increased urban heat islands) that are persistent and linked to health outcomes. Existing socioeconomic factors may therefore modify or amplify the adverse effects of environmental hazards and contribute to adverse and inequitable impacts on health and well-being due to climate change. Using measurement tools to screen, map, characterize, and identify vulnerable communities based on these indicators can support infrastructure decision-making that can improve existing conditions and prevent future harm (Morello-Frosch et al., 2011).

Frameworks of Vulnerability Measurement

Vulnerability, as defined by the IPCC, focuses on the characteristics of exposure, sensitivity, and adaptive capacity. While these three characteristics are commonly accepted within climate change literature, operationalizing vulnerability through these dimensions has remained challenging. Generally, these characteristics are measured in the literature using various socioeconomic, political, and environmental variables; however, the exact approaches, methods, and tools vary widely (Brooks et al., 2005, 2005; Gallopín, 2006; Luers, 2005; Smit & Wandel, 2006; Turner et al., 2003).

The literature identifies three conceptual models of operationalizing vulnerability that can clarify the types of circumstances (both physical and social) that put people and places at risk due to climate change and reduce their adaptative capacity and resilience to environmental threats (Lee, 2014). The three models of vulnerability include 1) physical (or biophysical), 2) social, and 3) capacity to cope with external stress, each of which aligns with the three characteristics of exposure, sensitivity, and adaptative capacity, respectively (Lee, 2014; Levison et al., 2018; Mendes et al., 2020; Tonmoy et al., 2014; Zarowsky et al., 2013).

Physical or biophysical vulnerability utilizes an approach centered on vulnerability as a dose-response relationship between exposure to a hazard and its effects on the system. Physical vulnerability looks at exposure to risks and is frequently measured based on a community or region's existing spatial and built environment characteristics that could affect

health or well-being (Lee, 2014). When used in urban planning and hazard mitigation, physical vulnerability measures frequently serve as proxy measures for social inequities within vulnerability assessments (Adger, 2006; Lee, 2014).

Social vulnerability approaches vulnerability through the lens of pre-existing social, economic, political, and institutional elements or conditions within a household, population, or community generated by unequal access to resources (Lee, 2014; Mendes et al., 2020). Social vulnerability is often considered to be the initial or underlying conditions of the affected groups or communities (Mendes et al., 2020). Some examples of factors identified in the literature as influencing a person or household's social vulnerability include socioeconomic status, minority status, and vehicle access. Understanding social vulnerability assists in revealing reasons why populations experiencing the same climate change impacts or hazards are not affected equally (Flanagan et al., 2018).

The capacity to cope with external stressors is the third approach to measuring vulnerability and recognizes the differential abilities of communities in their ability to cope or adapt to the risks and impacts of climate change (Lee, 2014; Zarowsky et al., 2013).

These three approaches provide insight into a key component of vulnerability to climate change impacts and hazards. Each is necessary for the overall picture because vulnerability is multifaceted and dynamic, particularly with regard to climate change (Lee, 2014; Turner et al., 2003). As urban planning and infrastructure decision-makers seek to understand and leverage health co-benefits and mitigate the potential for maladaptation from infrastructure planning, there is an increasing focus specifically on incorporating social vulnerability measures. The focus on social vulnerability is particularly important due to its close alignment to health and well-being and considerations of equity and justice within climate change outcomes (Levison et al., 2018; Turner et al., 2003). Social vulnerability assessments for climate change and health can support the identification of impacts of infrastructure decisions prior to climate change impacts or hazards occurring (Mendes et al., 2020).

Measurement Approaches

Social vulnerability is not easily defined due to its multiple social, economic, political, and spatial factors; therefore, vulnerability is neither easily reduced to a single measure nor easily quantifiable (Adger, 2006; Tonmoy et al., 2014). Despite the challenges in measuring this concept, that has not limited efforts that attempt to do so.

In the absence of a universal approach for measuring or assessing social vulnerability, different approaches have included qualitative and/or quantitative methods and have utilized

indicators, simulation models, or a combination of the two (Ahmed & Kelman, 2018; Tonmoy et al., 2014). The literature outlines four approaches utilized for vulnerability assessments: 1) *simulation-based assessments,* which simulate the future impacts using models and apply measures of exposure to model vulnerability; 2) *aggregation-based assessments,* which gather current metrics and aggregate them to determine potential future vulnerability; 3) *hybrid assessment* approaches that combined both simulation and aggregation approaches; and 4) *No simulation/no aggregation* assessments that utilize, discuss, and assess vulnerability measures without modeling or aggregation (Tonmoy et al., 2014). Addressing and understanding the role of social vulnerability is most visible through approaches that center current states rather than future impacts (i.e., aggregation, hybrid, or no simulation/no aggregation assessments).

At global, national, and subnational scales, index-based approaches utilizing quantitative data sets for measuring vulnerability are the dominant approach (Ahmed & Kelman, 2018; Brooks et al., 2005; Levison et al., 2018; Mendes et al., 2020). While access to quantitative data can be limited at the local level, quantitative data sets allow for clear measurements and comparison of vulnerability across places and time. Qualitative approaches have been utilized particularly at the local level to help identify key local factors relating to social vulnerability. Through community-centric qualitative data collection, vulnerability assessments can also develop partnerships with community stakeholders who can support actionable efforts outside of the assessments themselves (Levison et al., 2018; Mendes et al., 2020). A complementary balance between qualitative and quantitative approaches is crucial for ensuring a locally driven and equity-centered approach that provides measurable findings to influence infrastructure decision-making (Adger, 2006). One example of how this occurs in practice is through local-scale vulnerability indices that utilize qualitative scoping approaches to select local quantitative data and determine scaling and weighting criteria for the index (Ahmed & Kelman, 2018; Hughes, 2020).

Data Selection

The methods for selecting and evaluating the quality of measures differ by technical domain. They are based on the relevance of the data to the problem, the quality of the available data, and the ability to acquire the relevant data (Stróżyna et al., 2018). Stróżyna et al. (2018) present a framework for identifying, assessing, and selecting data sources that incorporate commonly agreed-upon quality criteria for data: accessibility, relevance, accuracy and reliability, clarity, timeliness and punctuality, and coherence and comparability. The three models of vulnerability discussed above combined with this framework of data considerations (relevance, quality, and ability to acquire) provide a starting point through which existing data measures can

be evaluated for their application to vulnerability measurements specifically related to climate change.

The complexity of vulnerability makes it particularly difficult to identify a common set of variables or indicators. To be able to answer who and what is vulnerable to climate impacts and where, identifying specific indicators is needed for the three main characteristics of vulnerability: exposure, sensitivity, and adaptive capacity (Turner et al., 2003). Frequently, data measures of race and ethnicity, class, gender, and age are used as proxy variables used to estimate social vulnerability. However, based on the type of assessment and its application, a number of different indicators have been used, including but not limited to socioeconomic status, gender, race and ethnicity, age, commercial and industrial development, employment status, infrastructure and lifelines, occupation, family structure, education, population growth, medical services, social dependence, special needs populations, religion, social isolation, and housing tenure (Bikomeye et al., 2021; Hendricks & Van Zandt, 2021).

For each of these and other indicators, it is crucial to consider spatial scale. Approaches to measuring vulnerability have often relied on the spatial context of the climate change impacts to understand the risk of exposure and outcomes. While social vulnerability adds a layer to this, spatial considerations are still necessary, particularly in the context of urban planning and infrastructure decisions, to ground the potential compounding interactions between socioeconomic factors and the spatial context in which they are either supported or exacerbated (Adger, 2006; Mendes et al., 2020).

Social vulnerability has been measured at various scales, including the individual, household, municipality, county, region, and nation (de Oliveira Mendes, 2009; Lee, 2014). Some factors of social vulnerability only manifest at certain scales; therefore, spatial scale should be considered in identifying and applying measures of social vulnerability (Adger, 2006; Mendes et al., 2020; Turner et al., 2003). The inclusion of spatial considerations is also consistent within public health literature, which has increasingly focused on the geospatial patterning of health risks and adverse outcomes (Alvarez & Evans, 2021). The literature emphasizes the importance of identifying data that is available at the smallest possible administrative unit to accurately understand factors of social vulnerability. Analysis at large spatial scales may mask important neighborhood-level variations in vulnerability risk factors (Manangan et al., 2014).

Further exploration of commonly selected variables will be completed and discussed within the scan of existing data tools and measurement approaches for vulnerability currently utilized by cities and jurisdictions across the U.S.

Identified Challenges and Potential Limitations

Like any data-focused assessment or tool, efforts to measure the impacts of climate change face the pitfalls and limitations of the data they use and the type of analysis they provide. Tools and programs to identify and quantify social vulnerability are no exception. Literature and research relating to vulnerability assessments and tools have identified the following limitations:

- Existing data do not capture the full range of health disparities (Adger, 2006; Min et al., 2019; Smith & Laribi, 2022),
- Some data points and relationships are better studied or understood than others (Adger, 2006; Smith & Laribi, 2022),
- Data is not always a complete picture of existing conditions, particularly for small populations (Korngiebel et al., 2015), and
- Data and tools cannot capture the complex interactions between environmental exposure and social stressors (Adger, 2006; Kuruppuarachchi et al., 2017; Smith & Laribi, 2022).

The first series of limitations are related to the robustness and credibility of the measures used and whether the selected measures accurately represent vulnerability at the scale of analysis (Adger, 2006). Generally, some data points and relationships are better studied or understood than others, with various levels of established causal links between the variable, health, and infrastructure planning (Adger, 2006; Remais et al., 2014; Smith & Laribi, 2022; Younger et al., 2008). In addition, varying levels of rigor in quality and collection exist across data types and scales (Min et al., 2019; Smith & Laribi, 2022). The scale of data collection, in particular, is a common limitation of data used to measure the community's level of risk or impact (University of Washington Department of Environmental & Occupational Health Sciences & Washington State Department of Health, 2022). For example, nationwide data can provide insight regarding national trends but often lacks the nuances that state or local-level data would. However, while more nuanced, county or state-level data can be limited or lack the rigorous nature of national datasets (de Oliveira Mendes, 2009; Lee, 2014; Manangan et al., 2014; University of Washington Department of Environmental & Occupational Health Sciences & Washington State Department of Health, 2022).

In general, the quality and applicability of data measures are limited by how they are collected and who is or is not included within each dataset. Data and data-driven decision-making can disempower those that are not counted within existing data sets. Within public health data sets, which are frequently utilized in vulnerability assessments, accurate data is often unavailable for small populations, particularly Indigenous groups. Additionally, national reports and public data

sets for small population groups can frequently fail to provide sufficiently detailed information or include misguided aggregation. These data problems can obscure existing inequities and social vulnerabilities or be treated as a lack of evidence that they exist. Without a clear picture of what is being measured and what might not be, the absence or lack of data can perpetuate and exacerbate inequitable resource allocation and poor health outcomes (Jafino et al., 2021; Korngiebel et al., 2015).

It is also important to acknowledge that measuring vulnerability alone is not enough. Data and tools that measure social vulnerability are unable to capture the dynamics and complex realities of the relationship between environmental exposures and social stressors. In infrastructure planning for climate mitigation and adaptation purposes, achieving climate justice and health equity should consider incorporating a more comprehensive approach. Vulnerability assessments are a crucial first step in identifying potential harmful impacts of planning decisions; however, considerations of accountability to procedural and distributive justice in decision-making processes should be considered (Adger, 2006; Jafino et al., 2021).

Despite these limitations, vulnerability assessments offer clear benefits in efforts to center public health and equity into climate-centered infrastructure planning. In particular, developing and using these tools can help planners and decision-makers identify areas that can be better supported through programs, investments, and policy changes that aim to remove the excess burden of environmental pollution (Sharifi, 2016). They also promote change by helping make environmental justice a "governable strategy" with quantifiable and measurable frameworks for implementation.

THE ROLE OF INFRASTRUCTURE: OPPORTUNITIES & BARRIERS

Vulnerability and Health Data in Infrastructure Planning: Current Practice

The focus on infrastructure as an avenue to generate protection from climate impacts or address existing social vulnerabilities is a growing field. There is a growing awareness of the need to integrate considerations of social factors into planning decisions to ensure a comprehensive and robust understanding of the impact of these decisions on local communities (Hendricks & Van Zandt, 2021).

The results of a study by Burton et al. (2015), which interviewed 42 urban planners in Australia confirm this need for further health-enhancing planning practices through its detailed summary of the planner's awareness and attitudes towards climate change and its potential health impacts. The study found that while planners largely agreed that the health impacts of climate change would be relevant to their work [n = 37 or 88.1%], they acknowledged little or nothing is

currently being done about it within their current planning practices. The study concluded that health considerations continue to be seen as potentially in conflict with other planning efforts, which leads to its devaluation as a priority within planning decisions. This gap results in a missed opportunity for co-benefits, as without guidance, planners seem to view health impacts as too complex to address (Burton et al., 2015).

The example from Australia aligns with other literature which consistently identifies the need for more health-enhancing planning practices to ensure equitable planning for vulnerable communities (Lowe et al., 2019). To address this need, the literature focuses on the role of evidence and data-driven decision-making as a core component of urban planning policymaking and practice (Hughes, 2020; Tonmoy et al., 2014). Vulnerability assessments are one avenue through which this information can be integrated into infrastructure planning and management through a data-driven approach (Simkins & Yang, 2018).

A 2020 study discussed the use of vulnerability assessments by city planning departments in Detroit, Michigan, and Cleveland, Ohio, to implement considerations of justice in local climate adaptation plans (Hughes, 2020). Both cities utilized vulnerability assessments to target and prioritize vulnerable communities with the greatest need for adaptation interventions. The assessments leveraged data sources, including downscaled climate projections, environmental and socioeconomic indicators, and spatial assessments of exposure and sensitivity of residents to heat and flooding events. Additionally, larger cities such as Chicago, Boston, New York, and Los Angeles have begun considering justice within their climate change adaptation plans (Hughes, 2020). While an important step forward, it is important to note that while these are examples of integration of vulnerability assessments, they do not necessarily directly consider public health and well-being (Sharifi et al., 2021). Additionally, these cities tend to be the exception rather than the rule, as research has found that despite policies and approaches within cities that endorse healthy, equitable, and sustainable cities, there is a lack of measurable policy approaches that are utilized to achieve these goals (Ahmed & Kelman, 2018; Lowe et al., 2019; Morello-Frosch et al., 2011).

Among city governments looking to increase data-driven decision-making and create measurable policy approaches to address and understand health, equity, and climate through planning, there is also an increasing use of indicators (Lowe et al., 2019; Pineo, Zimmermann, et al., 2020). Indicators offer key benefits, including creating awareness and providing evidence of urban health or equity issues, facilitating stakeholder collaboration, supporting health impact monitoring, and informing policy development and decision-making (Pineo et al., 2018; Pineo, Zimmermann, et al., 2020).

Given the potential benefits, the development of urban health indicators has grown in the past few years. A systematic review of urban health indicator tools identified 145 tools collectively comprising over 8,000 indicators (Pineo, Glonti, et al., 2020). Despite this growth of new tools, literature has discussed that the emphasis of both research and practice has overwhelmingly been on their development and validation rather than their application in policy and planning processes (Pineo, Zimmermann, et al., 2020).

However, to integrate health and climate data into planning decision-making processes, there must be both capacity and an existing structure through which data can be utilized in decision-making for urban climate change governance (Hughes et al., 2020). One existing structure outlined in the literature as a potential application is through budgeting and financial decision-making related to infrastructure investments. A study by Pineo, Zimmerman, et al. (2020) has outlined the specific application and benefits of using health indicators to make economic arguments within the urban planning and development process. Indicators related to health and vulnerability can provide an avenue through which evidence of "co-benefits" can be utilized in discussions with decision-makers. Evidence from urban health indicators can be used to identify baselines of social vulnerability and increase health-related design and planning. These benefits occur through negotiations with developers, arguments for or against policies, and informing and identifying where a particular infrastructure investment or budget allocation may deliver the most impact determining how budgets should be allocated (Pineo, Zimmermann, et al., 2020; Simkins & Yang, 2018).

The Role of the Capital Investment Plan (CIP)

Across our urban spaces, local governments and utilities are responsible for planning, financing, and managing a large portion of our capital infrastructure (Marlowe et al., 2009; Whittington & Lynch, 2015). As cities face ever-growing infrastructure needs and limited capital revenues, local governments increasingly need to set clear priorities regarding funding competing capital projects (Kaganova, 2011; Millar, 1988). As the evidence for inequality in health outcomes related to urban resilience, climate change, hazards, and decaying critical infrastructure continues to grow, there is an increasing need for the prioritization of these projects to take climate and health considerations into account (Hendricks & Van Zandt, 2021).

To make funding decisions regarding local capital projects – most local governments utilize a formal capital investment planning process and a policy tool known as a capital investment or improvement plan/program (CIP). While there is no universally agreed-upon approach, generally, a CIP is a short-range plan (typically five years) that identifies and prioritizes

capital projects and acquisitions and describes the governing policies, financial plan, and sources of funding for project expenditures (Elmer, n.d.; Kaganova, 2011; Marlowe et al., 2009; Whittington & Lynch, 2015; Zeb, 2022).

CIPs provide important benefits to local governments and utilities, including the provision of a method to plan for and anticipate future needs, an avenue for public involvement in resource allocation, a process of transparent decision-making, and encouragement of a cost-effective spending plan that acknowledges fiscal limits and administrative capacities (Kaganova, 2011; Marlowe et al., 2009; Whittington & Lynch, 2015).

The CIP is a crucial policy tool for urban planners and utility staff as expenditure decisions directly impact local community and economic development, environmental planning, climate resilience, community health and well-being, and overall urban form (Elmer, n.d.). For this reason, when executed properly, the CIP acts as a strategic management tool to support the vision for the community and promote community goals and objectives (Elmer, n.d.; Kaganova, 2011; Marlowe et al., 2009; Whittington & Lynch, 2015). As the procedural link between a proposed project and funded reality, CIPs provide a unique opportunity with local planning policy to pursue changes to the nature of city infrastructure investment, particularly related to climate change and health and well-being.

Prioritizing Budget Decisions: The Use of Criteria and Data for Decision-making

Three main decisions are made within the CIP process: how much to spend on capital projects, how to prioritize capital project requests, and how to finance capital projects (Marlowe et al., 2009). These steps allow jurisdictions to balance the need for capital projects with available funding and select critical projects within the limited funding. Therefore, to alter the nature of investments within the CIP, studies suggest the most important aspect of the budgeting process is the prioritization and utilization of selection criteria (Elmer, n.d.; Marlowe et al., 2009; Millar, 1988).

Despite the literature's agreement on the importance of the prioritization part of the CIP process, few sources provide explicit policy direction or agreement on how to do this or what criteria may be of the most value (Millar, 1988). Existing budgetary guidebooks and literature produce recommendations for broad principles or general categories (e.g., growth management, economic development opportunity), with the only specifics focused primarily on fiscal criteria (Elmer, n.d.; Marlowe et al., 2009; Means III et al., 2010; Millar, 1988).

Additionally, a survey of local government budget practices related to capital budgeting found that only a quarter of interviewed jurisdictions utilized a formal procedure for assessing or

prioritizing capital proposals (Millar, 1988). Typically, jurisdictions prioritize capital projects in a few ways, including using specific criteria, separating proposals into project categories (by impact or project type), or incorporating decentralized allocation (Marlowe et al., 2009). The most common approach identified in the literature was the utilization of some informal criteria in conjunction with cost considerations. But given the ambiguity of the criteria, this approach often resulted in highly subjective processes to prioritize projects (Millar, 1988). Over the past thirty years, literature has emphasized the need for greater definition and structure within the CIP project prioritization process (Hendricks & Van Zandt, 2021; Means III et al., 2010; Millar, 1988).

Climate-aligned CIPs: An Opportunity for Health Co-benefits

As cities seek to prioritize equity, justice, and climate adaptation and mitigation, the CIP prioritization process has been identified as a potential avenue to integrate these priorities into budget and policy planning cycles, statutory planning, and monitoring and evaluation frameworks. Given the limited definitions surrounding this structure, there is ample opportunity for jurisdictions to adjust or better define their processes to incorporate these new considerations.

Increasingly, research is identifying the role of the CIP as an important mechanism for achieving climate goals. For example, the Federal Emergency Management Agency (FEMA) has identified the benefit of integrating mitigation and adaptation into CIPs as a best practice for achieving community resilience (Rumbach & Colorado Resiliency Office, Department of Local Affairs, n.d.). FEMA lists the benefits as the potential to implement hazard mitigation measures, the assurance of expenditures that align with mitigation goals, objectives, and policies, and the guidance of new growth (Rumbach & Colorado Resiliency Office, Department of Local Affairs, n.d.).

In addition, a series of reports by the World Bank highlight the role of urban finance, and the CIP specifically, as a mechanism to support local climate action. Whittington and Lynch (2015) specifically call out the opportunity for the CIP to translate master and comprehensive planning climate goals into infrastructure projects to realize long-range emission reduction and adaptation goals. By including climate-specific criteria alongside other locally determined criteria, it can prioritize “climate-smart” alternatives for important community benefits (Whittington & Lynch, 2015).

In general, planning for climate change has taken large leaps forward in focusing on the impacts of infrastructure; however, it has frequently lacked integration of considerations of how to protect or enhance human health (Burton et al., 2015). Promoting climate-smart investments

within the CIP also creates an opportunity to produce health co-benefits and avoid maladaptation that negatively impacts health.

The IPCC has acknowledged that the greatest gains in health and well-being can be achieved by prioritizing financial decisions to reduce climate risk for vulnerable populations, including low-income and marginalized populations (Intergovernmental Panel on Climate Change, 2022). Integrated and inclusive infrastructure finance decisions based on equity and social climate justice can reduce risks, enable climate-resilient development, and improve health and well-being in the face of climate change. Vulnerability assessments within the CIP process are critical to achieving this goal. They can serve as a form of distributive justice in CIP infrastructure funding allocation by identifying communities and neighborhoods that could benefit from increased investment for climate mitigation or adaptation (Hughes, 2020; Intergovernmental Panel on Climate Change, 2022; Lee, 2014). However, this approach's effectiveness will depend on how social vulnerability is defined, measured, and applied within the CIP (Lee, 2014).

Considering climate change and health in the design and planning of infrastructure is crucial for overall community resilience and enhancing health and well-being (Intergovernmental Panel on Climate Change, 2022). While population health vulnerability measures may seem foreign to many planners, understanding and integrating measures of social vulnerability can provide large benefits in helping them reach their planning goals. Integrating, or mainstreaming, vulnerability measures into the CIP process is an important planning and implementation tool to enable infrastructure planning and management to anticipate and respond to the potential positive or negative health impacts of climate-related infrastructure decisions (Cutter et al., 2014; Hendricks & Van Zandt, 2021; Rosen, 2016).

II. METHODS

Based on the literature, this project proposes that an approach to infrastructure investments that includes considerations of social vulnerability within the context of climate change and public health presents an opportunity to create climate and health co-benefits while advancing equity and social justice (Anguelovski et al., 2016; Bikomeye et al., 2021; Buse & Patrick, 2020; Hughes, 2020). Therefore, this project aims to understand how public health data can support local governments in identifying and understanding who in their communities may be more sensitive or vulnerable to climate impacts as they seek to implement new capital projects.

The objectives of this project included: 1) understanding available data at the intersection of capital investment choices, climate change, and public health, particularly related to measuring

community vulnerability, and 2) determining the facilitators and barriers in practice to using public health data in infrastructure decision-making policy processes.

STUDY DESIGN

I sought to answer the research objectives and related research questions (See Table 1) through a multi-method approach that included a literature review, a scan of existing data tools used to measure or identify communities based on environmental burden, vulnerability, climate impacts, and/or health disparities, and a set of interviews with staff of city and county government agencies and utility departments. The project was submitted for review by the University of Washington Instructional Review Board and was determined to be exempt.

The following table provides an overview of the linkages between the two main research objectives, their related research questions, and study methods used to assist in answering each.

Table 1. Study Design Overview

OBJECTIVE	QUESTION	LIT REVIEW	SCAN OF DATA TOOLS	INTERVIEWS
Understand available data at the intersection of capital investment choices, climate change, and public health, particularly related to measuring community vulnerability	What measures belong at the foundational intersection of capital investment choices, climate change, and public health?	X		
	Do we use different measures to understand the relationship between infrastructure, health, and vulnerability when climate change is added as a consideration?		X	X
	How do you define vulnerability, and what measures can be used to determine vulnerability?	X	X	X
Determine facilitators and barriers in practice to using public health data in infrastructure decision-making policy processes	How can city planners, policymakers, and utility staff leverage the identified measures within capital investment planning to support more equitable and resilient infrastructure?	X		X
	What are the current barriers to using public health data in infrastructure decision-making processes?	X		X

The literature review explored the relationship between climate, public health, and infrastructure and reviewed existing precedents for identifying and linking data points from these areas in practice. The scan of existing data tools identified spatial data tools used to measure or identify communities based on environmental burden, vulnerability, climate impacts, and/or health disparities. The interviews were semi-structured and utilized a standard set of questions but allowed for the opportunity to follow each conversation's natural path. After the interviews, each response was coded through iterative qualitative analysis, which identified six themes relating to the use of public health data within capital investment decisions.

The following sections detail the processes for the scan of data tools and semi-structured interviews, including tool selection and assessment, interview recruitment, analysis and coding of transcripts, and thematic analysis.

SCAN OF DATA TOOLS

To begin to develop an understanding of what indicators and tools exist relating to social vulnerability in the context of climate change and infrastructure, this project completed a small-scale scan of eight spatial data tools. The scan sought to identify existing data tools that incorporate some measure or indicator of social vulnerability or sensitivity, focusing on those that highlight use related to public health and planning decision-making. This scan is neither comprehensive nor complete, but it offers an initial perspective on what tools exist and what data they leverage.

The following subsections outline the screening process used to select tools for inclusion in the scan and each tool's analysis and review process.

Tool Selection

Potential tools for inclusion in this scan were identified either through their inclusion in the literature, their mention by an interviewee (see methods and findings for semi-structured interviews in following sections), or through a targeted online search based on keywords and inclusion criteria. The goal was to include six to eight tools that use data to identify or measure environmental burden or vulnerability across communities.

The tools were selected using a series of inclusion and exclusion criteria to scope the scan. Tools were included if they 1) provided data on a statewide or national scale, 2) sought to measure or identify communities based on environmental burden, vulnerability, climate impacts, and/or health disparities, 3) included a spatial and mapping component, 4) provided some amount

of information regarding indicator selection, or tool methodology, and 5) were published and available for public use (i.e., not in piloting phases).

Additionally, tools were excluded if their focus was limited (e.g., measured climate impacts only) or if they focused on health indicators that are not directly linked to vulnerability (e.g., quality of life indicators).

In total, 18 tools were reviewed for potential inclusion. Ten ended up excluded from the analysis; four due to a sole focus on measuring climate impacts; one due to being in piloting phases; five due to lack of information on tool methodology. Eight spatial data tools were included in the final scan and analysis.

Tool Analysis

Once the list of tools was scoped, each tool was reviewed using the following six areas of analysis: 1) motivation for tool development, 2) definition of vulnerability, 3) type of vulnerability assessment, 4) purpose of data use, 5) inclusion criteria for data selection, and 6) included measures and indices. Each of these areas of analysis is based on key components of vulnerability measurement as identified in the literature (see Table 2).

Additionally, basic information was collected for each tool, including the name, developer, year of last update, geographic scope, scale of data analysis, intended audience, topical focus, and purpose.

Table 2. Selected Analysis Areas Based on Existing Literature

AREA OF ANALYSIS	RELATED LITERATURE
Motivation for Tool Development	Lowe et al., 2019; Simkins & Yang, 2018; Pineo, Zimmermann, et al., 2020
Definition of Vulnerability	Adger, 2006; Colburn & Seara, n.d.; Katz et al., 2020; Morello-Frosch et al., 2011; Turner et al., 2003
Type of Vulnerability Assessment	Tonmoy et al., 2014
Purpose of Data use	Adger, 2006; Alvarex & Evans, 2021;Mendes et al., 2020; Turner et al., 2003
Inclusion Criteria for Data Selection	Stróżyna et al., 2018
Included Measures/ Indices	Brooks et al., 2005, 2005; Gallopín, 2006; Luers, 2005; Morello-Frosch et al., 2011; Smit & Wandel, 2006; Turner et al., 2003

All information regarding the tools was collected based on details available on government websites, FAQ pages, methodological reports, and the interactive tools themselves. An Excel spreadsheet was created to track and collect information on each descriptive and analysis area. To complete the comparative analysis, the tools were reviewed for similarities and differences across each area. For most areas, categories or tables were created to better illustrate and compare the tools. However, for a few of the analysis areas (e.g., definitions of vulnerability), other forms of visualization, such as a word cloud, were used to identify similarities.

Tools by the Numbers

Four of the eight tools included in the scan were developed for national application, and four were developed for state-specific application. The four state-specific tools include two from California, one from Washington, and one from New York. A further overview of the tools and their comparative analysis can be found in the Findings section; see Tables 4 and 5.

SEMI-STRUCTURED INTERVIEWS

Semi-structured interviews were conducted with city and county government and utility staff to understand the selection and use of public health data and if and how it is incorporated into their department's infrastructure and climate decision-making processes. The following sub-sections outline the development of the interview guide, interviewee recruitment, interview process, and data analysis approach.

Interview Guide

Questions were informed by findings from the literature review and the project's central research questions and asked about broad topics, including the use and selection of public health data measures, infrastructure decision-making processes, the impact of the political environment, and challenges and limitations of data usage**.** A copy of the interview guide with initial questions and follow-up probes is included in Appendix I.

The questions were written to encourage respondents to offer reflective answers that could contribute to an overall understanding of how the research and data measures are applied in practice.

Interviewee Recruitment

Interviewees were identified through a mix of purposive, convenience, and snowball sampling. Recruitment was based on their geographic area of work, technical expertise, and professional role.

Potential jurisdictions and cities of interest were selected based on interest by the Urban Infrastructure Lab project team, previous or future partnership potential with the Urban Infrastructure Lab, or knowledge of jurisdictional efforts already linking climate adaptation and mitigation, infrastructure planning, and public health. Initial recruitment included outreach to staff in five cities: San Francisco, California; Boston, Massachusetts; Ann Arbor, Michigan; Portland, Oregon; and Seattle, Washington; the final interviews incorporated discussions with three cities.

Individual interviewees were identified and recruited via email through both professional connections and cold outreach. Inclusion criteria for this study included individuals, due to their position and/or expertise, who are working on identifying useful indicators for social equity and public health relating to climate, capital infrastructure, and social vulnerability. Individuals may be staff of public, private, or nonprofit entities, with a strong preference for government or public utility staff at the local, county, or regional level.

Without a direct connection to staff in each jurisdiction of interest, I completed online research on municipal websites and LinkedIn to identify individuals that meet the inclusion criteria. The search focused on individuals with job titles that included words and phrases such as "climate, infrastructure, planning, analyst, and health." Selecting individuals who work in a range of city departments and locations across the United States lends itself to providing diverse perspectives on using these data in practice from across the spectrum of individuals who either lead or partner on this work. For this reason, initial outreach attempted to balance invitations to individuals in traditional planning departments, public health departments, public utilities, and environmental agencies to incorporate a range of perspectives and approaches. Additionally, at the end of each interview, interviewees were asked if they could assist in identifying other individuals who may provide valuable insights for the study.

Interviews

Interviews were conducted via Zoom in April of 2023. Interviews were semi-structured and lasted 30 – 45 minutes, depending on the flow of conversation and interviewee responses. Questions were drafted before the interviews, but additional questions or conversation topics varied based on interviewee's responses. After conducting two interviews, the questions were reexamined to ensure they effectively gathered responses relevant to the research question,

which resulted in the replacement of one question which had caused interviewee confusion. The replacement question sought to evoke similar responses but was simplified for easier comprehension. Further, questions were adjusted slightly in each interview to tailor them to the interviewee's experience and role.

At the beginning of each interview, I provided interviewees with an overview of the purpose of the interview and how responses would inform the research project. I also obtained verbal consent to record the interview on Zoom for transcription and analysis before beginning the discussion. In total, 6 of the 7 interviewees consented to be recorded; for the interview that was not recorded, that interviewees comments were transcribed by hand.

Privacy and Confidentiality

To protect interviewee information, interview responses were de-identified before analysis. Additionally, to ensure interview privacy, a single master list was created that matches interviewee names with a unique ID code. Unique Interviewee ID codes were assigned based on type of jurisdiction departments: City Planning (1-1), City or County Public Health (2-1, 2-2), and Local or Regional Utility (3-1,3-2,3-3, 3-4). This list was securely stored in a separate file from the interviewee's transcript, linked only by their ID code. The master list linking names with ID codes was deleted at the completion of the project to protect interviewee privacy. Additionally, data were analyzed and reported in aggregate, and interviewees were ensured that any quotes utilized in final reports would be de-identified.

Data Analysis

A two-step thematic content analysis of the interviews was conducted after the completion of the interviews. First, the analysis leveraged an iterative coding approach utilizing both inductive and deductive content analysis. The initial codebook included 13 codes, grouped into six categories based on findings from the literature review and the interview guide. After the interviews but before analysis, codes were added, consolidated, or removed to ensure all codes and themes were useful and appropriate for the information collected. The final qualitative codebook (Appendix II) has 19 codes grouped into seven categories. The coding for each interview was completed using Dedoose, a web application for mixed methods research, to identify common themes and patterns across the completed interviews. During and after the coding of each interview, I noted initial observations of themes and ideas that emerged.

The second phase of the analysis included a review of each excerpt identified during coding (See examples of identified excerpts in Table 3 below).

Table 3. Selected Examples of Interview Content Analysis

CATEGORY	CODE	CODE DEFINITION	EXAMPLE QUOTE
Data Use	**Motivating Factors**	Interviewee mentions any motivating reasons for their department or city's use of health data in infrastructure planning	*"But having the data does allow us to be more consistent, right. And we have, you know, backing and solid rationale and why we're making these decisions" (3-2).*
Data Selection	**Sources of Measures**	Interviewee mentions information on the source of measures (e.g., other tools, databases, maps, partners)	*"For the health department, we have a community health needs assessment that we do every five years […] and that pulls together a lot of our just basic health data on like cancers, and cardiovascular illness and asthma and lead poisoning" (2-2).*
Partners	**External Reception of Data Usage**	Interviewee mentions how the work has been received or promoted by external individuals or agencies (e.g., political officials, capital project engineers, project managers, other depts./divisions)	*"When we rolled that out, we got a lot of traction, and a lot of parts of the county we had, you know, as we were making it, we'd met several times with the public health director at the time. And he got really interested […], and he […] advocated for us" (2-1).*
Decision-Making	**Phase of Decision-Making Process**	Interviewee discusses where or how in the decision-making process data is used	"*Before 30% design, like this is […] early, the options analysis is like pre-project design" (3-1).*
Challenges	**Challenges with Application**	Interviewee mentions challenges or limitations related to application (e.g., partners, decision-making, time, capacity)	*"The biggest issue that we have with deploying this is not necessarily the, the technology or the lack of data, we actually have a ton of data, [but] having enough analysts to be developing this" (3-2).*

I downloaded the excerpts into an Excel document, sorting key quotes and ideas from each interview into key themes to organize my findings. This process resulted in six themes, 1) use of public health data in practice, 2) basis of measure selection, 3) motivation for using public health measures, 4) challenges of using data in practice, 5) role and use of partnerships, and 6) theory versus practice, with key takeaways supporting each. The Findings section provides further details and presents quotes from interviews to illustrate each theme.

Interviews by the Numbers

Five of the six interviews were individual interviews (i.e., one interviewee), and one was a paired interview (two interviewees together). Out of 7 total interviews, three main types of jurisdictional departments were represented: City Planning (1), City or County Public Health (2), and Local or Regional Utility (4).

Job Roles were varied and included GIS Analyst, Capital Portfolio Manager, and Strategic Policy Advisor/Manager, among others. Cities represented included San Francisco, CA, Portland, OR, and Seattle, WA (See Figure 3).

Figure 3. Cities Represented by Interviewees

III. FINDINGS

SCAN OF DATA TOOLS

The information gathered from the scan of data tools provides important considerations for understanding how different measures are used in relation to infrastructure, health, and vulnerability, particularly when climate change is or is not included as a consideration. Findings from the scan highlight the basic structure, purposes, and motivation behind developing these types of tools. In addition, themes were identified relating to measurement topics, how different tools define and assess vulnerability, and what measures were selected for inclusion within each.

In total, eight tools were reviewed as a part of this scan, four that have national applicability (Climate and Economic Justice Screening Tool (CEJST), EJ Screen, Environmental Justice Index (EJI), Social Vulnerability Index (SVI)), and four that have state-level applicability (CalEnviroScreen (CA), Climate Change and Health Vulnerability Indicators (CCHVIz) (CA), New York Disadvantaged Communities Map (NY DC Map) (NY), Washington Environmental Health Disparities Map (WA EHD Map) (WA)). See Tables 4 and 5 for an overview of national and state tools, respectively. All eight tools were either developed or received a significant content or

methodological update at some point since 2020, and all tools offered data down to the census tract level. However, many clarified that while census tract scale was the goal, there is not 100% coverage of all variables at that scale.

The following sections provide an overview of each of the eight tools selected and key findings from comparative analysis regarding the motivation for tool development, definitions of vulnerability, types of vulnerability assessment, the purpose of data use, inclusion criteria for data selection, and categories of measures and indices used.

Tool Overview

Tables 4 and 5 below provide an overview of these national and state tools. From these tables, a few basic comparisons and insights can be drawn.

First, all eight tools were developed entirely or in partnership with a federal or state government agency. The identified purpose of these tools largely focused on highlighting or identifying communities based on a specific area of interest (e.g., environmental burden or social vulnerability); however, three of the eight tools also included a specific purpose of using the data tool to guide the provision of benefits or funding.

Second, the intended audience of these tools was centered on stakeholders that play a role in decision-making, particularly in government (e.g., federal or state government agencies, local planners and health officials, and policymakers). However, all tools also mentioned community partners, advocates, and the public as additional audiences.

Third, while all tools in this scan were selected due to their focus on measuring or identifying communities based on environmental burden, vulnerability, climate exposure or impact, and/or public health, the actual topical focus of each varied. It was most common across the tools to have a combined focus across two of the four thematic areas (e.g., environmental burden and public health, or vulnerability and climate exposure). Of the tools, only EJ Screen had a singular focus (environmental burden), and only the New York Disadvantaged Communities Map crosscut three areas (climate impacts, public health, and environmental burden). The topic areas in order of frequency are as follows: public health (6 tools), environmental burden (5 tools), climate exposure or impact (3 tools), and vulnerability (2 tools).

Table 4. Overview of National Tools

	CLIMATE AND ECONOMIC JUSTICE SCREENING TOOL (CESJT)[1]	EJ SCREEN[2]	ENVIRONMENTAL JUSTICE INDEX (EJI)[3]	SOCIAL VULNERABILITY INDEX (SVI)[4]
Developer	United States Council on Environmental Quality (CEQ)	United States Environmental Protection Agency (EPA)	Centers for Disease Control and Prevention's Agency for Toxic Substances and Disease Registry (CDC/ATSDR)	Centers for Disease Control and Prevention's Agency for Toxic Substances and Disease Registry (CDC/ATSDR)
Year Updated	2022	2022	2022	2022
Topical Focus	Vulnerability; Climate Exposure	Environmental Burden	Environmental Burden; Public Health	Vulnerability; Public Health
Purpose	**Guide Policy & Funding** To help guide the benefits of certain programs, including those in the Justice40 Initiative, by identifying disadvantaged communities overburdened by pollution and underserved.	**Identify** To highlight vulnerable communities facing higher environmental burdens using nationally available and consistent datasets.	**Identify** To help identify and map areas most at risk for the health impacts of environmental burden by measuring the cumulative impacts through the lens of human health and health equity	**Identify** To help identify, map, and plan support for communities that will most likely need support before, during, and after a public health emergency
Intended Audience	Federal Agencies; Community Partners	EPA Staff; Government Partners; Community Members	US Department of Health and Human Services Staff; Public Health Officials; Scientists; Researchers; Community Members	Emergency Response Planners; Public Health Officials
Scale of Data Analysis	Census Tract	Census Tract	Census Tract	Census Tract

Sources:

1. Council on Environmental Quality. (n.d.). Climate and Economic Justice Screening Tool [Government]. Climate and Economic Justice Screening Tool. Retrieved May 12, 2023, from https://screeningtool.geoplatform.gov
2. United States Environmental Protection Agency. (2014, September 3). EJScreen: Environmental Justice Screening and Mapping Tool [Government]. https://www.epa.gov/ejscreen
3. Agency for Toxic Substances and Disease Registry. (2023, March 16). Environmental Justice Index (EJI) [Government]. Centers for Disease Control and Prevention. https://www.atsdr.cdc.gov/placeandhealth/eji/index.html
4. Agency for Toxic Substances and Disease Registry. (2022, November 16). CDC/ATSDR Social Vulnerability Index (SVI) [Government]. Agency for Toxic Substances and Disease Registry. https://www.atsdr.cdc.gov/placeandhealth/svi/index.html

Table 5. Overview of State Tools

	CALENVIROSCREEN[1]	CLIMATE CHANGE AND HEALTH VULNERABILITY INDICATORS (CCHVIZ)[2]	NEW YORK DISADVANTAGED COMMUNITIES MAP (NY DC MAP)[3]	WASHINGTON ENVIRONMENTAL HEALTH DISPARITIES MAP (WA EHD MAP)[4]
State	California	California	New York	Washington
Developer	California Office of Environmental Health Hazard Assessment (OEHHA)	California Department of Public Health	New York State Climate Justice Working Group (CJWG)	University of Washington, Front and Centered, Washington State Department of Health, Washington State Department of Ecology, & Puget Sound Clean Air Agency.
Year Updated	2021	2021	2022	2023
Topical Focus	Environmental Burden; Public Health	Climate Impacts; Public Health	Environmental Burden; Public Health; Climate Impact	Environmental Burden; Public Health
Purpose	**Identify** To identify communities most affected by sources of pollution and where people are especially vulnerable to pollution's effects.	**Identify** To help better understand the people and places more susceptible to adverse health impacts associated with climate change.	**Guide Policy & Funding** To help identify disadvantaged communities to ensure that underserved communities benefit from the state's historic transition to cleaner, greener sources of energy, reduced pollution, and economic opportunities.	**Guide Policy & Funding** To reflect the cumulative health impacts of environmental risk on communities and to help highlight pollution burden and vulnerabilities to inform state environmental policy, budgeting priorities, and regulation enforcement to reduce health inequities.
Intended Audience	CalEPA; Other State Departments; Regional and Local Governments; Community Partners	Local Health Departments; Community Partners; Other Stakeholders	State and Local decisionmakers; Policymakers; State Departmental Staff; Other Stakeholders	State and Local Decision makers; Policymakers; The Public
Scale of Data Analysis	Census Tract	Census Tract	Census Tract	Census Tract

Sources:

1. California Office of Environmental Health Hazard Assessment. (2014, November 27). *CalEnviroScreen* [Government]. OEHHA. https://oehha.ca.gov/calenviroscreen
2. California Department of Public Health. (n.d.). *CCHVIz* [Government]. CCHVIz. Retrieved May 12, 2023, from https://skylab.cdph.ca.gov/CCHVIz/
3. New York State. (n.d.). *Disadvantaged Communities Criteria* [Government]. Climate Act. Retrieved May 12, 2023, from https://climate.ny.gov/resources/disadvantaged-communities-criteria/
4. Washington State Department of Health. (n.d.). *Washington Environmental Health Disparities Map*. Washington State Department of Health. Retrieved May 12, 2023, from https://doh.wa.gov/data-and-statistical-reports/washington-tracking-network-wtn/washington-environmental-health-disparities-map

Motivations for Tool Development

From the information available on each of the tool websites and background documents, there were varying motivations behind the development of these tools. The most common reason for development was due to an identified need or gap by the government agency itself, community advocate, or other decision-makers. These tools include CalEnviroScreen, EJScreen, Environmental Justice Index, Social Vulnerability Index, and the Washington Environmental Health Disparities Map.

Other tools in the scan were developed due to policy initiatives, regulations, or executive orders:

- The New York Disadvantaged Communities Map was designed to assist in identifying disadvantaged communities as required under the state's 2019 Climate Leadership and Community Protection Act (Climate Act) (Climate Leadership and Community Protection Act, 2019; New York State, 2023).
- The Climate and Economic Justice Screening Tool was designed to assist in identifying overly burdened or disadvantaged communities that will benefit from the Administration's Justice40 initiative as required under Executive Order 14008 (White House Council on Environmental Quality, n.d.).
- The Climate Change and Health Vulnerability Indicators for California Visualization platform (CCHVIz) was designed through funding from the Centers for Disease Control and Prevention's Building Resilience Against Climate Effects (BRACE) policy initiative, to assist communities in developing and implementing health adaption plans (California Department of Public Health, 2021b).

In addition, the linkage of these tools to policy or regulation can occur after the development, as illustrated by the Washington Environmental Health Disparities Map. The WA EHD Map was first published publicly in 2019; however, as a part of the Healthy Environment for All (HEAL) Act passed in 2021, the WA EHD Map was highlighted as a state-wide resource and was provided dedicated funding to maintain, update, and provide training for state agencies on how to use the map (Washington State Department of Health, n.d.).

It should be noted that these motivations were publicly acknowledged and known for each tool. It is likely that other motivations exist but were not available based on the methods used for this scan.

Definitions of Vulnerability Across Tools

The tools illustrate a lack of agreement on the definitions of vulnerability and sensitivity. Across the tools, terms included vulnerability, social vulnerability, health vulnerability, sensitive populations, disadvantaged community, and susceptibility. For tools with two or more definitions, distinctions were often made between biological and individual vulnerability and social or socioeconomic vulnerability. Even tools created by the same entity (e.g., EJI and SVI) utilize different definitions for the same term.

Regardless of the term used, the definitions were frequently similar, focusing on the degree to which certain populations, groups, or communities are directly or indirectly impacted by environmental, socioeconomic, demographic, and biological factors. The word cloud found in Figure 4 shows the frequency of word use across the definitions from each tool. It illustrates the commonly used terms and words, including environmental, hazards, health, disease, socioeconomic, pollution, and income. A full list of definitions from all eight tools can be found in Appendix III.

Figure 4. Definitions of Vulnerability Word Cloud

Types of Vulnerability Assessment

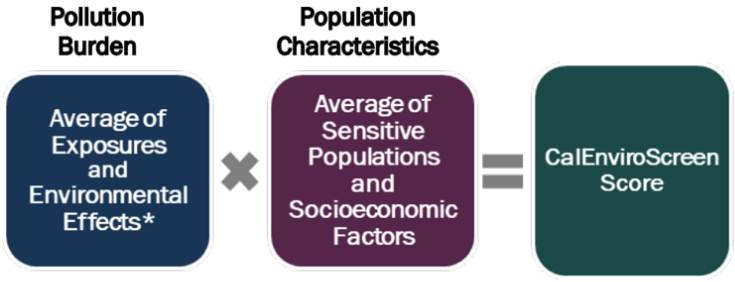
The literature outlines four approaches utilized for vulnerability assessments: simulation, aggregation, hybrid, and no simulation/no aggregation (Tonmoy et al., 2014). Of the eight tools scanned, the majority (6) fell under aggregation-based assessments, while the remaining two can be considered no simulation/no aggregation assessments (See Table 6).

Table 6. Types of Vulnerability Assessment: Overview of Selected Tools (Tonmoy et al., 2014)

TYPE OF ASSESSMENT	DESCRIPTION	TOOLS
Simulation - Based Assessment	Simulate the future impacts using models and apply measures of exposure to model vulnerability	None represented in scan
Aggregation - Based Assessment	Gather current metrics and aggregate them to determine potential future vulnerability	CalEnviroScreen EJ Screen EJI NY DC Map SVI Washington EHD Map
Hybrid Assessment	Combines both simulation and aggregation approaches	None represented in scan
No Simulation/ No Aggregation	Utilizes, discusses, and assesses vulnerability measures without modeling or aggregation	CEJST CCHVIz

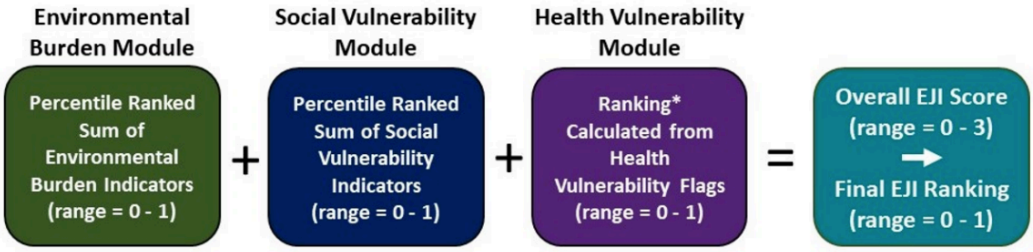
All six aggregation-based assessments adjusted selected measures or data to a percentile prior to its inclusion in any further calculations or aggregation. Aggregation processes occurred via two different approaches, either multiplicative or additive scoring. The differences between these approaches can be seen by comparing Figures 5 and 6 below. Figure 5 illustrates the multiplicative scoring methodology used by CalEnviroScreen, which multiplies pollution burden and population characteristics to calculate a final score. Comparatively, Figure 6 illustrates the additive scoring methodology used by the EJI, which adds together environmental burden, social vulnerability, and health vulnerability to calculate a final EJ Score.

Figure 5. CalEnviroScreen: Scoring Methodology (Zeise et al., 2021).



* The Environmental Effects score was weighted half as much as the Exposures score.

Figure 6. EJI: Scoring Methodology (McKenzie et al., 2022).



Regardless of the approach (multiplicative or additive), nearly all of the aggregation-based assessment tools result in a summative score that can be used to compare geographic areas. It is interesting to note that EJScreen is an outlier from the other five aggregation-based assessments in that it is the only tool that does not provide an overall summative score and instead only provides summative index scores. Table 7 provides an overview of the different approaches and further methodological information on each of the six aggregation-based assessment tools.

CEJST and CCHVIz are unique from the other six tools because they do not use simulation-based or aggregation-based assessments. However, similar to aggregation-based assessment, the CEJST also adjusts most selected measures or data to a percentile prior to their inclusion. But rather than using an indexing method to average and multiply indicators into a single index score, the CEJST instead uses a threshold approach. Threshold or cutoff values are based on the percentiles; these thresholds are used to identify overburdened and underserved communities (White House Council on Environmental Quality, 2022b).

Comparatively, the CCHVIz is the only tool that does not adjust measures into percentiles prior to their inclusion. Without aggregation or simulation, the CCHVIz offers three other avenues

for data review: 1) data is provided by census tract, 2) data is provided as ratios of the average values at both the county and state level to identify whether a particular county experiences great climate or health risks compared to other parts of the state, and 3) users can select and plot exposure and sensitivity indicators, which places counties into bottom, middle, or top third of overall vulnerability (California Department of Public Health, n.d.).

Table 7. Aggregation-Based Assessments: Comparison of Methodologies

SCORING METHODOLOGY	TOOL	ADDITIONAL NOTES ON METHODOLOGY
Additive Scoring: Sums the scores across selected components	**SVI**	Calculates a summative score that is provided as a percentile rank. Ranks are then compared to identify the most vulnerable communities (Agency for Toxic Substances and Disease Registry, 2022a).
	EJI	Calculates a summative score that is provided as a percentile rank. Ranks are then compared to identify the most impacted communities (McKenzie et al., 2022).
Multiplicative Scoring: Multiplies scores across selected components	**CalEnviroScreen**	Calculates a summative score for a given location relative to other locations in the state. Cumulative scores are used to understand a relative ranking of burdens across communities in the state (Zeise et al., 2021).
	EJ Screen	Calculates individual index scores (24 different indices) that are then reported as a percentile for comparability across geographic areas. No overall summative measure is calculated (U.S. Environmental Protection Agency, 2022).
	NY DC Map	Calculates a summative score that is provided as a percentile rank. A threshold percentile is then used to identify disadvantaged communities (New York State Climate Justice Working Group, 2022).
	WA EHD Map	Calculates a summative score that is provided as a percentile rank. Ranks are then compared to identify the most impacted communities (University of Washington Department of Environmental & Occupational Health Sciences & Washington State Department of Health, 2022).

Purpose of Data Use

Tools either focused on the identification of communities or measuring or scoring communities. Across the eight tools, a common thread was the differences in how the data was

used to meet the identified purpose of the tool. Four tools focused on using data solely to identify communities, and the other four focused on measuring impacts on communities and providing scores based on that impact, through which they used those scores to identify communities. Additionally, within each type of data use, there were clear distinctions between those tools that focused on identifying/scoring disadvantaged or vulnerable communities and those that identified or scored based on environmental, socioeconomic, or climate burdens. See Table 8 below for further distinctions.

Table 8. Purpose of Data Use: Overview of Selected Tools

DATA USE	FACTORS USED	TOOLS
Data used to identify a community or area based on specific factors	Disadvantaged Community	NY DC Map
	Environmental, Socioeconomic, and/or Climate Burden	EJ Screen CEJST CCHVIz
Data used to measure and score a community or area based on impact or exposure	Social Vulnerability	SVI
	Environmental, Socioeconomic, and/or Climate Burden	EJI CalEnviroScreen WA EHD Map

An example of data being used to identify a community can be seen in the approach of the CCHVIz map, which seeks to identify people and places in their jurisdictions more susceptible to adverse impacts associated with climate change (California Department of Public Health, 2021a).

Comparatively, an example of data used to measure or score a community or area is illustrated by the Washington Environmental Health Disparities map, which seeks to "estimate a cumulative environmental health impact score for each census tract reflecting pollutant exposures and factors that affect people's vulnerability to environmental pollution" (University of Washington Department of Environmental & Occupational Health Sciences & Washington State Department of Health, 2022).

Inclusion Criteria for Data Selection

Four of the eight tools included specific information within their methodological summaries regarding the inclusion criteria for selecting indicators or measures (CalEnviroScreen, CEJST, EJI, NY DC Map). The criteria selected by these tools largely aligned with commonly agreed-upon

criteria for data: relevance, quality, and ability to acquire (Stróżyna et al., 2018). Table 9 provides a summative overview of the inclusion criteria mentioned by the four tools. Criteria were only included in the table if mentioned by two or more tools.

All four tools included criteria related to data coverage, scale, and data quality. Most tools (3 of 4) included criteria related to the analytical soundness of the measures and relevance to tool goals or purpose. However, some criteria were only mentioned by one tool. CEJST included the specification that any data used must be publicly available, while the New York Disadvantaged Communities Map included considerations related to indicator correlation and uniqueness and a desire for standalone data versus summative indices.

It should be noted that these inclusion criteria were outlined within the methodology as general considerations for how data was selected; however, it is possible that other criteria or considerations may have been used. In addition, information was not readily available on data inclusion criteria for the four other tools included in this scan.

Table 9. Inclusion Criteria for Data Selection: Overview of Selected Tools

CRITERIA	DESCRIPTIONS USED	CALENVIROSCREEN	CEJST	EJI	NY DC MAP
Analytically Sound	Data is a quality measure of what it is intended to capture	X		X	X
Coverage and Scale	Data can be calculated at a specific scale (e.g., census tract) and/or can be easily manipulated to that scale. Data is also available either nationally or for the entire state (depending on the tool).	X	X	X	X
Quality	Data is current, accurate, from a trusted source, stable across time and space, and has limited measurement or sampling error	X	X	X	X
Relevance	Data is relevant to goals or purpose	X	X		X

Included Measures and Indices

Measure selection is, as expected, well-aligned with the identified topical focus and purpose of each of the selected tools. Across the eight data tools, five main categories and 13 sub-categories of data were used. The five main categories included population characteristics, environmental exposures, built environment and land use, health, and climate. Each category was also split into sub-categories; for example, population characteristics were divided into three categories: demographics, household characteristics, and socioeconomic status. Across these categories, there were 85 different areas of measurement. Appendix IV provides a complete comparative list of all measures and indices used in the selected tools.

There were three universally utilized sub-categories across all eight tools: household characteristics, socioeconomic status, and transportation. Other common sub-categories included pollution (seven tools), toxic sites (six tools), and demographics (six tools). While there were commonalities in the categories used by each tool, the combination and total number of measurement areas varied widely across the eight tools. Some used as few as 16 measurement areas, and others as many as 36 (See Appendix IV).

An overview of the representation of specific categories by tool is available in Table 10 on the following page. Tools are marked if they include at least one measure within the corresponding category.

Table 10. Measures and Indices: Comparison of Selected Tools

DATA CATEGORY	EXAMPLE MEASURES OR INDICES	CALENVIROSCREEN	CCHVIZ	CEJST	EJI	EJ SCREEN	NY DC MAP	SVI	WA EHD MAP	TOTAL TOOLS
Population Characteristics		X	X	X	X	X	X	X	X	8
Demographics	Age, Disability Status, Race		X		X	X	X	X	X	6
Household Characteristics	English Language Proficiency, Single Parent Household	X	X	X	X	X	X	X	X	8
Socioeconomic Status	Educational Attainment, Poverty, Unemployment	X	X	X	X	X	X	X	X	8
Environmental Exposures		X	X	X	X	X	X		X	7
Pollution	Air Toxics, PM2.5, Wastewater Discharge	X	X	X	X	X	X		X	7
Toxic Sites	National Priority List Sites, Risk Management Plan Sites	X		X	X	X	X		X	6
Built Environment and Land Use		X	X	X	X	X	X	X	X	8
Housing	Group Quarters, Mobile Homes		X	X	X		X	X		5
Land Use	Lack of Green Space, Tree Canopy		X	X	X		X			4
Transportation	Traffic Proximity and Volume, Vehicle Ownership	X	X	X	X	X	X	X	X	8
Technology	Broadband Access				X		X			2
Health		X	X	X	X		X		X	6
Health conditions	Asthma, Cardiovascular Disease, Diabetes	X		X	X		X		X	5
Mortality	Life Expectancy	X		X			X		X	4
Other	Violent Crime Rate		X							1
Climate				X			X			2
Climate Impact	Extreme Heat Days, Sea Level Rise			X			X			2

SEMI-STRUCTURED INTERVIEWS

The insights gathered from the interviewees are a key element of this research and represent a variety of viewpoints, priorities, and geographies, all shaped by the experiences and expertise of those willing to participate. Through interviews with seven government staff from three different cities, I was presented with a wide gamut of information and examples of how each interviewee thinks about and uses public health data in their work related to capital infrastructure and climate change. Throughout the findings, interviewees are referenced by their unique ID codes, which were assigned based on type of jurisdiction/department: City Planning (1-1), City or County Public Health (2-1, 2-2), and Local or Regional Utility (3-1,3-2,3-3, 3-4).

From these discussions, some themes emerged more strongly than others. After going through an iterative coding process, six themes were identified relating to the use of public health data within capital investment decisions (See summary in Table 11 below). The following sections dive into each of these themes and their related key takeaways. Direct, anonymous quotes from interviews provide illustrative examples of each.

Table 11. Summary of Interview Findings

THEME	KEY TAKEAWAY	SAMPLE REPRESENTATIVE QUOTE
Use of Public Health Data in Practice	Formal application of public health data within government departments and utilities for capital planning is inconsistent and often a work in progress.	*“We are just starting to use the CDC social vulnerability index […] we are just starting to weave that into our processes. And so, it is something we're hoping to do or not something we're currently doing” (3-2).*
Basis of Measure Selection	Measure selection is based on an approach that frequently uses public health, equity, and vulnerability as proxies for one another.	*"To use public health data, we use equity priority areas, which have health indices within them. So that's like, it is embedded” (3-4).*
Motivation for using public health measures	Motivation for using public health measures is centered on developing more informed decision-making, particularly related to equity.	*“Equity can be very abstract, right? Like, it's really easy for people to throw equity around, right? […]. And so, I do think that using more data, it helps, it helps us be more objective for whatever that's worth” (3-2).*

Challenges of using data in practice	City governments still face many challenges in using public health data for capital planning, with the majority existing in resources and processes, rather than in the data itself.	***"****Data is a little easy. Decision-making using the data is hard. So, data is only as valuable as it is used as a tool to, like, put resources in spaces that they might not have been otherwise" (2-2).*
Role and Use of Partnerships	Partnerships were common across the cities interviewed; however, challenges exist in cross-departmental standardization, funding, and implementing collaborative ideas.	*"So, what we're trying to do is trying to get other bureaus to work with us, […] So maybe we'd have one tool that we all use. But of course, that takes resources" (3-2).*
Theory versus Practice	Linkages between climate change, public health, and capital planning were universally acknowledged; however, in practice, these largely remain siloed in the use of measures, projects, and government initiatives.	*"We have a really strong focus on using public health data to understand climate impacts […] And what are different solutions that are needed? [...] But most of it, I think, is not related to infrastructure, right" (2-1).*

1. Use of Public Health Data in Practice

The formal application of public health data within government departments and utilities for capital planning is inconsistent and often a work in progress.

When asked if they used public health data or indicators to design, plan or prioritize capital projects, four interviewees said yes. The other three interviewees utilized the data but did not feel they could confidently say that they incorporated that data due to lack of consistency, lack of process, or limited application across projects.

> *"We are just starting to use the CDC social vulnerability index as a tool that we've embedded within our equity data toolkit. And we're literally just starting to pilot it to help us with our capital project planning and design. […] but I wouldn't say that we're currently doing it; we are just starting to weave that into our processes. And so, it is something we're hoping to do or not something we're currently doing" (3-2).*

Even for those who affirmed their use of public health data, many described their efforts as still in development or piloting stages. In addition, multiple interviewees mentioned a desire or need for further efforts to refine or develop a more formalized structure for the use of the data.

One staff of a utility stated*, "All the time I prioritize work based on social and health metrics. But I also will underscore that […] I don't have like a tool measuring that" (3-1).*

For those using public health data, a clear emphasis was placed on the importance of using the data early on within the capital planning and decision-making process to ensure an impact on actual outcomes.

One interviewee mentioned the role the data could have in illuminating the problem that needs to be addressed, stating, *"Having the data to actually tell the story, it's a critical first piece. And to be able to then use that, you know, we sort of focused in and layered more information on top of it to say, okay, like, we know, that, you know, these are the critical areas, but where are we actually going to look at focusing initial project" (2-1).*

Another mentioned the need to incorporate public health considerations as early as possible, stating they integrated it *"before 30% design, like this, is early […] like, pre-project design" (3-1).*

Another provided some reasoning behind the need for the initial push by discussing the frequent tunnel vision by experts when developing infrastructure options. This interviewee presented the idea of using a checklist or questions at the beginning of the process to ensure the consideration of upstream dependencies, downstream dependencies, and vulnerabilities in the capital planning process *(3-3).*

Additionally, for all interviewees, efforts to include public health data were not limited to capital planning but bled into other programmatic efforts within their departments as well.

> *"We're using the Social Vulnerability Index, which does have some health data in it, to inform decision making, in terms of assets and infrastructure, but also just programmatic efforts" (3-2).*

> *"I would say it I use it somewhat, and part of the goal [...] is to standardize the use of health data to not only for capital projects but when we're deciding places to do like weatherization services, that it corresponds to [...] the health data" (2-2).*

2. Basis for Measure Selection

Measure selection is based on an approach that frequently uses public health, equity, and vulnerability as proxies for one another.

Measures discussed by interviewees ranged from demographic factors to built environment conditions; however, despite the range of measures, there was a lack of distinction

between the reason for their selection when discussing topics such as public health, equity, and vulnerability. Interviewees often discussed concepts of public health, equity, and vulnerability almost interchangeably, and selected measures based on this idea that they serve as proxies for one another (i.e., a measure of public health can also measure equity and vice versa).

One interviewee mentioned how climate change, public health, and equity are one and the same in their work - and that you can't really separate them. Other comments combined concepts of vulnerability, equity, and public health interchangeably within their discussion of metrics or even explicitly mentioned them as embedded within or proxies of one another.

> *"The CDC index that looks at risk due to dread public health emergency is based on socioeconomic status household competent composition, right like essentially it looks at disparity in access to like, public health, right, like in emergencies, but it's as much as anything a proxy for an assessment of equity and access to resources, right" (2-1).*

> *"To use public health data, we use equity priority areas, which have health indices within them. So that's like, it is embedded" (3-4).*

Despite most interviewees linking these ideas and doing so in a manner that implied it provided positive benefits to the usage of the measures, one interviewee provided an alternative opinion. This interviewee discussed how mixing these ideas resulted in public health considerations of infrastructure often being an assumed result rather than a focused outcome. This interview noted concern for this approach given increasing climate impacts, which could threaten the reality of our often baseline health standards. They provided the example of their region's assumption of water quality, which, while often viewed as a given, may be less guaranteed in future years due to climate impacts such as flooding or wildfires. This same interviewee, therefore, mentioned that they purposefully do not use data interchangeably and discussed instead overlaying public health data with layers focused on vulnerable populations. (3-3).

When asked which public health measures they use, interviewees mentioned measures relating to population demographics, environmental exposures, land use, health conditions, life expectancy and climate impacts. See Table 12 below for the specific measures mentioned by interviewees (number of mentions across the interviews included in parentheses).

Table 12. Measures and Indices Mentioned by Interviewees

DATA CATEGORY & SUB-CATEGORY		MEASURES OR INDICES MENTIONED
Population Characteristics	**Demographics**	Age (x2)
Environmental Exposures	**Pollution**	Air quality Water quality (x2)
	Toxic Sites	Distance to contaminated sites
Built Environment and Land Use	**Land Use**	Distance to green space (x2)
Health	**Health Conditions**	Asthma (x3) Cancer Obesity Cardiovascular diseases
	Mortality	Average life expectancy
Climate	**Climate Impacts**	Health impacts of heat events (x2) Urban heat islands

Most interviewees also mentioned using an existing spatial data tool (either local, state, or national) that they then integrated into their processes. See Table 13 below for a summary of existing tools used by interviewees (number of mentions across the interviews included in parentheses).

Table 13. Tools mentioned by Interviewees

SCOPE OF TOOL	TOOLS MENTIONED
National	CDC Social Vulnerability Index (x2)
State	CalEnviroScreen Washington Environmental Health Disparities Map
Local	Community Health Needs Assessment/ Impact Assessment (x2) Community of Concerns Map Environmental Justice Map Race and Social Equity Map

Interviewees mentioned that using a tool, such as those listed above provided key baseline data and a reliable source of information.

“We initially thought of developing our own index, but we quickly realized that, you know, doing so effectively in a way that's statistically valid, and that, you know, passes the kind of research criteria in a way that you're also not doing more harm than good, is quite difficult. And the reality is that we would be reinventing the wheel; there's no need to do that. […] But we are also hoping not to solely rely on the social vulnerability index. In the future, we are hoping to add our own data layer " (3-2).

However, even with the use of a tool(s), it was also important for interviewees to be able to layer or add in their own departmental or city data based on local priorities or on a project-by-project basis.

“Part of it is using the data to sort of focus in and then adding additional data on top of that to layer in, like, where is the most strategic places to work? Right, and so, and then I think the data comes back in […] to do further work and to sort of pinpoint other areas as we go forward” (2-1).

3. Motivation for Using Public Health Measures

Motivation for using public health measures is centered on developing more informed decision-making, particularly related to equity.

Reasons mentioned by interviewees for the inclusion of public health measures were frequently linked with a desire to identify ways to address inequity due to historic infrastructure investment and/or existing and future forecasted climate change impacts.

“So, I think having the data and having the data in the context of, like, using the data on equity to show, right, like, to me, it illustrates the historical, institutional racism. [...] It opens up all of those conversations in a really visual way. [...] And so I think it makes it, it takes it from sort of an abstract conversation to a really concrete conversation that then enabled us to look at both elevating the issue as well as getting money to work on it” (2-1).

“Equity can be very abstract, right? Like, it's really easy for people to throw equity around, right? You see a lot of political leadership throughout the country, you know, say we're [going to] be equitable and anti-racist, but it's like, well, what does that actually mean? […]. And so, I do think that using more data, it helps, it helps us be more objective for whatever that's worth, you know” (3-2).

“What are our values so that as we select our sites that, we can start to try to prioritize around that? […]. So again, like the equity priority areas would be like influencing that like upstream of the work before it comes to us. And then now we're on this kind of block scale of like, okay, what are we doing? And this question of how do we answer this, like expanded public health outcomes? (3-4).

However, several other motivations were mentioned by respondents, including supporting the goals of long-range and strategic planning efforts, updating outdated models, and increasing accountability and transparency through consistent decision-making.

"But having the data does allow us to be more consistent, right? And we have, you know, backing and solid rationale and why we're making these decisions. [...] It also provides [...] an expectation of how we're going to behave, right, like we're being transparent about, here's the criteria we're using to make our decisions. And so, it adds also more transparency to the decision-making processes" (3-2).

"What are the values that we're trying to embed into our projects, so are like all the different types of values that were like using in this kind of value screening approach, there it is expanded public health outcomes. So there, so we, we have our [departmental] strategic business plan kind of goals, and then our kind of more refined and articulate [long term visioning]" (3-4).

4. Challenges of Using Data in Practice

City governments still face many challenges in using public health data for capital planning, with the majority existing in resources, processes, and timelines rather than in the data itself.

Despite including several examples of their use in practice, interviewees were quick to mention the many challenges government agencies and utilities face in utilizing and integrating public health data into capital planning processes and prioritization. One interviewee summarized the challenge of this work by stating*:*

“Data is a little easy. Decision-making using the data is hard. So, data is only as valuable as it is used as a tool to, like, put resources in spaces that they might not have been otherwise. And so, I think everybody's really down to collect data and to see the data and to look at these maps and to be like, Okay, this is awesome. But when rubber meets the

road, and it's like, how can I use this data to like drive investment or to like increase the power of marginalized communities or like, all of these whole host of other things? I don't think we're there yet" (2-2).

Challenges mentioned by interviewees fell under the following five main areas, 1) staff knowledge and capacity, 2) competing priorities, 3) timeframe of impact, 4) scale of data, and 5) the tendency to overcomplicate data.

Staff Knowledge and Capacity. Data use and implementation in capital planning are limited by staff knowledge and capacity to identify and deploy data tools. Interviewees specifically mentioned knowledge related to mapping software among existing staff and a lack of staff in general as reasons for limited capacity.

"Until, until a few months ago, or until like maybe six months ago, we didn't have a GIS person in our in our division in environmental health. And so, there was a lot of, like, relying on, […] County GIS, which was great, but sort of limited, in terms of its proximity to our work […]. Having the folks that have the skills to access and know what data to pull together is a big part of the puzzle" (2-1).

"The biggest issue that we have with deploying this is not necessarily the, the technology or the lack of data, [but] having enough analysts to be developing this right" (3-2).

"I think, probably, planning is more able to onboard health data than health is at this point to provide it to planning. And so, like figuring out how you can build health to be able to be better equipped to be at the table, I think is really important" (2-2).

Competing Priorities. All interviewees highlighted that public health is just one of many priorities within governments, meaning it often competes with other priorities (including climate change) for its role and weight in processes and resources. Interviewees mentioned the challenge of finding the equilibrium of these priorities within the process while still considering project costs and which projects provide the opportunity to move the needle the most.

"Because of the way our capital planning process occurs, which is a like ostensibly nonpolitical process that like, is a political process, […] And so it's a little tricky to, like, have climate or really any […] specific thing […] really overpowered? And I think that the disconnect of it could be a little bit better is, like, how does that then link into informing what projects move forward and in what state" (1-1).

“I think there are like conflicting incentives. […] For instance, [our] capital projects are managed by our project delivery and engineering branch. And their focus, their responsibility is to deliver projects, within scope, under budget, and on schedule. Those are like the three things they care about. [...] it makes it very difficult to make changes or amend project scope to account for climate risk or health impacts because it means more expensive, longer time, you know, broader scope, which is exactly what, you know, a project manager does not want” (3-1).

“One of the struggles that we're going to have in the climate world is how do you make space for climate change when it's always going to be the third most important thing that's going on at any one time and one and two might change. [They] might be displacement and addiction right now, but […] two years ago was COVID. And […] next year, it's probably going to be the fact that our downtown has no businesses anymore, but […] climate change will always be number three” (2-2).

Timeframe of Impact. In addition to competing with other local priorities, gaining support for these efforts is challenging due to the long timeframes before the potential “visible” impact associated with public health and climate change benefits of infrastructure investments. These impacts go beyond electoral cycles, making prioritization of them more challenging for decision-makers and funders.

"But the obstacles are, are similarly obvious. There are long-term challenges that span beyond an electoral cycle. And the payoff will not come during the term of these elected officials. And unless we continue feeling these climate impacts, like in terms of like these tangible crises, I don't see, like, I don't see much action. That's a major, major challenge" (3-1).

Additionally, one interviewee focused in detail on the challenge of designing capital infrastructure due to project design life of fifty to 100 years - a timeframe they felt made most people uncomfortable. Impacts of health and climate in these infrastructure choices have intergenerational impacts, but considering the equity impacts of future generations is where they noted this work gets “hard and tricky” (3-3).

Scale of Data. Challenges related to the data were limited; however, several interviewees mentioned geographic scale of data as an area where they at times faced the most limitations. The main challenge was ensuring data was available at the census tract level. In addition, a couple of interviewees mentioned that while smaller scoped data might be helpful based on the

project size or location, it often was unavailable due to data reliability or privacy concerns. Interviewees coalesced around the idea that zip codes were too broad of a scale and that for governmental infrastructure census tract is the best available option for analysis.

> *"It is at the census tract, we ideally would want to get more fine than that, but the data gets really inconsistent. And so, we've found that the census track is the smallest scale at which we can get reliable data" (3-2).*

Some interviewees also mentioned the incongruent nature of government capital projects, factors impacting vulnerability, and scale of data. One interviewee discussed the policy disconnect between what impacts vulnerability and health and the scope of the city's infrastructure impact.

> *"I think that there is a tricky bit […] when we're talking about the city's capital expenditures, it's so much about like, what buildings, [and] what infrastructure does the city own, and so much of the, like, health impacts […] from things like heat and air quality are occurring in private buildings. They're occurring […] in places where […] the city doesn't necessarily have either the authority or the, you know, fiscal capacity to [create large impacts]" (1-1).*

Tendency to Overcomplicate Data. If anything, multiple interviewees noted that despite its important role, too much of a focus on data can complicate things further, noting that it should be used in simplified and specific ways to ensure the potential for true adoption within planning processes.

> *"I honestly don't feel like a dearth of data is our problem […] And sometimes I think that we overcomplicate it. […] I think that there is a chance to overcomplicate the process and make it almost make implementation more challenging, kind of create a barrier to adoption. And so that is something that I struggle with" (3-1).*

> ***"**I think we recreate indicator systems a little bit probably too often, which is probably, which is probably to our detriment when it comes to using something to guide investment because every single project needs to have its own indicator system to do it" (2-2).*

> *"So, when you're developing a tool like that, and you expect project managers to use it and integrate it into the […] project planning process and project delivery process. It's, it's got to be simple, simplified, right? And so, you're going from something very complex to trying to make it simple enough to be useful and to be effective. And I think that's an area where we struggle […] that's a challenge" (3-1).*

5. Role and Use of Partnerships

Partnerships were common across the cities interviewed; however, challenges exist in cross-departmental standardization, funding, and implementing collaborative ideas.

Partnerships and collaborators mentioned by interviewees included both local and regional governmental organizations and community-based organizations and were frequently discussed as large groups of stakeholders rather than individual collaborators.

> *"We've […] worked together to facilitate workgroups of community-based organizations and everything. And we have, like,18 different city departments and like 15 different community-based organizations, and we have like a plan, that is 33 strategies that we're releasing, that is our heat and air quality plan. And a lot of that is based on how can we better incorporate health data to design interventions, both in the planning department, but also in the health department, too. But we haven't implemented that yet" (2-2).*

> *"We had a team that included folks from regional planning, [the wastewater department], and Department of Local Services […] looking at this issue together, right, and ended up putting together a white paper sort of describing the issue and using the data to illustrate the problems […] I think the data was key in being able to illuminate the problem again, right, and get buy-in" (2-1).*

While these groups were helpful to create buy-in, identify problems, and share information, challenges identified included lack of standardization, difficulty in resource sharing, and limited opportunities to move the partnership beyond discussions into actionable change.

> *"I think that there's some work on standardizing [but] it hasn't been done yet. We're not very good at standardizing it" (2-2).*

> *"It's […], that aspect of trying to get departments to [make] the budget requests they might not have. They might not have viewed anything having to do with climate about their projects, or just, they might not have any knowledge or expertise on […] how that should be informing departmental priorities […] like there's still that disconnect" (1-1).*

> *"So, what we're trying to do is trying to get other bureaus to work with us, […] what we're trying to see is like, is there something that we can do to standardize how the entire city*

looks at this? So maybe we'd have one tool that we all use. But of course, that takes resources" (3-2).

6. Theory Versus Practice

Linkages between climate change, public health, and capital planning were universally acknowledged; however, in practice, these largely remain siloed from one another in the use of measures, projects, and government initiatives (e.g., health and climate, or health and planning, or planning and climate).

Interviewees discussed at length about how these three areas are related, and how in practice, data can be linked and layered to tell stories about how infrastructure, climate, and health are connected. As discussed above, practice is moving towards ways of using data to address these areas together within planning process; however, currently efforts remain linked in tandem between two of these areas, rather than all three together.

For example, one example highlighted how health and infrastructure are tied together: *"There's also some other like health and health adjacent indicators that are being used to inform that infrastructure grant program" (1-1).*

Another interviewee provided an example of health and climate: "*We have a really strong focus on using public health data to understand climate impacts on different communities and sort of digging into that, right? And so, we have folks that are focused on climate health equity, that are working with our GIS folks to do a lot of analysis of data and mapping and looking at. Right, what are different impacts? And what are different solutions that are needed? [...] But most of it, I think, is not related to infrastructure, right" (2-1).*

And a third talked about infrastructure and climate: "*We have a lot of super detailed metrics that we are reporting on a quarterly basis around our direct greenhouse gas emissions associated with our projects with our emissions with our city municipal emissions and with the city writ large" (3-1)*.

In general, despite interviewees interests and efforts in this area, the examples they discussed illustrated the policy and programmatic disconnects in how these three areas are not actually frequently linked in practice.

IV. DISCUSSION

The literature review, scan of data tools, and interviews with current planning, public health, and utility staff provide important insights into the identification and selection of measures

of vulnerability, what measures and tools are available for use in capital infrastructure decision-making, and how data is being considered and used in practice.

In general, there is agreement across literature and practice related to the need for this work and a clear picture that the work is not yet common in practice, with current efforts remaining siloed. Compared to findings from the literature, interviewees, and tools agreed on general components of vulnerability, and common categories of measurement, despite continued divergence on how to measure those categories. In addition, contrary to the research, interviewees were able to identify and select measures of interest. Instead of measure identification and selection, interviewees noted most challenges were related to the implementation of the measures within their decision-making processes and policies.

The following section outlines these and other considerations related to the definition, identification, and use of health measures in capital planning for climate change, as well as barriers and opportunities for using these measures in decision-making practice. Limitations of these results are discussed, and potential future areas for exploration are proposed.

APPLYING HEALTH MEASURES IN CAPITAL PLANNING FOR CLIMATE CHANGE

Measures at the Intersection of Infrastructure, Climate Change, and Public Health

There is agreement across the literature, data tools, and interviewees that there is an intersection between capital investment, climate change, and public health; however, despite awareness of the interrelation of these areas, efforts are frequently linked between two areas (health and climate, climate and infrastructure, or infrastructure and health) rather than all three together. Both the scan of tools and comments from interviewees confirmed that efforts to link climate change, public health, and planning often remained siloed in both projects and in the integration of measures to prioritize, select, or design those projects.

The growing interest in this intersection is often hindered by this lack of consensus on how to discuss and measure the relationship, particularly in relation to capital infrastructure (Ebi et al., 2006; Hernández, 2013; Pineo, Glonti, et al., 2020; Remais et al., 2014; Rider, 2020; Romanello et al., 2021; Younger et al., 2008). This lack of consensus was consistent with the approaches used by interviewees and the data tools scanned for this project.

However, despite a lack of agreement on specific measures, the literature, tools, and interviewees largely agreed on a set of common categories of measurement that belong at this intersection. Common categories across these three sources included population characteristics, environmental exposures, and the built environment. While a part of the picture, specific

measures related to health outcomes or climate impacts remained less frequently used compared to indicators such as socioeconomic status, land use, and pollution.

Data tools illustrated this surface-level agreement on general topics of relevance but deep divergence in how those topics were measured. The tools used five common categories of data (population characteristics, environmental exposures, built environment and land use, health, and climate); however, within the five categories, tools were spread across 13 sub-categories and utilized 85 different measurement areas. Even those seeking to measure/score or identify communities based on similar criteria often disagreed on which measures to use. Part of this difference is due to variances of applicability required (national versus state tool development), which results in differing availability of measures themselves. However, a review of the methodology behind these tools confirmed a tool-by-tool approach to reviewing literature and selecting measures for inclusion. The lack of consensus in the literature results in both this ad hoc approach and inconsistency across tools.

When considering what measures belong and exist at the intersection of these three areas, both data tools and interviewees agree that combining multiple categories of measures allows for a multi-faceted review of the relationship. In addition, even with differing sub-measures, agreeing on common categories helps further streamline and create commonalities across vulnerability assessment approaches.

Centering Climate Change: Does Our Choice of Measures Change?

The growing priority of climate mitigation and adaptation has emerged against the historical backdrop of urban segregation, redlining, spatial inequality, and uneven planning prioritization and infrastructure investment (Anguelovski et al., 2016). Therefore, attempting to mitigate or adapt to climate change without consideration of pre-existing vulnerability can exacerbate socio-spatial inequities and existing health disparities (Anguelovski et al., 2016; Hendricks, 2022; Hendricks & Van Zandt, 2021).

Understanding the pre-existing relationship between infrastructure and vulnerability is key to determining if our measurement choices change when we begin to also center climate change. As discussed in the literature, vulnerable populations, particularly low-income individuals and people of color who are already more likely to be negatively impacted by our current built environment, also are expected to face disproportionately larger impacts of climate change (Anguelovski et al., 2016; Intergovernmental Panel on Climate Change, 2022; Younger et al., 2008). Because of this existing linkage, it was not entirely surprising that both the scan of data

tools and discussions with interviewees noted limited or no changes in the selection and use of measures when climate change was added as an additional consideration.

Climate change is often seen as an impact amplifier, exacerbating the existing conditions. Given this, the research found that existing measures, indices, or tools that measure vulnerability are often still used to review climate-specific vulnerability. Tools and interviewees mentioned adding climate impacts either as supplemental data through which to review the results of other measures or as a layer or lens through which existing data is filtered.

The three tools identified in the scan that focused on climate (CEJST, CCHVIz, NY DC Map) are prime examples of this distinction. All three utilized similar measures of vulnerability as other tools (population characteristics, environmental exposures, built environment and land use, and health); however, they added a category of climate impacts to their tool to place the findings of the other measures in the context. The baseline measures of vulnerability do not change in these tools compared to other non-climate-focused tools; instead, climate impacts are simply additional measures added to the analysis.

The lack of variation in vulnerability measures when incorporating climate considerations also aligns with interviewee discussions about their motivation to use measures in practice. Interviewee motivations were often tied to a desire to identify ways to address inequity due to historic infrastructure investment and/or existing and future forecasted climate change impacts. Interviewees saw their motivation linked so that there was often a lack of distinction between measures selected for public health, equity, and climate vulnerability. They even discussed how often they are often used as proxies for one another. These findings illustrate that existing measures used by cities to understand relationships between inequity or public health and infrastructure may be useful baseline measures through which the city can also view vulnerability in the context of climate change.

Defining and Measuring Vulnerability

The literature review focused on the lack of agreement around a common definition or measurement of vulnerability across disciplines. Generally, however, definitions and measurement efforts used by interviewees and data tools aligned with the IPCC's definition and characterization of vulnerability, showcasing that there may be more agreement than the literature acknowledges.

The largest area of disagreement was in the terminology itself, with tools utilizing over six different terms to describe the concept of vulnerability. Despite this, definitions were frequently

similar, focusing on the degree to which certain populations, groups, or communities are directly or indirectly impacted by environmental, socioeconomic, demographic, and biological factors

In addition, both the data tools and interviewees aligned with the noted shift and evolution of definitions and measures of vulnerability, incorporating an increasing focus on social factors rather than just environmental exposure or burdens. This was not surprising given the existing focus on equity, justice, and health disparities within the built environment by jurisdictions on both a state and national scale.

This linkage between definitions and measures of equity, health, and social vulnerability is important as it could provide an important opportunity to use capital planning to respond to issues of both procedural and distributive injustice. Defining and measuring social vulnerability in the context of social and health equity can provide another framework that can promote actionable change by helping make environmental justice a "governable strategy" with quantifiable and measurable frameworks for implementation. Both the acknowledgment of current injustices and the design of interventions to correct them is crucial to achieving equitable opportunities for resilience.

MEASURES IN PLANNING PRACTICE: BARRIERS AND OPPORTUNITIES

In general, interviewees confirm that the use of health or climate information, data, and tools in planning, capital improvement processes, and infrastructure standards and guidelines is not yet common practice. The urban planning, city and county public health officials, and utility staff highlighted some of the barriers they face in implementing these in practice and offered some insights into potential areas of opportunity. The alignment between barriers and opportunities mentioned by interviewees and those discussed in the literature was mixed. Still, it highlighted a clear need for further exploration of the implementation of measures in capital planning decision-making processes rather than the identification of measures.

Barriers

Interviewees agreed that the health impacts of climate change are relevant to infrastructure planning. Yet, similar to Burton et al.'s 2015 study, most acknowledged that the integration of measures to influence planning is limited. Even those that stated they were using measures provided a caveat they were still in the early stages of these efforts and noted a desire for better or more robust methods. This confirms the need for further guidance, not necessarily around selecting measures for use but for meaningfully integrating measures within existing policies and processes.

As discussed in the interview findings, staff of city and county governments and local and regional utilities face common challenges in using public health data for capital planning. Interestingly these challenges diverged from the literature regarding the identification and selection of measures. The literature highlighted the challenges in measure identification as a key potential area where barriers exist in implementation; however, interviewees mentioned the wide range of data available to them and listed many categories and types of measurement they were able to use. Instead of measure selection, most of these challenges were related to process and implementation, such as limited resources and capacity, complicated or unclear processes, and the need to navigate public health considerations with other competing important priorities. These barriers align with a clear gap in the literature around the lack of research and support related to applying measurements and tools in policy and planning processes. The findings from this research identify and support this need for ongoing exploration of the implementation of these efforts rather than the definitions or measures behind them.

Opportunities

Measure selection and use were bolstered by using existing tools and indices. Most interviewees mentioned using an existing spatial data tool, including some of those included in this project (i.e., CalEnviroScreen, SVI, WA EHD Map). The benefits of the tools included easy access to baseline data, a reliable and trusted source of information, and the ability to layer or review this data alongside local or departmental data for project-by-project analysis. While any approach to measurement selection and tool use has limitations, it was clear that they provide a helpful starting point for jurisdictions looking to implement measures in their infrastructure decision-making processes. Exploring what pieces of these tools are most useful could provide insight into how to better support and design tools for future use.

The motivation for both the development of these spatial data tools and their use by planning departments provide interesting insights into how integrating public health and vulnerability measures could become more widespread in practice. For many of the tools, development was due to an identified need or gap in available information. However, a few of the more recently released tools were developed as a part of or in response to climate policy initiatives, regulations, or executive orders. Interviewees also mentioned the linkage between their efforts and local or citywide initiatives and long-range planning efforts. These both illustrate a potential opportunity for using policy to prioritize, incentivize, or mandate the incorporation of these considerations in practice to build and formalize measurement use.

Even if more formalized in processes and policy, both interviewees and existing literature agree that in order to integrate health and climate data into planning decision-making processes, there must be both capacity and an existing structure through which data can be utilized. The CIP is a clear procedural link between a proposed project and funded reality; however, there is a policy disconnect between most individuals working on climate and health and those who truly have a seat at the CIP decision-making table. Therefore, while CIPs offer a unique opportunity, there is a need for a more specific understanding of the range of decision-making processes to determine where these efforts might best fit in practice or how to increase collaboration across those leading measurement work and those making infrastructure decisions.

LIMITATIONS

This data collection and analysis process had several limitations regarding sampling and overall generalizability. Time constraints were also present, so the scan of data tools and interviewees was intentionally small in scope.

Due to the use of purposive and convenience sampling, participation in this study was specifically focused on individuals already knowledgeable and interested in the project topic. While a study design choice, the sampling approach may have skewed results related to the use of measures in practice. Interviewees tend to be both more knowledgeable of these issues and more likely to be using measurements in practice compared with other jurisdictions or individuals not known to be experts in this area. In addition, interviewees were skewed toward staff at local utilities. While perspectives from utility staff are valuable, they alone do not provide a full picture of departments that prioritize, design, and plan capital projects. Therefore, the listed themes and key takeaways are not exhaustive; they represent a limited collection of perspectives and opinions. These considerations, along with the small sample size and limited geographic scope, limit the generalizability of these findings.

Additionally, scale and context are integral to prioritizing, selecting, and designing infrastructure projects. Regarding scale and context, it is important to acknowledge that this project was not place-based and did not focus on a singular specific jurisdiction. Instead, it presents broad frameworks and findings that may not apply to every situation or jurisdiction.

Also, while the project specifically sought to bridge disciplines, often, fields are siloed in practice. Therefore, these findings may be more applicable to some disciplines than others. It is important to consider the findings in the context of a specific jurisdiction and department rather than assuming the ability for direct application.

SUGGESTIONS FOR FUTURE RESEARCH

Given that this was an exploratory study of public health measures and their use in capital planning for climate change, the opportunity for additional exploration and research on topics discussed in this project are extensive. The following is a brief list of potential areas for further research that could build on or supplement the findings from this project:

Tool Comparison and Development

1. Vulnerability assessments are not the only process or tool used in infrastructure prioritization, selection, and design. Future research could compare approaches and measures within other processes or tools, such as Health Impact Assessments or Environmental Impact Assessments, to determine alternative options for practitioners.
2. This project focused on the use of quantitative measures within vulnerability assessments; additional research could explore the use of qualitative measures in vulnerability assessments and how qualitative and quantitative measurement could partner to support infrastructure decision-making.

Improvement and Identification of Implementation Strategies

3. Additionally, given the role of existing spatial data tools in providing accessible vulnerability assessments for practitioners, additional research could focus on identifying useful components and existing gaps and exploring how to improve and design tools for future use that better measure or identify vulnerability communities in this context.
4. Motivation for measurement highlighted the role of policy, including regulation, executive order, and legislation. Additional research could explore and compare these as avenues to develop "governable strategies" for integrating health and vulnerability measures into infrastructure decision-making and funding.

Implementation and Evaluation

5. This project highlighted frequent policy disconnects that create data implementation and integration challenges within infrastructure decision-making. Research and technical guidance are needed to support jurisdictions integrating measures into existing policies and practices. This research could also review how jurisdictions adjust policies or practices to allow for the integration or inclusion of these measures.
6. Additionally, as the use of measures in these processes continues to grow, future research could evaluate their use in decision-making to determine the impact on decisions and project outcomes.

V. FINAL REMARKS

Evidence shows that adverse impacts from climate change, such as rising heat, increased risks of flooding, and growing wildfires and smoke, pose many growing risks to our natural and built environments and human health and well-being with inequitable impacts on vulnerable populations and communities (Ebi et al., 2006; Remais et al., 2014; Younger et al., 2008). With the majority of the world's population living in urban areas, cities are at the center of many of the efforts to reduce emissions and adapt to a changing climate (Coalition for Urban Transitions, 2019). Therefore, local government-led infrastructure and capital projects can provide many opportunities to support these efforts (Whittington & Lynch, 2015; World Bank, 2021).

As cities look to mitigate emissions and adapt to climate impacts, planners must investigate if current efforts effectively address the needs of vulnerable populations or if they are continuing business-as-usual practices that have so often created or exacerbated inequities. Cities are beginning this work, but it is not yet common in practice. The results of this research illustrate an interest in this work and efforts to move it forward. However, they also highlight a need for more support to ensure it as a consistent component of planning practice.

In the short term, cities can leverage existing tools, utilize data to tell stories that can build support for this work, and, when possible, integrate data into decision-making discussions and processes. A hope is that this research can serve as a starting point for jurisdictions looking for information on both the process and tools available to them. In the long term, cities may need additional support in the shape of policies, funding, and regulation that incentivizes, prioritizes, or requires the inclusion of these considerations. In addition, further research such as that listed above has the potential to expand and enhance planning practice in this space.

Whether these measures are included in a formal CIP process, this research confirms the opportunities and impact of vulnerability assessment in infrastructure planning for climate change. The incorporation of vulnerability assessments at various scales within infrastructure decision-making, regardless of formality, provides an opportunity to increase education around the potential for maladaptation, build the will for identifying formal ways to implement this work, and eventually prioritize, select, and design infrastructure projects with these factors in mind.

Despite varying levels of use in practice, there is still space for influence. Acknowledging current injustices related to capital infrastructure and climate change and designing interventions to correct them is crucial to achieving equitable opportunities for sustainable, resilient infrastructure that creates climate and health co-benefits while advancing equity and social justice.

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APPENDICES

I. SEMI-STRUCTURED INTERVIEW GUIDE

Project Background:

Evidence shows that adverse impacts from climate change, such as rising heat, increased flooding risks, and growing wildfires and smoke, pose many risks to our natural environments, built environments, and human health and well-being. With the majority of the world's population living in urban areas, cities are at the center of many efforts to reduce emissions and adapt to a changing climate. Therefore, local government-led infrastructure and capital projects can provide many opportunities to support these efforts. However, both climate impacts and historical infrastructure development have had disproportionately negative impacts on vulnerable populations, particularly low-income individuals, and people of color.

This project is researching how public health data can support local governments in identifying and understanding who in their communities may be more sensitive or vulnerable to climate impacts as they seek to implement new capital projects. Identifying these communities can assist in designing and selecting projects based on their potential impacts on public health.

Goal: This interview aims to understand your current selection and use of public health data and if and how it is incorporated into your infrastructure and climate decision-making processes.

Informed Consent

Your participation in this interview is completely voluntary. You're free to end the interview at any time. I will be asking some open-ended questions, and if you do not wish to answer a question, just tell me, and we will skip it and go on to the next one.

I would like to record today's discussion for transcription purposes only. While quotes may be used in my final thesis and related publications and presentations, I will not identify you or use any identifying information. Additionally, I will be deleting all of the recordings at the completion of my thesis research in June.

This interview will take around 30 minutes. Before we continue, do you agree to participate in the interview today?

- Yes
- No [If not, thank the interviewee for their time and end the interview.]

Do I have your permission to record this interview?

- Yes – Be sure to press record after this answer!!
- No (rely on notes)

Before we begin, are there any questions that you'd like to ask?

Interview Questions

[Use of Data]

1. Do you currently use public health data or indicators to choose, design, or prioritize capital projects?
    a. [*if yes…]* If so, what indicators have you been utilizing?
        i. Why do you think these are appropriate?
    b. [*if not…]* If not, is there any data that you know about that would be appropriate for this purpose?
        i. What is it? Why do you think it is appropriate?
        ii. [If there is no answer - move to question 10]
2. Do you currently use public health data or indicators to identify and/or prioritize vulnerable populations (either generally and/or directly vulnerable to climate change impacts)?
    a. [*if yes…]* If so, what indicators have you been utilizing?
        i. Why do you think these are appropriate?
    b. [*if not…]* If not, is there any data that you know about that would be appropriate for this purpose?
        i. What is it? Why do you think it is appropriate?
    c. How do you feel these data align or potentially do not align with your efforts to choose, design, or prioritize capital projects

[Selection of Data]

3. Are or were there any specific sources you used to select these data or indicators?
    a. How about any specific people, research articles, or existing tools?
4. How do you collect, access, or update this data?
    a. Who else, if anyone, do you partner with to identify, collect, or apply these data?
5. Is there public health data that you feel is missing from your own organization's processes?
    a. Are there any data that you feel are missing from larger discussions about this?

[Decision-making Process]

6. How is this data used *[or how could it be used]* as a part of current decision-making processes?
    a. Where within the decision-making process is it referenced?
    b. Is this a formalized process?
        i. If so, in what way?
        ii. If so, for how long?
        iii. If not, are there efforts to try and formalize it? Why or why not?

[Decision-making Environment]

7. How has this work been received and/or promoted by **political officials** in your jurisdiction? Is there a sense of value for this work?
    a. [If they focus on a single person] Is this opinion held by others?
8. How has this work been received and/or promoted by **capital project engineers and managers** in your jurisdiction? Is there a sense of value for this work?
    a. [If they focus on a single person] Is this opinion held by others?
9. What awareness or interest have you seen from other departments or divisions in your organization related to public health measures (e.g., financial experts)?

[Challenges/Limitations]

10. What challenges or limitations have you faced in utilizing public health data?
    a. Have you experienced limitations with the data itself (*e.g., Scale of data, measure ambiguity, outdated data)*
    b. Have you experienced any specific challenges in the application or use of the data *(e.g., in decision-making staff knowledge)*

[Wrap up]

11. Is there anything else you would like to share?
12. Do you have any recommendations of other individuals I should talk with?
13. Would it be okay for me to contact you in the future if I have any clarifying questions?

II. QUALITATIVE CODEBOOK

CATEGORY	CODE	DESCRIPTION
Data Use	Data in Capital Projects	Interviewee mentions how public health data is used in choosing, designing, or prioritizing capital projects
	Data in Other Projects and Programs	Interviewee mentions how public health data is used in other departmental efforts or Programs
	Motivating Factors	Interviewee mentions any motivating reasons for their department or city's use of health data in infrastructure planning
	Case Example	Examples of data used in practice
Data Selection	Measures in Use	Interviewee mentions public health data that are currently being used
	Desired Measures	Interviewee mentions data they would like to use but is **not** being used currently
	Reasons for Measure Selection	Interviewee mentions any reasons behind their selection of specific measures (e.g., alignment with definition, alignment with policy, alignment with strategy or visioning)
	Sources of Measures	Interviewee mentions information on the source of measures (e.g., other tools, databases, maps, partners)
	Data Management	Interviewee mentions information relating to processes for accessing, collecting, and updating data
Partners	Role of Partners	Interviewee mentions partnership or collaboration
	External Reception of Data Usage	Interviewee mentions how the work has been received or promoted by external individuals or agencies (e.g., political officials, capital project engineers, project managers, other depts./divisions)
Decision Making	Data in the decision-making process	Interviewee discusses the role of data in the decision-making process
	Phase of decision-making process	Interviewee discusses where or how in the decision-making process data is used
Challenges	Challenges with Data	Interviewee mentions challenges or limitations related to data (e.g., access, collection, updating, ambiguity)
	Challenges with Application	Interviewee mentions challenges or limitations related to application (e.g., partners, decision-making, time, capacity)
	Other Challenges or Limitations	Interviewee mentions any challenges or limitations that do not clearly fall under either data or application
Vulnerability	Measuring Vulnerability	Interviewee mentions or discusses definitions or measurements specifically of vulnerability
	Climate Change Impacts	Interviewee mentions how measurements or approach changes when climate change is taken into consideration
Other	Quotes	Potential quotes for use in the report

III. TOOL SCAN: COMPLETE LIST OF DEFINITIONS

TOOL	TERM	DEFINITION
CalEnviroScreen	**Sensitive Population**	"Populations with physiological conditions that result in increased vulnerability to pollutants"(Zeise et al., 2021).
CCHVIz	**Sensitivity**	"The physiological and socio-economic factors which directly or indirectly affect the degree to which a population is impacted by climate-related change" (California Department of Public Health, 2021a).
	Vulnerability	"Where a person's or neighborhood's susceptibilities to injury or disease exist due to their distance and sensitivity to climate-related environmental exposures or hazards" (California Department of Public Health, 2021a).
CEJST	**Disadvantaged Communities**	"Communities that have been historically marginalized and overburdened by pollution and underinvestment in housing, transportation, water and wastewater infrastructure, and health care" (White House Council on Environmental Quality, 2022a).
EJScreen	**--**	--
Environmental Justice Index	**Health Vulnerability**	"Intrinsic biological factors such as chronic, pre-existing conditions that can worsen the effects of environmental burden" (McKenzie et al., 2022).
	Social Vulnerability	"The combined demographic and socioeconomic factors that adversely affect communities that encounter hazards and other community-level stressors" (McKenzie et al., 2022).
New York Disadvantaged Communities Map	**Disadvantaged Community**	"Communities that bear the burdens of negative public health effects, environmental pollution, impacts of climate change, and possess certain socioeconomic criteria, or comprise high-concentrations of low- and moderate- income households" (New York State Climate Justice Working Group, 2022).
	Social Vulnerability	"The susceptibility of social groups to the adverse impacts of external stresses on human health. Such stresses include natural hazards or human-caused disasters, or disease outbreaks. Impacts may include disproportionate injury, death, loss, or disruption of livelihood" (New York State Climate Justice Working Group, 2022).

TOOL	TERM	DEFINITION
New York Disadvantaged Communities Map	**Vulnerability**	“Vulnerability Population characteristics that may be indicators of susceptibility to climate change, certain factors that impact community health, or pollution exposures. A population’s vulnerability is influenced by socioeconomic factors and may also consider health outcomes. Examples of vulnerability include a high proportion of low-weight births, earning less than 80% of Area Median Income, limited English proficiency, or poor access to health insurance” (New York State Climate Justice Working Group, 2022).
	Sensitive Population	“Groups experiencing a biological or physiological condition such as genetic predisposition, general health status, low socioeconomic status, and possible interactions with certain medications, that increases susceptibility to environmental factors that may lead to increased negative health outcomes” (New York State Climate Justice Working Group, 2022).
Social Vulnerability Index	**Social Vulnerability**	"The degree to which a community exhibits certain social conditions, including high poverty, low percentage of vehicle access, or crowded households, may affect that community’s ability to prevent human suffering and financial loss in the event of disaster” (Agency for Toxic Substances and Disease Registry, 2022a).
Washington Environmental Health Disparities Map	**Vulnerability**	“A person’s (or population’s) non-biological situation that affects their ability to cope with risk factors. Examples of vulnerability include low income, language barriers or poor access to health care” (University of Washington Department of Environmental & Occupational Health Sciences & Washington State Department of Health, 2022)
	Susceptibility	“A person’s (or population’s) inherent biology that affects their risk. Examples of susceptibility include youth or old age, or whether a person is already affected by a disease—such as asthma or heart disease—that place them at increased risk when exposed to environmental hazards” (University of Washington Department of Environmental & Occupational Health Sciences & Washington State Department of Health, 2022)

IV. TOOL SCAN: COMPLETE LIST OF MEASURES AND INDICES

DATA CATEGORY	AREAS MEASURES OR INDICES USED (ALTERNATIVES IF MORE THAN ONE WAY USED TO MEASURE) *SOME TOOLS INCLUDED MORE THAN ONE MEASURE IN EACH AREA*	CALENVIROSCREEN	CCHVIZ	CEJST	EJI	EJSCREEN	NY DC MAP	SVI	WA EHD MAP	TOTAL TOOLS
Population Characteristics		X	X	X	X	X	X	X	X	8
Demographics	Age: Children (17 and under; 5 and under)		X		X	X		X		4
	Age: Elderly (65+)		X		X	X	X	X		5
	Civilian with a Disability		X		X		X	X		4
	Race and Ethnic Minority Status		X		X	X	X	X	X	6
HH Characteristics	English Language Proficiency	X	X	X	X	X	X	X	X	8
	Outdoor Workers		X							1
	Single Parent HH						X	X		2
Socioeconomic Status	Educational Attainment (No HS Diploma; % without a bachelor's degree)	X	X	X	X	X	X	X	X	8
	Energy Cost/ Energy Poverty			X			X			2
	Housing Cost Burden	X		X	X		X	X	X	6
	No Health Insurance		X		X		X	X		4
	Poverty (Low Income, Low-Median Income, <100% FPL, 80% AMI) *	X		X	X		X	X	X	6
	Transportation Expense								X	1
	Unemployment	X	X	X	X	X	X	X	X	8
Environmental Exposure		X	X	X	X	X	X		X	7
Pollution	Air Toxics				X	X			X	3
	Air Toxics Cancer Risk				X	X				2
	Benzene concentration						X			1
	Diesel Particular Matter	X		X	X	X	X		X	6
	Drinking Water Contaminants	X								1
	Groundwater Threats	X								1
	Hazardous Waste	X								1
	Impaired Water Bodies	X			X					2
	Lead Paint	X		X		X			X	4
	Ozone	X	X		X	X			X	5
	Pesticide Use	X								1
	PM2.5	X	X	X	X	X	X		X	7
	Respiratory Hazard Index					X				1
	Wastewater discharge			X		X	X		X	4
Toxic Sites	Active Land fills						X			1
	Formerly used Defense Sites			X						1

DATA CATEGORY	**AREAS MEASURES OR INDICES USED** (ALTERNATIVES IF MORE THAN ONE WAY USED TO MEASURE) **SOME TOOLS INCLUDED MORE THAN ONE MEASURE IN EACH AREA*	CALENVIROSCREEN	CCHVIZ	CEJST	EJI	EJSCREEN	NY DC MAP	SVI	WA EHD MAP	TOTAL TOOLS
	Hazardous Waste Treatment, storage, and disposal sites	X		X	X	X			X	5
	Major Oil Storage Facilities						X			1
	Mines (Coal, Lead, Abandoned) *			X	X					2
	Power Generation Facilities						X			1
	Proximity to Superfund or National Priority List Sites	X		X	X	X	X		X	6
	Regulated Management Plan						X			1
	Risk Management Plan Sites			X	X	X			X	4
	Solid Waste Sites and Facilities	X					X			2
	Toxic Release Inventory Sites	X			X					2
	Underground storage tank (UST) and leaking UST			X		X				2
Built Environment and Land Use		X	X	X	X	X	X	X	X	8
Housing	Air Conditioning		X							1
	Crowding							X		1
	Group Quarters				X			X		2
	Historic Underinvestment			X						1
	House Construction Date (Pre-1960, pre-1980)				X		X			2
	Housing Tenure				X					1
	Housing Vacancy Rates						X			1
	Lack of Indoor Plumbing			X						1
	Mobile Homes				X		X	X		3
	Multi-Unit Structures,							X		1
	Renter occupied homes						X			1
Land Use	Agricultural Land Use						X			1
	Impervious Surfaces		X							1
	Industrial Manufacturing Land Use						X			1
	Lack of Green Space			X						1
	Recreational Parks				X					1
	Tree Canopy		X							1
Technology	Lack of Broadband Access				X		X			2
Transportation	Airports				X					1
	Driving time to urgent/critical care						X			1
	High-Volume Roadways	X			X					2
	Railways				X					1

DATA CATEGORY	AREAS MEASURES OR INDICES USED (ALTERNATIVES IF MORE THAN ONE WAY USED TO MEASURE) *SOME TOOLS INCLUDED MORE THAN ONE MEASURE IN EACH AREA	CALENVIROSCREEN	CCHVIZ	CEJST	EJI	EJSCREEN	NY DC MAP	SVI	WA EHD MAP	TOTAL TOOLS
	Traffic Proximity and Volume			X		X			X	3
	Traffic: Diesel Trucks						X			1
	Traffic: Number of Vehicles						X			1
	Transportation Barriers			X						1
	Vehicle Ownership		X					X		2
	Walkability				X					1
Individual Health		X	X	X	X		X		X	6
Health Conditions	Asthma (Asthma ED Visits)	X		X	X		X			4
	Cancer				X					1
	Cardiovascular Disease (CVD ED Visits, Heart Attack Hospitalizations, COPD ED Visits, CVD Mortality Rate)	X		X			X		X	4
	Diabetes			X	X					2
	High Blood Pressure				X					1
	Low Birth Weight Infants	X					X		X	3
	Poor Mental Health				X					1
Mortality	Life Expectancy			X						1
	Premature death						X			1
Other	Violent Crime Rate		X							1
Climate Change			X	X			X			3
Climate Impact	Expected Agricultural loss rate			X						1
	Expected Building loss rate			X						1
	Expected Population loss Rate			X						1
	Extreme Heat Days		X				X			2
	Flood Risk (Coastal, Inland)			X			X			2
	Sea Level Rise		X							1
	Wildfire Risk		X	X						2
Total areas of measurement included*		22	19	30	36	19	37	16	19	