Stakeholder Assessment of Equity-Centered Coastal Adaptation: Insights from Norfolk, Virginia's Climate Resilience Efforts

by Valerie Michel

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Ph.D. DEGREE DISSERTATION

The Ph.D. degree dissertation of Valerie Michel has been examined and approved by the dissertation committee as satisfactory for the dissertation required for the Ph.D. degree in Systems Engineering

Dr. Garrick Louis, Advisor

Dr. William Scherer, Chair

Dr. Michael Porter

Dr. Majid Shafiee-Jood

Dr. Rosalyn Berne

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Abstract

The looming threat of climate change and the rapid urbanization of coastal communities present a growing challenge for policymakers and community leaders. As sea levels rise and tides become more damaging, creative, and innovative solutions are necessary to maintain the vital functions of our coastal cities. However, the focus on creating resilient coastlines can overshadow the social equity impacts of our actions. The most vulnerable populations in these communities are likely to bear the heaviest burden of coastal climate risk management policies and programs.

This research delves into the wicked problem of coastal climate change adaptation by examining the interactions among stakeholders and policies, with a particular focus on incorporating social equity into the planning process. Norfolk, Virginia, with its diverse population and commitment to community protection, serves as the case study. The study offers a framework for transforming qualitative assessments into quantitative influence and dependence matrices, which explore the relationships among multilevel governance stakeholders and policies.

Through a series of semi-structured interviews with over forty influential stakeholders in Norfolk's coastal climate adaptation policymaking, this research elucidates the intricate network of people, programs, and policies involved in coastal climate risk management. The research reveals inconsistent attempts from stakeholders to integrate social equity into coastal adaptation planning and analyzes the variation of how social equity issues vary across different coastal climate risks and stakeholder perceptions of solutions to address them.

Stakeholders identified challenges in measuring social equity, noting that federal and state-developed tools often lack consideration for local sociocultural norms. This research assesses the strengths and weaknesses of aggregated social equity indices and their applicability in planning. Using key components essential for quality index development, a scorecard is designed to evaluate and compare social equity indices. By deconstructing indicators and mapping them with specific coastal climate adaptation planning scenarios such as managed retreat and green infrastructure projects, and incorporating stakeholder-informed local knowledge, the study identifies how adaptation solutions can potentially exacerbate existing social equity issues.

It is essential to engage stakeholders and community members in the assessment process to ensure that their concerns and needs are incorporated into all stages of the decision-making process. It further demonstrates the importance of considering the interactions among stakeholders and policies, as well as the social inequities that can arise in policy making and program implementation. By doing so, policymakers and researchers can use the results of this study to develop more effective and equitable coastal climate change adaptation strategies that address the challenges faced by coastal communities around the world.

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Acronyms

Centers for Disease Control and Prevention (CDC)

Chief Resilience Officer (CRO

Chief Resilience Officers (CRO)

Climate Assessment (NCA)

Climate Change (CC)

Coastal Climate Risk Management (CCRM)

Community Rating System (CRS)

Conference of the Parties (COP 21)

Conference of the Parties (COP 21)

Department of Conservation and Recreation (DCR)

Department of Energy (DOE)

Department of Environmental Quality (DEQ)

Department of Homeland Security (DHS)

Department of Interior (DOI)

Elizabeth River (ER)

Environmental Justice Index (EJI)

Environmental Protection Agency (EPA)

Federal Emergency Management Agency (FEMA)

Flood Risk Insurance Map (FIRM)

Greenhouse Gas (GHG)

Hampton Roads Planning District Commission (HRPDC)

Housing and Urban Development (HUD)

Human induced climate change (HICC)

Intergovernmental Panel on Climate Change (IPCC)

Management and Transition Framework (MTF)

National Climate Assessment (NCA)

National Flood Insurance Program (NFIP)

National Weather Service (NWS)

Natural and Nature-Based Solutions (NNBS)

Planning District Commissions (PDCs)

Regional Greenhouse Gas Initiative (RGGI)

Sea Level Rise (SLR)

Social vulnerability index (SVI)

The Fifth National Climate Assessment (NCA5)

Tree Equity Score (TES)

United Nations Framework Convention on Climate Change (UNFCCC)

United States (US)

United States Department of Agriculture (USDA)

US Army Corps of Engineers (USACE)

Virginia Department of Emergency Management (VDEM)

Virginia Department of Environmental Quality (DEQ)

Virginia Department of Transportation (VDOT)

Virginia Institute of Marine Science (VIMS)

1. Introduction to Human Induced Climate Change and Sea Level Rise

1.1 The Scale of Human Induced Climate Change

Human-induced climate change (HICC) is causing increasing, harmful environmental, social, and economic impacts worldwide. According to the Environmental Protection Agency (EPA), almost 80% of all greenhouse gas emissions in 2020 were due to carbon dioxide, predominantly from anthropogenic sources (Environmental Protection Agency, 2015). Climate change is leading to global warming, melting polar ice caps, and unprecedented sea-level rise (SLR), resulting in an increased risk of routine and extreme event flooding in coastal regions (Milly et al., 2002; Van Aalst, 2006). Paleoclimate records show that the past few decades are the warmest in at least the past 1,500 years in the United States (Vose et al., 2017). Due to climate changes, annual precipitation has altered, increasing in the north and east, and decreasing in the west and south, with future increases projected. Global mean SLR has accelerated to 3.25 millimeters per year (1993-2018) from 1.35 millimeters per year (1901–1990) (National Aeronautics and Space Administration, 2023). As of 2021, the global mean sea level was 3.8 inches above 1993 levels, the highest annual average in the satellite record (1993-present) (Rebecca Lindsey, 2022).

On the East Coast, sixty-one percent of major southeastern cities are experiencing worsening heat waves, a higher percentage than any other region in the country (Habeeb et al., 2015). Ocean and coastal temperatures along the Northeast Continental Shelf have risen by 0.033°C per year over the 1982-2016 period, three times faster than the 1982-2013 global average rate of 0.01°C per year (Pershing et al., 2015). Tide gauge data collected over several decades through 2009 along the Mid-Atlantic coast (from Cape Hatteras, North Carolina, to Cape Cod, Massachusetts) show that sea-level rise rates were three to four times higher than the global average rate (Boon, 2012; Ezer & Corlett, 2012; Sallenger et al., 2012). The term "climate change" has gained wider use than "global warming" because the latter term implies that rising temperatures are the only consequence. However, climate change has much broader impacts, including droughts, threatened freshwater supplies, wildfires, sea-level rise, melting ice caps, storms, flooding, and the loss of biodiversity (United Nations, 2022a).

This research focuses on the efforts of the United States (US) to combat climate change and will not directly assess actions by international governmental bodies such as the United Nations, as these fall largely outside the influence of US domestic policymakers. The US government response to climate change occurs at the federal, state, and local levels. Key federal agencies involved in the US response to climate change include the Environmental Protection Agency (EPA), Department of the Interior (DOI), and Department of Energy (DOE) (US EPA, 2021b). For example, the EPA works with external organizations to develop the National Climate Assessment (NCA), which is published every four years. The fourth version of the NCA, published in 2018, found that natural variability and human-induced change are equally strong factors contributing to climate change and described the difficulty of predicting the climate at the decadal scale due to the interdependent nature of earth systems (U.S. Global Change Research Program, 2018). It also found that annual average temperatures over the contiguous US have increased by 0.7°C for the period 1986–2016 relative to 1901–1960 and by 1.8°F (1.0°C) when calculated using a linear trend for the entire period of record (Vose et al., 2017). The fifth version of the NCA (NCA5) is currently being prepared and is anticipated to be delivered in 2023. State and local governments have their own policy and program responses to climate change, which are not necessarily consistent or coordinated with those of the federal government. Additionally, there are some multi-state regional responses, such as the Regional Greenhouse Gas Initiative (RGGI) by the Northeastern states of Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, and Virginia (RGGI, Inc., 2023). Regional governmental bodies, such as regional planning district commissions, also coordinate climate change responses across multiple local governments (Hampton Roads Planning District Commission, 2021).

1.2 Far-Reaching Impacts of Climate Change

1.2.1 Risk to Public Health

Identifying the effects of climate change is a complex challenge due to the interdependencies in society, where weather events have cascading impacts on potable water quality, food security, housing security, human health, and other societal impacts (NOAA, 2021). Climate change harms health through air pollution, coastal displacement, food scarcity, disease, and contributes to 13 million environmentally-related deaths every year (World Health Organization, 2022). As temperatures rise, water and food resources are stressed due to decreases in freshwater reserves and the spread of drought, which threatens the sustainability of ecosystems and agricultural systems (U.S. Global Change Research Program, 2018). Extreme droughts threaten water supply, agriculture, transportation, energy, and public health (Center for Climate and Energy Solutions, 2022a). In 2020, over 800 million people faced food insecurity (António Guterres, 2021). Additionally, unsustainable practices along the food value chain, including production, packaging, and distribution processes, contribute to one-third of greenhouse gas emissions, which could rise to 40% by 2050 given population projections in the absence of appropriate interventions (United Nations, 2021b).

1.2.2 Costly Weather Disasters

Climate change is expected to have significant economic impacts (Tol, 2010). The magnitude and distribution of these impacts depend on a range of factors, including the level of greenhouse gas emissions and the specific effects on different sectors and regions of the economy. Temperature increases have significant negative impacts on crop yields, particularly in regions with warmer climates. As temperatures continue to rise due to climate change, these impacts are likely to become more severe in the future (Deschênes & Greenstone, 2007). Policymakers and other stakeholders seeking to understand the economic impacts of climate change can benefit from using weather data (Kolstad & Moore, 2020).

he United States has experienced over 300 climate disasters since the 1980s, resulting in damages exceeding one billion dollars and totaling over 2.275 trillion dollars (Smith, 2022).

Figure 1 shows a map of billion-dollar weather disasters in the US during 2022, highlighting the variety of climate disasters across the country and the different burdens that each region carries.

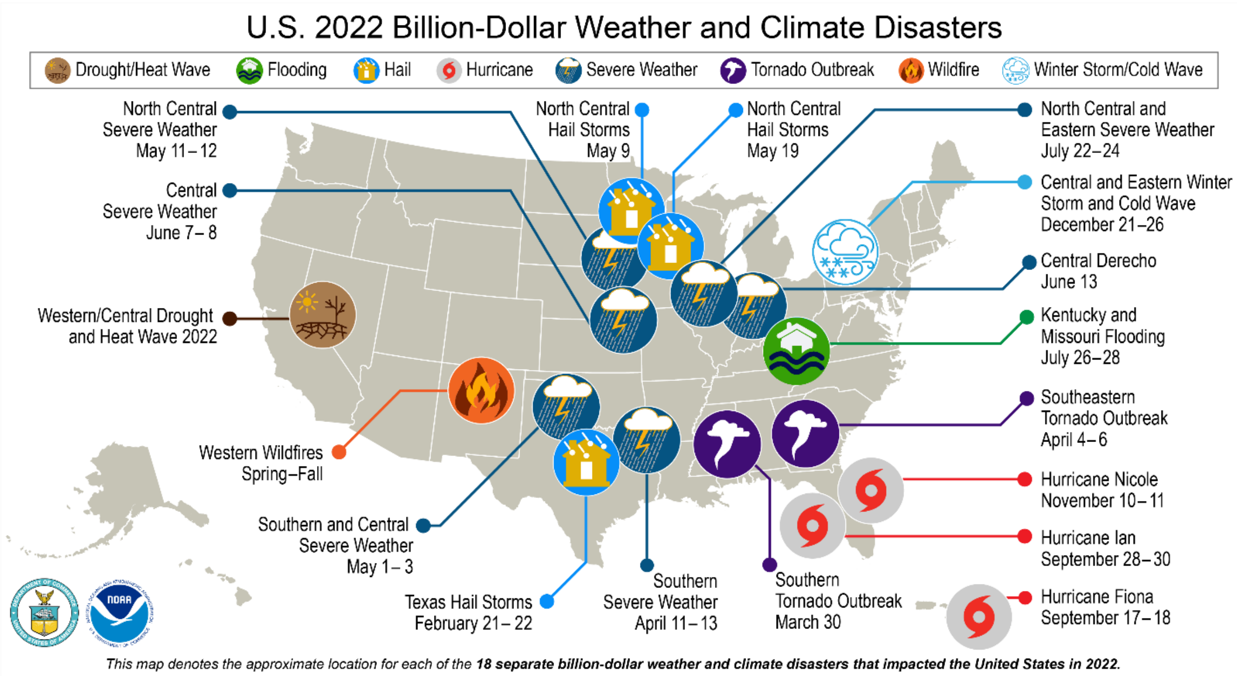

Figure 1: U.S. 2022 Billion-Dollar Weather and Climate Disasters by State (Smith, 2023)

Weather events in the United States vary from coast to coast, but primarily include droughts, extreme heat, extreme precipitation, hurricanes, tropical storms, tornadoes, and wildfires (Center for Climate and Energy Solutions, 2022b).

Wildfires

More frequent wildfires are a dangerous consequence of climate change, with estimated frequencies expected to vastly exceed historical levels. In the Western United States, the frequency of wildfires is projected to double the national average, contributing nearly one-third of global carbon emissions (Parmesan et al., 2022). Wildfires can also cause power outages and strain the power grid (US EPA, 2021a). These wildfires not only cause environmental damage but also pose a significant threat to public health and safety, as well as exacerbating climate change.

Winter Storms

Winter storms, especially those with high winds, pose a significant risk to society and the economy. The increasing frequency and severity of catastrophic winter storms have made managing their impacts an escalating problem. Future climate scenarios project a rise in winter windstorm losses in Europe, emphasizing the need for proactive measures to address these risks (Schwierz et al., 2010). Case studies of catastrophic winter storms in the United States have highlighted the need for improved forecasting, infrastructure, and communication to better prepare for these events (Changnon, 2007). Addressing the risks associated with winter storms and implementing adaptation measures will be crucial to minimizing their impact on society and the economy.

Tornados

The total yearly count of tornadoes has not significantly changed, but the annual, monthly, and daily variability has increased since the 1970s (Brooks et al., 2014; Tippett et al., 2016). For example, 2011 was the most active and destructive tornado year in modern records, while the following year was the quietest (Henson, 2021). Additionally, the distribution of tornadoes is shifting eastward. However, the relationship between tornadoes and climate change remains unknown, and research is ongoing.

Hurricanes

As air continues to warm, hurricanes can hold more water vapor, leading to more intense rainfall during storms (Angela Colbert, 2022). While the likelihood of increased hurricane frequency remains undetermined, there is evidence of increasing variability and intensity of hurricanes (Angela Colbert, 2022; Center for Climate and Energy Solutions, 2022c). Heavy precipitation events, in particular, have become more frequent and intense, with nine of the ten most extreme days of precipitation occurring since 1996 (US EPA, 2022b). This trend, combined with the likelihood of storm surges, elevated mean sea level, and extreme precipitation, will have a significant impact on compound flooding along coastlines worldwide (Bevacqua et al., 2020).

Floods

Climate change has significant impacts on flooding and poses risks to human health and the economy. Global warming and changes in precipitation patterns increase flood risks, especially in floodplains and coastal regions (Bronstert, 2003). Subtropical and tropical regions are particularly vulnerable to extreme weather events, sea level rise, and changes in precipitation patterns, resulting in increased riverine flooding (Eccles et al., 2019). Addressing the complex interactions between flooding, health, and climate change requires an interdisciplinary approach and adaptive strategies that include ecosystem-based solutions, community engagement, and improved data and modeling (Few et al., 2004)

Extreme Heat

Climate change has led to more frequent and severe extreme heat events, which pose a significant risk to public health, particularly in urban areas (Luber & McGeehin, 2008). The negative impacts of extreme heat include heat stroke, dehydration, and exacerbation of existing health conditions. Additionally, extreme heat can negatively affect crop productivity and soil moisture, leading to lower crop yields and quality (Harrison, 2021). The vulnerability of sprawling cities to extreme heat events has been noted due to factors such as low-density development and a lack of green spaces and shade (Stone et al., 2010). The prevalence and severity of extreme heat events underscore the need for proactive measures to manage the risks associated with climate change. This creates a cyclical impact on the environment: as temperatures and populations rise, more central air conditioning is needed, which in turn increases greenhouse gas emissions, including refrigerants such as hydrofluorocarbons, which are among the most potent greenhouse gases (Intergovernmental Panel on Climate Change, 2021; Underwood, 2021).

1.2.3 Role of Policy

Climate change poses significant economic risks to various sectors such as agriculture, forestry, fisheries, and tourism, and the impacts are already being felt and are expected to become more severe in the future (Renee Cho, 2019). Inaction on climate change can lead to reduced economic growth due to factors such as increased healthcare costs and reduced labor productivity, with climate change potentially reducing global GDP by up to 18% by the end of the century (World Economic Forum, 2021). However, investing in climate change mitigation and adaptation measures can lead to economic benefits such as job creation in renewable energy and energy efficiency sectors and reducing the costs associated with climate change (Renee Cho, 2019; World Economic Forum, 2021). Policymakers and businesses must work together to address climate change and build a more resilient and sustainable economy to avoid the worst economic impacts of climate change (Renee Cho, 2019; World Economic Forum, 2021).

1.3 Public Policy Approach to Climate Change from the United States Multilevel Government

1.3.1 The Global Effort

Governments around the world are collectively attempting to address the issue of climate change through various initiatives. One example is the United Nations Framework Convention on Climate Change (UNFCCC), which was operationalized by the Kyoto Protocol. The protocol committed industrialized countries and economies to limit and reduce greenhouse gas (GHG) emissions (Kyoto Protocol, 1997). The United Nations has also included climate action as goal thirteen of the Sustainable Development Goals and hosted the Climate Action Summit in 2019. The call to action included a 45% reduction in GHG emissions over the next decade and net zero GHG emissions by 2050 (United Nations, 2022b). The United Nations created the Intergovernmental Panel on Climate Change (IPCC) in 1988 to prepare comprehensive reports based on scientific evidence on the causes and impacts of climate change, as well as recommendations on adaptation and mitigation tools and techniques (Sergey Paltsev, 2021). During the twenty-first session of the Conference of the Parties (COP 21), the Paris Agreement was reached, which aims to shift all nations towards a net-zero emissions world (United Nations, 2021a; United Nations Climate Change, 2021). Under the Paris Agreement, countries are required to submit updated national climate action plans every five years to reduce their emissions. Former President Trump released a statement in June 2017 to "cease all implementation of the Paris Agreement," (Columbia Law, 2017), but President Biden reversed this decision on his first day in office on January 20th, 2021 (The White House, 2021).

1.3.2 The US Federal Government Response

The US federal government plays many roles in mitigating the risks from climate change. These include resilience, mitigation and adaptation planning, disaster risk management, public education, and capacity-building and support for state and local government. The case study for this research is on the east coast of the US. The primary concern in this region is sea level rise, land subsidence, and increased flooding and storm events.

The federal government's role as the primary provider of flood insurance through the National Flood Insurance Program (NFIP) is both a preventative and reactive approach to protecting communities against repeated flood damage and storm surges. The Federal Emergency Management Agency (FEMA) is the agency responsible for NFIP. NFIP collects nearly $4.6 billion annually from premiums, fees, and surcharges for over five million flood insurance policies (Horn, 2022). NFIP has two policy goals: 1) to provide access to flood insurance, assuming financial property risk, and 2) to reduce the risk of flooding by maintaining management standards and encouraging adaptation (Horn, 2022).

Beyond executive agency support the federal government has passed large legislative bills that will aid in the effort to adapt to climate change impacts. For example, the Infrastructure Investment and Jobs Act became law in November 2021 and it establishes a grant program to begin the process of transitioning to electric vehicles, supports resilient transportation infrastructure by funding climate vulnerability assessments, and other methods of adaptation and mitigation support from the federal government (DeFazio, 2021). The bill provides $550 billion in new spending over five years (The House Committee on Transportation and Infrastructure, 2022). The Inflation Reduction Act of 2022 additionally provides funds for multiple agencies. These agencies include the United States Department of Agriculture (USDA) for grant programs in climate mitigation efforts. The Department of Housing and Urban Development (HUD) for loans and grants to address affordable housing and climate change issues. The NOAA helps coastal communities prepare for storm surges and other climate issues. The Office of Insular Affairs to help the territories (i.e., American Samoa, Northern Mariana Islands, Guam, Puerto Rico, and the U.S. Virgin Islands). The EPA to create a GHG reduction fund amongst other climate related issues and climate justice work, the Council on Environmental Quality, and other regulatory agencies to aid in their efforts to address climate change (Yarmuth, 2022). The Infrastructure Investment and Jobs Act, combined with those in the Build Back Better Act, will add an average of 1.5 million jobs each year for the next decade (House Committee on Transportation and Infrastructure, 2022).

1.3.3 The Varied Approaches at a State Level

At a state level, the response has varied both in methods to address climate change and focus on locally relevant climate risks. For example, the Department of Environmental Protection in New Jersey established the Blue Acres program to help households that are subject to repeated flood damages by buying the properties and converting them to a community space (Department of Environmental Protection, 2022). Maryland enacted the Greenhouse Gas Reduction Act in 2009 requiring 25% reduction of GHG emissions by 2020. This was updated in 2016 by requiring a 40% reduction by 2030, although the IPCC stated Maryland needs to cut emissions by 60% in 2030 to reach net zero by 2045 (Chesapeake Climate Action Network, 2022). As noted earlier, Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, and Virginia entered the RGGI to cap carbon emissions from the power sector. The RGGI is the first regional cap-and-invest initiative in the US (The Regional Greenhouse Gas Initiative, 2021). The wealth generated from selling carbon credits in the RGGI are invested into local businesses, low-income communities, industrial facilities, and households throughout the region (RGGI, 2022). Across states there are different responses but also across political terms. Virginia’s Governor, Glenn Youngkin began his term in January 2022 by signing an executive order to reevaluate Virginia’s commitment to participate in the RGGI, claiming the burden is placed on Virginia residents through increased energy bills (Glenn Youngkin, 2022). The executive order aimed to remove Virginia from the RGGI, but it ultimately failed because executive actions cannot conflict with legislative agreements. Despite the attempt, the General Assembly reaffirmed Virginia's commitment to the RGGI for the period of 2022 to 2025 (Regional Greenhouse Gas Initiative; Preexisting Contracts, 2022).

The majority of progressive actions towards climate change adaptation and mitigation in Virginia occurred during the administration of Governor Ralph Northam from 2018 until 2022 (Eghdami, et al., 2023). These included several executive orders committed to the development of the Virginia Coastal Resilience Master Plan and the appointment of the Special Assistant to the Governor for Coastal Adaptation and Protection (Voyles, 2021). Although the Master Plan was released in 2020 the Special Assistant position is now vacant. Because that position was based off an executive order, when the administration changed the climate change priorities changed as well.

1.3.4 Regional Attempts at Coordination

At the regional level, the Hampton Roads Planning District Commission (HRPDC) plays a critical role in regional planning for climate adaptation, given the region's vulnerability to sea-level rise, flooding, and extreme weather events (Eghdami et al., 2023). The HRPDC facilitates collaboration and coordination among different levels and sectors of government in the Hampton Roads region, providing a platform for stakeholder engagement and public input that emphasizes a whole-of-community approach to regional planning for climate adaptation (Yusuf et al., 2018; Toll, 2018). The commission's role in regional planning for climate adaptation is crucial, as it helps to develop and implement effective climate adaptation plans in the region, which include strategies for building community capacity and fostering social cohesion (Yusuf et al., 2015)

he Hampton Roads Intergovernmental Pilot Project (HRIPP) and the Hampton Roads Sea Level Rise Preparedness and Resilience Intergovernmental Pilot Project (HRP) offer valuable insights into effective approaches to regional planning for climate adaptation that prioritize collaboration and intergovernmental coordination (Yusuf et al., 2018; Toll, 2018). These projects highlight the importance of stakeholder engagement and social justice considerations in developing comprehensive and effective climate adaptation plans that are inclusive of all community members (Bonnett & Birchall, 2023). By prioritizing community involvement and equitable decision-making processes, effective regional planning for climate adaptation can help build resilience and sustainability in the face of adversity.

HRPDC's role in regional planning for climate adaptation in Hampton Roads is critical, given its mandate to promote regional planning and cooperation on issues of common concern and facilitate collaboration among different local and state government agencies. By adopting a whole-of-community approach that engages all community members in developing solutions to the challenges posed by climate change, effective regional planning for climate adaptation can help build resilience and sustainability in the face of climate-related risks and challenges.

1.3.5 Localized Resilience

Local planning for climate adaptation in Norfolk has been informed by a collaborative and adaptive approach that incorporates diverse stakeholder perspectives and expertise. Norfolk's government has played a key role in leading and coordinating these efforts. The city's Department of Public Works has developed a comprehensive coastal resilience strategy that includes measures such as coastal flood mapping, hazard mitigation planning, and public education and outreach campaigns (Eghdami et al., 2023). Norfolk has also established a Community Resilience Committee to facilitate stakeholder engagement and coordination across local government agencies, non-profit organizations, and community groups.

Moreover, the city of Norfolk has taken steps to integrate climate adaptation into its land use and zoning policies. The city's Vision 2100 Comprehensive Plan includes provisions for sustainable development and climate adaptation, including the promotion of green infrastructure, the protection of natural areas, and the establishment of floodplain and wetlands protections (Jeffers et al., 2016). By adopting such an approach, Norfolk's government has been able to prioritize community engagement and equitable decision-making processes in the development of effective and comprehensive climate adaptation plans.

1.3.6 Multilevel Governance Coordination in Virginia

In a functioning multilevel government, the federal government supports the state with resources, which it, in turn, allocates to localities. The federal government will set standards like regulations over water quality that the states are required to meet or surpass. Localities are monitored by departments such as the Virginia DEQ or the VDOT. In Virginia there are Planning District Commissions (PDCs) that have little governmental authority; however, are deeply involved with coordinating between localities in a region on climate change risk management. Political and administrative representatives that called for multilevel government coordination in fact invested most of their efforts and resources into other issues either due to lack of political will or of resources and support (Clar, 2019). Policy practitioners often refer to the shared governance solution as the “stay in your own lane” approach, which remains close to the status quo and does not involve any new organizations, expansions of authority or planning processes (Lubell, 2017). This type of attitude discourages coordination and coherence between federal, state, and local governments.

1.4 Limitations in Coastal Resilience Planning

1.4.1 Disaster Recovery Issues

In 2017 Hurricane Irma hit Florida on September 6th, then on September 20th Hurricane Maria hit, two Category 5 storms within two weeks. A measure of a state’s capacity to manage climate risk comes from its rate of recovery after an extreme event. Figure 2 compares the recovery of electricity service to customers in Florida and Puerto Rico after being hit with two Category 5 hurricanes in 2017 (Chavez, 2017). On September 20th, Puerto Rico reported 100% of customers were without electricity (US DOE Office of Electricity, 2018). At the same time Texas was recovering from Hurricane Harvey which occurred a couple of weeks prior, on August 25th, 2017. Researchers at the University of Michigan reported that Florida and Texas received more aid and faster than the US territory Puerto Rico, finding that not only was the lack of emergency response a likely contributor to avoidable deaths but a reminder how the lack of federal representation can penalize the public health of a community (Willison et al., 2019).

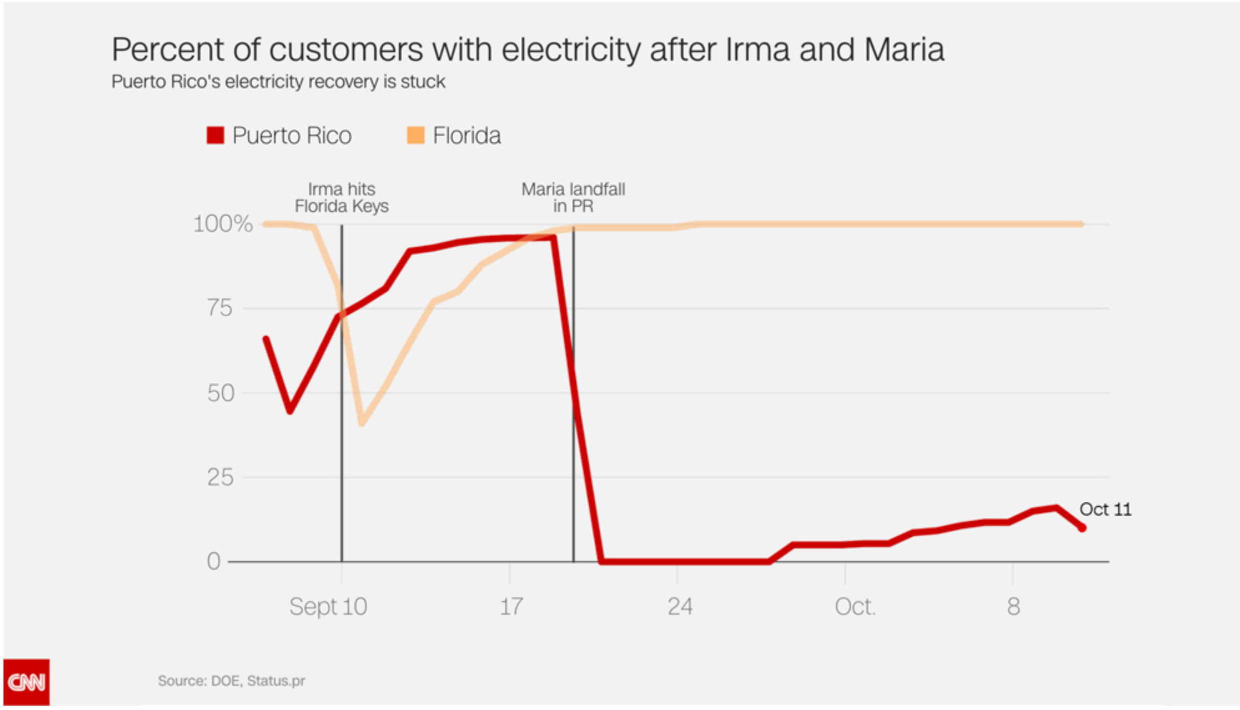

Figure 2: The percentage of customers with electricity after Irma and Maria, shown for Florida and Puerto Rico (DOE figure published by CNN) (Chavez, 2017).

The State of Texas submitted a State Action Plan for Round One of Community Development Block Grant-Disaster Recovery (CDBG-DR) for Hurricane Harvey Recovery for $5.024 billion in funds to the U.S. Department of Housing and Urban Development Coastal Management, which was granted in June 2018 (The Texas General Land Office, 2018). The purpose of the CDBG is to financially support the development and viability of urban communities by providing decent housing and fair living quarters as well as expanding economic opportunities particularly for low- and moderate-income persons. A complaint was filed against the state of Texas from the Director of Texas Low Income Housing Information Service claiming the post-Harvey relief funds prioritized homeowners, who are disproportionately white with moderate to high income, and fewer opportunities for minority renters and households (*Housing Discrimination Complaint*, 2018). This is an example of federal support being granted but inequitably executed at a state level.

1.4.2 Repeated Daily Flooding

The climate issues on the Eastern Shore of the United States are not exclusive to storm surges and major flood events. The term "nuisance" flooding or "sunny day" flooding is becoming increasingly common due to SLR (NOAA, 2022; US EPA, 2016). The highest rate of relative sea-level rise on the entire Atlantic coast is in Virginia. Indeed, the Hampton Roads region is second only to New Orleans as the largest U.S. population center at risk (Chesapeake Bay Foundation, 2022; NOAA Office for Coastal Management, 2022a). Coastal Virginia employs over two million people and fifty-nine percent of Virginia's population lives in coastal areas (NOAA Office for Coastal Management, 2022b). Thus, coastal climate risk management is a high priority for Virginia's state government and local governments in its coastal regions.

Is it enough? This is the vital question every policymaker should be asking themselves about their climate change risk management policies and programs. The first challenge is inconsistent policies and programs that change with each new administration. The second challenge is legislative and budget inaction that results from the influence of large interest groups and lobbyists for oil, coal, and gas. The acceptance of climate change in the political sphere is far from universal even in the face of increasingly destructive climate driven extreme events. From a systems perspective solutions are driven by goals and metrics. One study found that many flood resilience metrics are an assessment of a singular moment in time and cannot reflect the dynamic and evolving characteristics of resilience on past or present conditions (Bulti et al., 2019). If a resident lives in a community enrolled in the Community Rating System (CRS), then they can receive a discount on flood insurance from the federal government. These communities earn between 5% and 45% discount based on the CRS classification. The CRS tried to update their guidelines in a new system called Risk Rating 2.0 which does not use flood zones to determine the risk of flooding. Instead in a particular area the discounts are uniformly applied throughout the community. (FEMA, 2022a). A 2018 study found that the CRS communities would initially attract low-income residents and then later identify them as a vulnerable population and relocate them away from high flood risk areas. This discourages income inequality in areas that are prone to floods. Some would argue that attracting lower-income residents to an area concentrates them in areas of high flooding risk. These are the residents that have the least financial mobility in the event of flooding. An income inequality argument is not an effective basis for equity in CC risk management policy making. If one community is predominantly lower-income and another is predominantly higher-income, there may not be income inequality in either community. However, the lower-income community is more likely to be in the high-risk area. But in areas not high risk, the CRS encourages income inequality, attracting high-income migration and gentrification (Noonan & Sadiq, 2018). Once an area becomes fully gentrified, there is no longer income inequality.

Coastal adaptation in the US lacks a unifying goal and vision, communities are walling themselves off from the ocean without regionally understanding the impacts. Furthermore the discussion of managed retreat remains controversial (Siders, 2019c). Where there are buyout programs, there is a lack of transparency in the criteria used by the government on deciding which homes to purchase (Siders, 2019a). In the US there is a history of racially driven housing policies. Buyout programs that target homeowners, excludes renters who are more likely to be racial minorities and low-income populations (Dundon & Camp, 2021). This exacerbates and compounds the cumulate burden of historical racially discriminatory housing policies.

1.4.3 Social Equity and Government Policy

Social Equity and Environmental Justice are more recent CC policy initiatives. In fall 2022 the EPA announced a new department within the EPA focused entirely on Environmental Justice (US EPA, 2022c). But to understand the meaning of climate justice, academics and policymakers must first appreciate the diverse history of social movements that have formed the concept over the last few decades (Schlosberg & Collins, 2014). For example the federal government began redlining in the 1930s, the practice of classifying neighborhoods into a rating system based on discrimination towards ethnicity, income, and occupation, which now can be spatially linked to extreme heat in urban areas (Li et al., 2022). Research has found that the objectives of sustainability lead policymakers to favor environmental and economic metrics over social equity (Fiack et al., 2021). Age can be considered a metric of social vulnerability however a review of over 900 European cities found a link between senior population and adoption of adaptation policy, which the study contributed to their vulnerability to heat (Yang et al., 2021). Another study determined the correlation between equity policies and social vulnerability at a district level and found that the social equity policies were not prioritizing risk reduction in the areas that had the highest social need (Berke et al., 2019). This is attributed to the lack of equitable policies throughout the planning process, adopting them into just certain aspects. These systems are linked and codependent so investment in equitable policies is necessary from infrastructure to hazard mitigation planning. These policy selections come down to the metrics that are used in analysis. In federal policy, cost benefit analysis is the typical approach to selecting mitigation strategies. However, this metric has serious shortcomings when considering the tradeoffs between policies (Gibbs, 2015). Beyond just the equity of policies and metrics the equity of representation in coastal climate risk management is crucial to implement practical solutions that will be socially and culturally acceptable.

Perceptions on the problem of flooding both in cause and intensity in the Hampton Roads region differs between residents and decision-makers, leading to different perspectives from their representative (Bukvic & Harrald, 2019). The Social Representation Theory (SRT) potentially explains this discrepancy between perception of environmental risks by non-experts and how to connect objective and subjective risk perception (Lemée et al., 2019). Coastal climate risk management policies can be seen as intrusive, leading to relocation efforts being rejected and emergency evacuation protocols ignored. Siders (2022) offers a recommendation for the academic role in bridging the gap between climate adaptation justice in theory and in practice: do not give recommendations for participation without considering population nuances, provide tradeoffs and a ‘menu of solutions’, and be interdisciplinary in the approach (Siders, 2022). It is also necessary to include behavioral science and learn how to motivate socially desirable behaviors through public policy. This research attempts to offer a variety of approaches and perspectives outside the boundaries of academia by soliciting recommendations and knowledge from individuals close to coastal climate risk management through a series of interviews.

1.5 Objectives, Methodologies, and Results

The goal of this research is to tackle some of the complex systems questions regarding coastal climate adaptation planning through a mixed methods approach that combines qualitative assessments with quantitative research. The objectives are to assess the complex network of actors and interactions in coastal climate adaptation using a case study of Norfolk, Virginia. Then working in the same urban area assess how those agencies and actors incorporate social equity into coastal climate adaptation planning. Finally, the goal is to evaluate the efficacy of social vulnerability indices commonly used among planners and suggest alternative localized and regional approaches to meet the social equity goals in coastal climate adaptation planning for a particular region. Are recent coastal climate adaptation planning efforts increasing social equity through policy, programs, and projects or do their efforts continue to drive social gaps in the area due to a lack of measuring and defining their goals? The principal research method is a series of interviews completed in 2022 with two pending publications and one recent publication in the Journal of Climate Policy (Eghdami, et al., 2023). To understand the complex network of people, programs, and policies trying to adapt to coastal climate change it was critical to get firsthand input from those involved in or influencing decision-making within government, non-government organizations, and academia.

1.5.1 Chapter 2

Chapter two dives into the complex multi-governance network of actors engaging in coastal climate adaptation planning in Norfolk, Virginia. The driving research questions include:

- How do policies influence decision-making for coastal climate risk management by relevant stakeholders?
- How do stakeholders influence the policies (formation or execution) on coastal climate adaptation?
- When there are networks of stakeholder and policies:
    - Who is dominant in influencing policy and other stakeholders?
    - What policies are driving coastal adaptation planning and multilevel governance?

To answer these questions this research will use a policy-stakeholder interaction matrix analysis tool developed and published at the American Science and Engineering Management conference in 2018 (Michel et al., 2018). The method will be adapted from water systems to coastal adaptation systems and is a tool to convert qualitative knowledge to a quantitative analysis. By investigating the relationships among stakeholders and policies this investigation yields a better understanding of how federal, state, and local governments and policies interact and the pathways of multilevel governance.

1.5.2 Chapter 3

Chapter 3 focuses on how stakeholders incorporate social equity considerations into planning for Norfolk's climate change impacts. Chapter 3 also dives into historical policies of unfair housing practices that have impacted the social and political landscape today.

- How do stakeholders in Norfolk's coastal climate adaptation planning network incorporate social equity into their planning decision-making?
- How do stakeholders define social equity and measure it?
- How does is social equity perceived by stakeholders for different climate risks?

These research questions are addressed by performing a comprehensive review of the problem and literature, and an analysis of current social equity metrics, the projects they are applied to and local solutions that have excluded them. Additionally, some of the historical injustices in housing practices are overlaid with climate equity data in Norfolk, Virginia.

1.5.3 Chapter 4

Chapter 4 follows up on the future directions in Chapter 3, to assess the efficacy of certain social equity related indices employed in coastal climate adaptation planning. The chapter recommends techniques to incorporate social equity into tools used by decision-makers that measure social vulnerability and aim to support equitable policies and programs. Although it is not possible to free our systems completely from bias it is feasible to reduce bias or at least be aware of it. These primary research questions drive the motivation for this project:

- What are the limitations of applying state and federally developed social vulnerability indices to social equity related indices?
- How can we evaluate the efficacy of social equity related indices?

Multiple state and federally developed social vulnerability indices, environmental justice indices, and a non-profit developed tree equity index are all evaluated and compared in this Chapter to better understand the individual limitations and common trends in limitations amount all. The results include a scorecard for researchers to track the inclusiveness of their index performance.

1.5.4 Chapter 5

Chapter 5 uses the scenarios of managed retreat and nature and natural based solutions to discuss how particular social equity metrics will be of interest when employing policies that directly impact vulnerable communities. The goal is to break down several scenarios and discuss how a particular indicator might relate to a particular climate risk.

- How does the incorporation of social equity into objective decision-making impact the outcomes of managed retreat?
- How does the incorporation of social equity into objective decision-making impact the outcomes of green infrastructure?
- How does the incorporation of social equity into objective decision-making impact the outcomes of grey infrastructure?

This chapter dives deeper into potential methods to view social equity on a case-by-case basis. It provides recommendations on implementing scenario planning. The resulting maps are helpful for socially equitable decision-making that incorporates historically marginalized populations.

1.5.5 Chapter 6

In all these cases the analysis tools are applicable outside the Norfolk, Virginia region. Although the focus is on localized and regional planning methodologies and argues for localized solutions and therefore the case study throughout this research is Norfolk, Virginia. This coastal area is a prime case study due to the steady rise in flooding incidences and sea level as well as subsidence of the land. Chapter 6 summarizes the following chapters, reflects on the methods, proposes future directions, and provides concluding remarks.

1.6 Key Definitions

This paper mentions many key terms used by researchers and stakeholders throughout this study. This section reviews the literature definitions of those terms and demonstrates the connections between them.

Climate change causes many interrelated risks that impact physical and social systems, ecosystems, the economy, and the structure of society (Adger et al., 2018). **Climate risks** are risks that result from climate change such as flooding events, severe storms, excessive heat, saltwater intrusion, and land subsidence. **Coastal climate adaptation** (CCA) is a response to climate risks, as discussed previously, it can be a variety of reactive and proactive methods to mitigate financial damages and save lives. CCA is meant to increase a community's resilience. But the definition of **resilience** is much more nuanced and depends on the type of system in question.

Despite the discourse surrounding resilience in ecology, the concept of resilience was rapidly popularized in the social sciences, where it is still used to describe and characterize economies, communities, and institutions (Holling, 1973; Folke et al., 2005; McCubbin, 2001; Taşan-Kok et al., 2013; Van Meerbeek et al., 2021). Adger and colleagues defined **social resilience** as the ability within human societies to adjust to change, particularly "to absorb recurrent disturbances such as hurricanes and floods so as to retain essential structures, processes and feedbacks" (Adger et al., 2005). But the definition of resilience has been straying from its ecological origins, as the role of social equity in community resilience becomes more important. **System resilience** is defined as the capacity to bounce back to normal functioning after a perturbation (Scheffer et al., 2018). The criticism of the definition of resilience is that in application, it fails to address the social inequities within a population (Hart et al., 2016). The failure to include social vulnerabilities disregards that "bouncing back" is not only more difficult for some populations, but it could be a return to the original inequitable state. This research adopts the definition of **equitable resilience** as, "one which takes into account issues of power, subjection, and resistance; makes visible socially constructed limitations faced by groups and communities at all levels; and thinks about these issues in a joined-up way to avoid unsustainable interventions being made in the name of either disaster response or development (Matin et al., 2018)".

Community resilience is directly impacted by the vulnerability of their population. The Rural Coastal Community Resilience Framework developed in North Carolina depicts vulnerability and resilience as opposite sides of a spectrum, with adaptive capacity acting as the agency to move towards resilience (Jurjonas & Seekamp, 2018). The definition of **adaptive capacity** has been largely left out of research articles covering the subject; however, "the ability of a system to adjust" is the most frequent adaptation of the term (Siders, 2019b). In this context, adaptive capacity is the resilience of a system to cope with climate change risk which is exacerbated in vulnerable systems. **Vulnerability** can simply be regarded as an exposure to risk; however, there is a difference between vulnerability and social vulnerability. The United State Federal Emergency Management Agency (FEMA) defines **social vulnerability** as "the susceptibility of social groups to the adverse impacts of natural hazards, including disproportionate death, injury, loss, or disruption of livelihood" (FEMA, n.d.). The social vulnerability and resilience of a community are functions of wealth, infrastructure, and demographics, and they are all assessed on a comparative basis. For example, Florida's energy system is resilient when compared to Puerto Rico's after two Category 5 hurricanes hit in 2017 (Chavez, 2017). Yet many of Florida's communities were identified as socially vulnerable based on race, number of dependents, education, poverty, and other risk variables (Mitsova et al., 2018).

A socially vulnerable community is less resilient and, when compared to less vulnerable communities, less able to recover effectively from natural or human-made disasters (Karakoc et al., 2020). This can create or exacerbate existing social inequities. Social inequity, the opposite of social equity, is derived from a disparity in distribution of resources. This is not to be confused with **equality** which is a fair or even distribution of resources; however, it may not be a just distribution of resources. **Environmental justice** is the protection against climate risk and inclusion of all peoples in environmental planning, regulating, and policymaking regardless of their race, age, income, or other demographic characteristics(US EPA, 2022a). Environmental justice and social equity (with regards to CCA planning) are intrinsically linked, where an equitable society is a just society.

2. Influence and Dependence Matrix for Policy-Stakeholder Interaction Analysis

2.1 Introduction

2.1.1 Background

Multilevel governance involves the collaboration among various levels of government in the United States, such as federal, state, regional, and local governments, to address the diverse needs of their constituents (Alcantara et al., 2016). Coastal climate adaptation presents a unique challenge to multilevel governance due to the differences in populations, demographics, resources, and climate impacts across government jurisdictions. Effective multilevel governance is crucial for complex decision-making, such as managed retreat, a form of climate adaptation where communities or assets are relocated from high-risk areas to lower-risk ones (Siders, 2019c). Implementing programs like managed retreat necessitates careful coordination among multiple government agencies and their policies (Hino et al., 2017). In the absence of such coordination, multilevel governance may fail to achieve its intended goals and might produce negative, unintended consequences (Siders, 2019a). This study investigates the factors that affect policy coordination across local, state, and federal governments in the context of coastal resilience to climate change.

2.1.2 Novel Contribution

The aim of this study is to present a robust analytical framework that can accommodate changes in state variables, such as alternative locations, domains, boundaries, and stakeholders. This research offers an interdependency analysis of stakeholders and policies involved in coastal climate risk management systems (CCRM) in coastal areas. By utilizing impact analysis, the study identifies the relative influence of stakeholders and relevant policies in terms of their dependency and power over other stakeholders and policies within the coastal climate risk management system.

Although stakeholder analysis makes assumptions about stakeholders' roles and their vulnerability in each system, the impact of these assumptions and their results might be influenced by assessment biases based on political, economic, and societal factors. The methodology of this paper reduces such biases by subjectively assessing each stakeholder and combining impacts along an influence and dependence matrix for a more comprehensive understanding. This approach takes a large, complex, and loosely bound system and quantitatively assesses the interdependence of salient stakeholders, offering valuable insights into multilevel governance dynamics in the context of coastal resilience and climate change adaptation.

2.1.3 Research Questions

As climate risks increase and the need for effective policy grows, adaptable management through strategic public policy becomes more challenging. The complexity of coastal risk management is driven by multiple physical, social, and economic impacts of climate change, further complicated by the denial of climate change by some coastal residents and their elected representatives (Johnson, 2012). This situation exacerbates the challenge of science-based policymaking. With the eastern coastline receding, populations being displaced, natural habitats depleting, and the urgency for effective public policy growing, this research asks: How can coordinated multilevel governance and equitable policy implementation manage or mitigate climate risk for communities based on an understanding of their complex interdependent networks? To address this complex systems question, it is divided into smaller research questions:

- How do policies influence decision-making for coastal climate risk management by relevant stakeholders?
- How do stakeholders influence the policies (formation or execution) on coastal climate adaptation?
- In the presence of networks of stakeholders and policies:
    - Who is dominant in influencing policy and other stakeholders?
    - What policies are driving coastal adaptation planning and multilevel governance?

2.2 Literature Review

2.2.1 Background

The interaction between policy makers and stakeholders is a critical aspect of effective and sustainable policy outcomes. Scholarly research has recognized the importance of such interactions, as demonstrated by the increasing number of studies in this area. This literature review provides an overview of policy and stakeholder interaction analysis in literature, how it has failed in practice, and the methodology inspiration for this chapter.

Scheffran's (2006) study offers an extensive discussion on the tools used to assess and interact with stakeholders in natural resource management (Scheffran, 2006). Another method is a multi-criteria analysis weighting methodology that incorporates stakeholders' preferences into energy and climate policy interactions (Grafakos et al., 2010). Lieu et al. (2018) evaluates the consistency of environmental policy mixes through policy, stakeholder, and contextual interactions (Lieu et al., 2018). Lastly, Keown et al. (2008) emphasizes the importance of stakeholder engagement opportunities in systematic reviews for knowledge transfer to policy and practice (Keown et al., 2008).

These studies collectively emphasize the significance of considering stakeholder perspectives in policy-making processes. Stakeholder engagement can enhance the quality and effectiveness of policies, facilitate their acceptance and implementation, and ultimately lead to more sustainable outcomes. Thus, the findings of this literature review support the need for continued research in this field.

2.2.2 Case Studies of Failed Multilevel Governance Coordination

A study conducting interviews on risk communication for Sweden’s Environmental Protection Agency (EPA) found these critical themes for success and/or failure: organizational planning and decision making, collaboration and responsibility, knowledge and understanding, available resources, the message, public trust, and the media (Boholm, 2019). The study goes on, naming the importance of efficiency and accountability, collaboration with other agencies and stakeholders, and professionalism in public administration. Not only does communication break down between agencies but sometimes within agencies as well. Many of these departments, especially at the federal level, have hundreds of employees and multiple interdepartmental agencies working on CC issues. For example, during Hurricane Dorian in 2019 an incident that has been coined ‘Sharpiegate’ undermined the credibility of the NOAA. The US President at the time drew his forecasting of the hurricane, which was directly at odds with federal reports. When the National Weather Service (NWS) in Birmingham corrected the statement, the National Oceanic and Atmospheric Administration (NOAA) responded by undermining its own scientists at the direction of the White House and Department of Commerce (oversees NOAA agency) political officials (Nick Sobczyk, 2020). The head of the NOAA was at odds with the administration deeming the stunt ‘political’ and a ‘danger to public health and safety’ (Kayla Epstein et al., 2019; Romo, 2019) . In this example the Department of Commerce, which oversees the NWS, and the NOAA had conflicting priorities, though they were within the same administration.

When national support for states and localities fails, the consequences can be profound. During Hurricane Katrina in 2005, the US Army Corps of Engineers (USACE) faced numerous lawsuits over their shipping channel maintenance, which left levees unprotected. Although a US District Court Judge ruled that the USACE was negligent and "shortsighted," an appellate court determined that the evidence did not prove the damage was intentional or foreseeable (Grigg, 2020). Regardless of the legal outcome (which favored the USACE in most cases), the human, economic, and environmental costs of failed multilevel governance during Hurricane Katrina are well documented (Fussell et al., 2010; Menzel, 2006; Vigdor, 2008).

Another case involved plaintiffs alleging that the Federal Emergency Management Agency (FEMA) and the Department of Homeland Security (DHS) violated the Rehabilitation Act (1973), the Fair Housing Act (1968), and the Stafford Act (1988) by denying equitable and meaningful access to persons with disabilities in providing temporary housing assistance after Hurricane Katrina and Hurricane Rita (*Settlement Agreement*, 2006). This complaint was settled for $310,000.

In a 2021 lawsuit, the USACE issued a Nationwide Permit 12 (US Army Corp of Engineers, 2022, p. 12) for oil and gas pipeline projects without properly assessing potential environmental damage. This action violated multiple federal laws, including the Clean Water Act (1972) and the National Environmental Policy Act (1969) (*Complaint for Declaratory and Injunctive Relief*, 2021). This case demonstrates that even within a single level of government, such as the federal level, policy coordination among agencies can be lacking.

2.2.3 Stakeholder and Policy Interdependent Relationships

Feng et al. (2010) demonstrate a method to quantify stakeholder interdependencies using value pathways developed from matrix analysis of values and subject interests. Freeman (2010) discusses the necessity for stakeholder analysis, its theoretical principles and how it can be used for strategic planning purposes (Freeman, 2010). A review of stakeholder analysis methods for natural resource management by Reed et al. (2009) provides a useful framework for selecting government stakeholders in the context of climate change adaptation in Norfolk, Virginia. The study highlights the importance of considering the complex and cyclical nature of the relationship between government stakeholders and public policy, particularly when multiple levels of government are involved. The influence/dependence matrix methodology presented by the authors offers a simplified representation of the bidirectional influence between pairs of stakeholders and/or policies, which can inform the selection of stakeholders for the case study (Reed et al., 2009).

2.3 Methodology

2.3.1 Case Study and Stakeholder Selection

In the context of this study, stakeholders will be limited to government decision-makers who have a direct role in developing and implementing climate change adaptation policies and programs in Norfolk, Virginia. This will include federal, state, and local government agencies and departments responsible for climate change adaptation planning and management.

The selection of government stakeholders will be based on their relevance and influence in climate change adaptation policymaking and implementation in Norfolk, Virginia. This will involve identifying decision-makers who are responsible for developing or implementing policies and programs related to climate change adaptation, as well as those who have direct or indirect influence on these policies and programs. The selection of government stakeholders will also consider their expertise, resources, and willingness to participate in the stakeholder engagement process.

2.3.2 Influence/Dependence Matrix

The state of the system in this study is such that government stakeholders enact laws that define the rules and regulations of our society and governance. The relationship between government stakeholders and public policy or programs is complex and cyclical in nature. Moreover, this complexity is further amplified when considering multiple levels of government, along with inter- and intra-agency policy interactions between federal, state, and local laws. The methodology in this research attempts to simplify these relationships and represent their bidirectional influence between pairs of stakeholders and/or policies through a matrix analysis. Figure 3 represents that bidirectional nature of stakeholders influencing policy which in turn influences stakeholder decision-making.

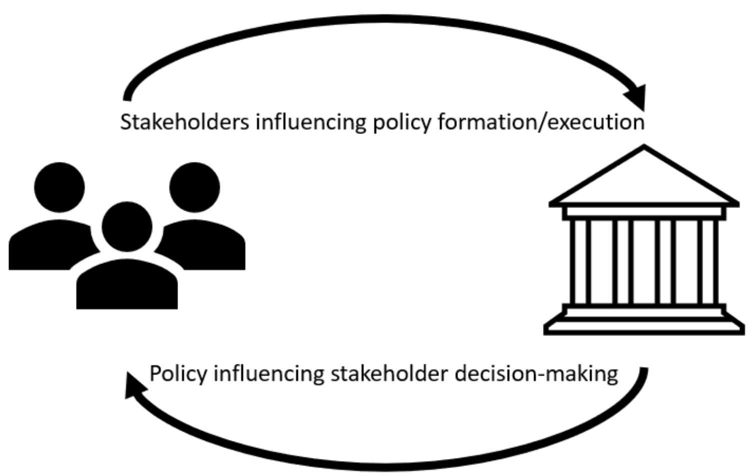

Figure 3: Basic Policy Interaction Analysis - Single Level of Government

Figure 4 represents the conceptualization of the matrix analysis which explores these bidirectional relationships among all stakeholders and policies. Influence being received is interpreted as dependence in this study. Therefore, a powerful stakeholder is one with many influential connections but a low dependence. This design can be a useful tool when assessing and visualizing the role of a stakeholder in a defined network.

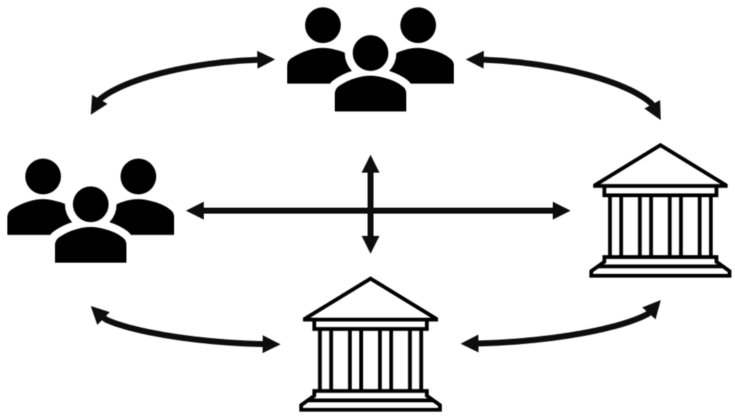

Figure 4: Policy Interaction Analysis – Multiple Levels of Government

The first application of this design was published in the 2018 American Society of Engineering Management Conference proceedings, which studied power dynamics between stakeholders in California's Water Systems (Michel et al., 2018). This study extends the methodology beyond stakeholders to include public policy, while the subject and location of the system have changed to include decision-making in CCRM for Norfolk, Virginia. Table 1 is designed to illuminate the influence of each stakeholder, S, or policy, P, with R representing the relationship among any pair of policies, stakeholders, or between a policy and a stakeholder. The value of the relationship, R, between stakeholders or policies can be categorized into three levels of interaction: no interaction, indirect influence, and direct influence.

Table 1: Influence-Dependence Matrix Design

	$S_{1\ldots}$	S_n	$P_{1\ldots}$	P_n
$S_{1\ldots}$		R_{S1Sn}	R_{S1P1}	R_{S1Pn}
S_n	R_{SnS1}		R_{SnP1}	R_{SnPn}
$P_{1\ldots}$	R_{P1S1}	R_{P1Sn}		R_{P1Pn}
P_n	R_{PnS1}	R_{PnSn}	R_{PnP1}	

No interaction occurs when stakeholders or policies are independent agents and their choices do not affect or influence each other. Indirect influence occurs when one stakeholder or policy does not outwardly direct or interact with another, but their decisions or policies may still indirectly impact them. Direct influence occurs when one stakeholder or policy overtly and directly has power over another, such as through funding, influence, or oversight. It is important to note that direct influence does not necessarily indicate dominance, and the positive or negative nature of the relationship can be further analyzed through surveys or interviews using sentiment analysis. Understanding the levels of interaction and influence can help stakeholders identify potential opportunities for collaboration and potential areas of conflict.

Ideally, the matrix would be filled in by the stakeholders, and each square averaged for the most accurate understanding of the system. Each government agency/public policy is given two scores: the sum of the column is their dependency score, and the sum of the row is the power or influence score. The matrix directionally can change, but it is critical to keep track of the perspective when filling out the matrix. In this case, all rows were filled for each agency/policy regarding its influence.

Before selecting the entities for analysis, it is necessary to state the problem definition and scope. In this case, the problem is the interaction between policies and the management of coastal climate risk across federal, state, and local government, including adaptation and mitigation practices to help communities address the issue of climate change. The scope is a case study of the City of Norfolk, Virginia, and the relevant coastal climate risk management policies promulgated by the United States government, the Commonwealth of Virginia, and the City of Norfolk.

The stakeholders and policies in this case were identified based on previous collaborative work and interviews conducted in 2021 with over 40 federal, state, regional, and local government representatives, academic researchers, and non-governmental organizations (Eghdami et al., 2022). The list of stakeholders and policies was then narrowed down by reviewing and updating relevant information, ensuring that the entities included were directly involved in the scope of this problem (environmental adaptation governance).

The methodology for policies was similar but not comprehensive. As too many policies would make the matrix too unwieldy and more difficult to yield results. The policies selected for this analysis were 1) directly relevant to environmental/climate adaptation and mitigation management policy, 2) currently enacted, and 3) identified as important, either by repeatedly being mentioned in the interviews or directly impacting influential stakeholders' decision-making. The analysis presented in this study captures the state of government functioning as of Fall 2022. As the political landscape changes, so do the priorities of federal, state, and local governments. For example, Virginia's Governor elected in 2021 to serve from 2022 through 2026, deprioritized clean energy (by scaling back the Regional Greenhouse Gas Initiative fund) and climate adaptation efforts at a state level. On the federal level, the US 46th President, Joe Biden, has increased the level of federal participation in climate change policy, awareness, and research. This highlights the dynamic nature of the network of government entities and policies, which change as political systems change.

In conclusion, this research presents an interdependency analysis of stakeholders and policies involved in climate change risk management systems in coastal areas, using the case of Norfolk, Virginia. By incorporating a matrix analysis, the study seeks to simplify the complex relationships between stakeholders and policies, providing a more comprehensive understanding of the system. The methodology outlined in this research can serve as a robust analytical framework for examining other locations, domains, boundaries, and stakeholders, with the ultimate goal of facilitating better coordination and implementation of climate risk management policies across various levels of government.

2.4 Analysis

2.4.1 Informed Stakeholder and Policy Analysis

The first step in this analysis is to research the relationships between each of the agencies and policies. Table 2 represents the policies selected in this study, their function, and their primary stakeholders. Some of the information was gathered from stakeholder interviews, some from expert knowledge of the research, and the rest was from researching policies (in the case of federal law). The levels of regulation are indicated by color type, which will remain consistent throughout this chapter. Each level of governance has a color-blind friendly for the most common type of color blindness, which is red-green color (deuteranopia). The Federal level is hex color #6191c1 (**a blue shade**) policy, the State is hex color #86bda8 (a **greenish-blue shade**), the regional is hex #f5a369 (a light orange shade), and local is hex #d14d4d (a **reddish-brown shade**). This color theme is continued throughout the document. It should be noted for the policies below, there are no regionally identified policies here. That is because even if policy is developed and executed at a regional level, the regional government authority in Virginia planning district commissions do not have the legal ability to pass or enforce legislation. Therefore, all legal action takes place at a state and local level with the support and influence but not regulation of regional government. Furthermore, two studies are executed locally but approved federally due to their regional nature of working between counties. These policies include the Joint Land Use Study (JLUS) and the CCRM Study. These policies cross boundaries between federal and local levels but are designated as local policy since the USACE is located locally but with federal oversight.

Table 2: Policy Interaction Analysis and Connections

Policy	Definition	Direct Connections
Community Rating System (CRS)	The Community Rating System (CRS) is a voluntary incentive program that provides discounts on flood insurance for communities that exceed requirements for coastal adaptation and flood mitigation (FEMA, 2022b).	➢ FEMA Initiative ➢ City Manager Coordinates ➢ The Chief Resilience Officer (CRO) and Planning Department try to improve rating. ➢ Green Infrastructure plan helps improve status
Inflation Reduction Act	The Inflation Reduction Act is a recent legislative initiative that will combat the climate crisis, reduce the deficit, and raise taxes for the wealthy (House, 2022).	➢ Funds FEMA, NOAA, EPA, & Housing and Urban Development (HUD) ➢ Written by Executive & Legislative Branch ➢ Funds Virginia Department of Transportation (VDOT) initiatives ➢ Funds local projects for the city managers, CROs, and planning departments

DOD Climate Action Plan (CAP)	DOD's CAP was approved and signed last year and lays out how operations, planning activities, business processes, and resource allocation decisions will include climate change considerations (U.S. Department of Defense, 2021).	➢ Executive Branch Approved (Council on Environmental Quality) ➢ Department of Defense (DOD) Created the Document ➢ USACE helps execute the plan. ➢ JLUS includes military bases – no one can "opt out"
Infrastructure Bill	The Infrastructure Law will rebuild America's roads, bridges, and rails, expand access to clean drinking water, tackle the climate crisis, advance environmental justice, and invest in communities that have too often been left behind (The White House, 2022).	➢ Funds EPA, Federal Highway Administration (FWHA) ➢ VDOT helps execute on a state level. ➢ The planning department works with VDOT to plan locally. ➢ Funds local initiatives like the Green Infrastructure Plan
Virginia Clean Economy Act (VCEA	VCEA establishes a schedule by which Dominion Energy Virginia and American Electric Power are required to switch to clean energy. It was passed by the general assembly and effects private energy companies (Richard C. Sullivan Jr. et al., 2020).	➢ The Governor and General Assembly enforce this plan. ➢ The RGGI is a method to gradually work towards this goal
The Regional Greenhouse Gas Initiative (RGGI)	RGGI is a market-based effort among Eastern states to cap and reduce CO2 emissions from the power sector. It represents the first cap-and-invest regional initiative implemented in the United States. The profits go to low-income communities for flood mitigation and housing projects (The Regional Greenhouse Gas Initiative, 2021).	➢ The Governor and General Assembly enforce this plan. ➢ The Virginia Clean Economy Act motivates joining this initiative. ➢ The regional planning departments help localities apply to RGGI funds. ➢ The City Manager, CRO, Planning Department, and Housing Department work together to apply for funded programs in low-income communities
Community Flood Preparedness (CFPF)	CFPF was established to provide support for regions and localities across Virginia to reduce the impacts of flooding (Department of Conservation and Recreation, 2022).	➢ Codified by the General Assembly ➢ Virginia Department of Emergency Management (VDEM) helps execute plans. ➢ The Mayor, City Council, City Manager, and CRO use the support to plan. ➢ A part of the short-term plan Norfolk 2030 in preparing for community floods, also Green Infrastructure plan aids in mitigation efforts

Coastal Resilience Master Plan (CRMP)	The CRMP was a highly collaborated document that plans for future flooding of coastal Virginia, giving project ideas and adaptation steps to mitigate flooding. It also notes areas of weakness that may need reinforcement later (*Virginia Coastal Resilience Master Plan Phase 1*, 2021)	➢ The general assembly approved this work. ➢ Department of Conservation and Recreation (DCR), Secretary of Natural Resources, VDEM, VDOT, Department of Environmental Quality (DEQ), Housing and Development, are just some of the state level contributors. ➢ Local City Mangers, CROs, City Council members participates in the planning
Chesapeake Bay Preservation Act	The purpose of the Bay Act program is to protect and improve water quality in the Chesapeake Bay by requiring the implementation of effective land use management practices (Virginia Department of Environmental Quality, n.d.).	➢ EPA helps regulate. ➢ DEQ enforces. ➢ Codified by the General Assembly ➢ Long term policies like Vision 2100 and zoning & land planning are impacted by the regulations of this law
Joint Land Use Study	Joint Land Use Studies (JLUS) are planning processes among localities, states, and military installations to encourage local governments to work closely with the military installations to preserve and protect the public health, safety, and welfare of those living near an active military installation (*Joint Land Use Studies*, n.d.).	➢ USACE executes these studies. ➢ Hampton Roads Planning District Commission (HRPDC) works with VDOT, DCR, and the local City manager, CRO, & planning department to complete the assessment. ➢ Impacts policies like the coastal risk management study and zoning and land use planning.
Plan Norfolk 2030	Norfolk's General Plan, plaNorfolk2030, adopted by Norfolk City Council on March 26, 2013, is used to guide decision-making about physical development and public infrastructure. It is intended to be sufficiently flexible to respond to changes in development patterns and contains the broad outlines neighborhoods will use to guide and plot their path to the future (Fraim et al., 2022).	➢ The City Manager, CRO, City Council, Mayor, Planning Department, Housing Department are all locally involved or impacted by this short-term community planning. ➢ Other plans like Vision 2100, zone and land planning, green infrastructure planning is all impacted by the plaNorfolk2030. ➢ Resilience money helps fund relevant projects.
Vision 2100	By working with residents, the City of Norfolk is building a long-term strategy to address the flooding challenges due to sea level rise (*Opportunity. Collaboration. Vision*, 2016)	➢ The City Manager, CRO, housing department, and the planning department all worked on this document. ➢ Impacts short term planning and green infrastructure investments.

Zoning and Land Planning	City Planning is responsible for developing and implementing short and long-range plans, goals, and policies, as developed with the community, and approved by the City Council, that reflect the needs and interests of residents and the city (City of Norfolk, n.d.).	➢ Approved by City Council ➢ City Planning develops these plans. ➢ The State department of housing and local housing community development has to plan within these guidelines. ➢ Impacts City manager and CRO as community planners. ➢ Has short- and long-term impacts on policies like plaNorfolk 2030, Vision 2100, green infrastructure plan, joint land use study
Coastal Storm Risk Management Study	As a result of Hurricane Sandy in October 2012, Congress passed P.L. 113-2, a portion of which directed actions for USACE to take, including preparation of two interim reports to Congress, a project-performance evaluation report and comprehensive study to address the flood risks of vulnerable coastal populations in areas affected by Hurricane Sandy within the boundaries of North Atlantic Division, U.S. Army Corps of Engineers (US Army Corp of Engineers, 2018).	➢ The Congress takes updates from the USACE. ➢ Locally impacts the Planning department, City manager, and CRO as consultants and planning agents. ➢ Direct influence in state coastal resilience plan for risk evidence ➢ Plan Norfolk 2030, Vision 2100, Zoning and Land Planning, and Green Infrastructure Plan all are impacted by the risk assessment results in their planning efforts
Green Infrastructure Plan	The Green Infrastructure Plan provides more detailed guidance on the City's "green" infrastructure: the marshes, creeks, parks and trees that provide habitat, filter the air and water, moderate air temperatures, and provide recreation and scenic beauty (Green Infrastructure Center Inc., 2018).	➢ State level agencies such as DCR give input and DEQ give approval for projects. ➢ Resilience Penny (property tax in Norfolk) funds projects ➢ Plans influence the choices of City Manager, CRO, planning department. ➢ Impacts short- and long-term Norfolk planning (plan Norfolk 2030, Vision 2100, zoning & land planning)
Resilience Penny	Norfolk adopted a property tax increase of $.01 per $100 assessed value for resilience efforts—it is called "the resilience penny." The tax generates about $1.8 million a year (Plastrik et al., 2019).	➢ The city council approves tax changes. ➢ The planning department, CRO, and city manager use these funds for projects. ➢ Housing and Development uses these funds for Ohio creek project to supplement funds from HUD. ➢ Helps execute Green Infrastructure plans.

In this case study there were twenty-four stakeholders: eight from federal government, eight from state government, one from regional government, and seven from local government. There were sixteen policies: four at the federal level, five at the state level, and seven at the local level. Table 3 shows the outcome of the matrix which totaled in 1560 relationships.

$$(40 \ stakeholders \ and \ policies \ )^2 - 40 \ for \ invalid \ connections = 1560 \ relationships$$

Table 3: Policy-Stakeholder Interaction Influence and Dependence Matrix

		01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
01	US Army Corp of Engineers		1	1	1	1	1	0	0	1	1	0	0	2	1	2	0	2	1	1	1	1	1	1	0	1	2	1	1	0	0	2	1	1	2	1	1	0	2	0	0
02	Federal Emergency Management Agency	2		1	1	1	1	1	0	2	1	1	1	2	0	1	1	1	1	1	2	2	1	1	1	2	0	1	0	0	0	2	1	1	1	2	1	2	2	0	0
03	National Oceanic and Atmospheric Administration	1	1		1	0	2	0	0	1	0	1	1	2	0	2	1	0	1	0	0	1	1	1	1	0	0	1	0	0	0	1	1	0	0	1	1	0	2	1	0
04	Environmental Protection Agency	2	2	2		1	1	0	0	0	0	1	1	1	0	0	2	0	1	0	1	1	1	1	1	1	2	1	1	2	1	1	1	2	0	1	1	1	1	1	1
05	Department of Housing and Urban Development	0	0	0	0		0	0	0	0	0	0	0	0	2	0	0	1	0	0	1	1	2	1	0	0	0	0	1	0	0	0	1	0	0	1	1	1	0	1	0
06	Federal Highway Administration	1	1	0	1	0		0	0	0	0	0	0	0	1	2	0	1	0	0	1	1	0	2	1	0	1	0	1	0	0	1	1	0	1	1	1	2	0	1	0
07	Council on Environmental Quality	1	2	2	2	2	2		2	2	2	1	1	1	0	1	1	0	1	1	1	1	1	1	1	1	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0
08	Congress	1	2	2	2	2	2	2		2	2	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	2	1	2	0	0	0	0	0	0	0	0	0	0	0	0
09	Governor	1	1	0	0	0	1	1	1		2	2	2	1	2	1	1	1	2	1	1	1	1	1	1	0	0	0	0	1	1	0	2	1	0	0	0	0	0	0	0
10	General Assembly	1	1	0	1	0	0	1	1	2		1	1	2	2	2	2	2	2	2	1	1	1	1	1	1	0	0	0	2	2	2	2	2	1	1	1	1	0	0	0
11	Secretary of Natural Resources	0	0	0	0	0	0	0	0	1	1		2	0	0	0	1	1	1	1	1	1	0	1	1	0	0	0	0	1	0	0	2	2	1	0	0	1	0	1	0
12	Department of Conservation and Recreation	0	0	0	1	0	0	0	0	1	1	2		0	0	1	2	1	0	0	1	1	1	1	1	0	0	0	0	0	0	0	2	2	2	1	1	1	0	1	0
13	Virginia Department of Emergency Management	1	2	0	0	0	2	0	0	2	1	0	0		0	1	0	0	2	0	1	0	0	0	0	0	0	0	0	0	0	2	1	0	0	0	0	0	1	0	0
14	Department of Housing and Community Developm	1	1	0	0	2	0	0	0	1	1	0	0	0		1	0	1	0	1	1	1	2	2	0	1	1	0	0	0	0	1	1	0	0	1	1	2	0	2	1
15	Virginia Department of Transportation	1	1	0	1	1	2	0	0	1	1	0	1	1	1		0	1	1	1	1	1	1	1	0	0	1	1	2	1	0	2	1	0	1	1	1	1	1	1	0
16	Department of Environmental Quality	1	0	0	0	0	0	0	0	0	0	2	2	0	1	0		0	0	0	2	2	1	2	2	0	0	0	0	0	0	0	1	2	0	0	0	2	0	2	0
17	Hampton Roads Planning District Commissions	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0		1	1	1	1	1	1	1	0	0	0	0	0	0	1	2	1	1	1	1	1	0	0	0
18	Mayor	1	1	0	0	0	0	0	0	1	1	0	1	1	1	1	0	2		2	1	1	1	1	1	0	1	0	0	1	1	1	0	0	1	1	1	1	0	1	1
19	City Council	1	0	0	0	0	1	0	0	1	1	0	1	1	1	1	0	1	1		2	1	2	2	2	0	0	0	0	0	0	1	1	1	1	1	1	2	0	2	2
20	City Manager	1	1	0	0	0	1	0	0	0	1	1	1	1	1	1	0	2	0	1		2	2	2	2	1	0	0	0	0	0	1	1	1	1	2	2	2	0	2	2
21	Chief Resilience Officer	1	1	0	0	0	0	0	0	0	1	1	1	0	1	1	0	1	0	1	1		1	1	1	1	0	0	0	0	0	1	2	0	1	1	1	0	2	1	2
22	Norfolk Housing and Redevelopment Authority	0	0	0	0	1	1	0	0	0	0	0	0	0	2	1	0	1	0	0	2	1		2	2	0	0	0	0	0	0	0	0	0	1	1	1	1	0	1	2
23	Department of City Planning	1	1	0	0	1	1	0	0	0	0	0	1	1	1	1	0	2	1	1	2	2	2		2	1	0	0	0	0	0	1	1	0	1	2	2	2	1	2	2
24	Public Works	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	2	1	2	2		0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1
25	Community Rating System	1	2	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	1	2	2	1	2	1		1	0	0	0	0	1	0	0	0	1	0	1	1	2	1
26	Inflation Reduction Act	1	2	2	2	2	1	2	2	1	1	1	1	0	1	2	0	1	1	1	2	2	1	2	0	1		0	1	2	0	1	0	0	0	0	1	0	0	1	0
27	DOD Climate Action Plan	2	0	0	1	0	1	2	1	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0		1	1	0	1	0	0	2	0	0	0	0	1	0
28	Infrastructure Investment and Jobs Act	1	1	0	2	1	2	2	2	1	1	1	2	1	1	2	0	1	1	1	1	1	1	2	1	0	1	1		1	0	1	0	0	0	1	1	0	0	2	0
29	Virginia Clean Economy Act	0	0	0	1	0	0	0	0	2	2	0	0	0	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0		1	0	0	0	0	0	1	0	0	0	0
30	Regional Greenhouse Gas Initiative	0	0	0	1	0	0	0	0	2	2	1	1	0	1	0	0	2	1	1	2	2	2	2	0	0	0	0	0	2		0	0	0	0	1	1	0	0	0	0
31	Virginia Community Flood Preparedness Fund	1	1	0	0	0	2	0	0	2	0	0	1	2	0	1	0	1	2	2	2	2	1	1	1	0	0	0	0	0	0		1	0	1	1	1	1	1	1	1
32	Coastal Resilience Master Plan	1	0	0	0	0	0	0	0	1	2	2	2	2	2	2	2	1	1	1	2	2	1	1	1	0	0	0	0	1	0	1		0	1	1	1	1	1	2	1
33	Chesapeake Bay Preservation Act	0	0	0	2	0	1	0	0	1	2	1	1	0	1	1	2	1	1	1	1	1	1	1	1	0	0	0	0	1	0	0	1		1	1	2	2	1	1	0
34	Joint Land Use Study	2	0	0	0	0	1	0	0	0	1	1	2	0	1	2	0	2	1	1	2	2	1	2	0	0	0	0	1	1	0	1	1	0		1	1	2	2	1	0
35	Plan Norfolk 2030	0	0	0	0	0	0	0	0	0	0	1	1	0	1	0	0	1	2	2	2	2	2	2	1	0	0	0	0	0	0	0	1	0	1		2	2	1	2	2
36	Vision 2100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	2	2	2	2	0	0	0	0	0	0	0	0	0	0	0	2		1	0	2	1
37	Zoning and Land Planning	1	0	0	0	1	1	0	0	0	0	1	1	0	2	1	0	1	1	1	2	2	2	2	1	1	0	0	0	1	0	0	1	1	2	2	2		1	2	1
38	Coastal Storm Risk Management Sudy	2	1	0	0	0	0	0	0	1	1	1	1	1	1	1	0	1	1	1	2	2	1	2	1	0	1	0	0	1	0	1	2	0	1	2	2	2		2	2
39	Green Infrastructure Plan	1	0	0	0	1	0	0	0	0	0	1	1	0	1	1	0	1	1	1	2	2	1	2	1	1	0	0	1	1	0	0	1	0	1	2	2	2	1		1
40	Resilience Penny	1	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	1	1	2	2	2	2	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	2	

Each box was entered with zero for no influence, one for indirect influence, and two for direct influence. Demonstrations of how the connections were justified are shown in examples 1 and 2.

Invalid connections are the diagonal terms in the matric, which represent interaction between a stakeholder or policy and itself. Those are not included in the matrix and can either be represented by zero or just shaded out. Below are two examples of the reasoning that took place to fill out the matrix.

Example 1: The Inflation Reduction Act directly influences (+2) FEMA and EPA by providing direct funding for their coastal adaptation planning efforts. The RGGI indirectly influences (+1) the Governor, as they cannot legally remove the policy but can influence the general assembly to reform it. For example, RGGI can provide data and analysis demonstrating the positive impacts of the policy on the state's economy and environment.

Example 2. NOAA indirectly influences (+1) VDEM by providing weather forecasts that inform VDEM's decision-making process. For instance, NOAA's storm warnings and predictions help VDEM prepare for natural disasters and allocate resources accordingly. The Chesapeake Bay Preservation Act directly influences (+2) land-use policies and practices within the Chesapeake Bay watershed by establishing a framework for preserving and protecting the Bay's natural resources. The Infrastructure Bill directly influences (+2) the Green Infrastructure Plan by providing funding for projects within that plan and establishing guidelines for allocating resources to support green infrastructure initiatives.

Effective policy implementation requires understanding and leveraging the indirect and direct relationships between stakeholders and policies, as demonstrated through the use of a relationship matrix. This matrix becomes more meaningful as iterations are continued and stakeholders are brought in to define relationships and fill it out to better reflect the interactions taking place.

2.4.2 Influence and Dependence Graphs

Multilevel Government Stakeholders

After several iterations of reviewing the matrix, the results are reviewed below. Figure 1Figure 5 is broken down into four quadrants based on the degree of influence and dependency. In each of these roles there is a stakeholder highlighted in red. The respective roles of these stakeholders are broken into four quadrants and then labeled to reflect the corresponding influence or dependence in relation to other stakeholders. “Stakeholder” in this case regards persons that engage in coastal adaptation policymaking and does not include Indigenous rights holders and their corresponding representatives. The **dependent** stakeholder is one with relatively low influence in comparison to their received influence from other agencies. The **independent** stakeholder is one with both low influence and does not rely heavily on the decision-making of others. The **facilitating** stakeholder has both high influence and dependence. These stakeholders are at the core of coastal climate risk management and would be considered leaders or hinderers depending on their actions, but not a neutral party. The **dominant** stakeholders are those who do not need to report to other agencies' influence and are independent but powerful.

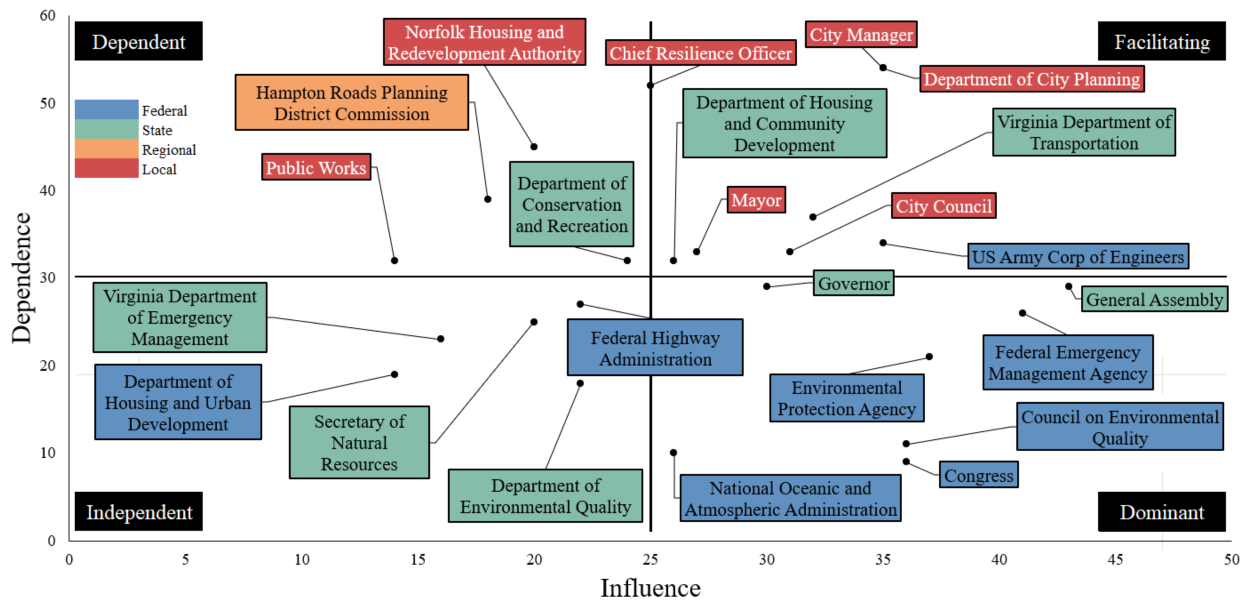

Figure 5: The Stakeholder Interaction Map by Power/Influence and Dependence for Federal, State, Regional, and Local Government regarding Coastal Climate Risk Management

The Hampton Roads Planning District Commission (HRPDC) is a dependent stakeholder in this system which is in accordance with the interview research. Although HRPDC has significant regional and local influence, their ability to create policy is limited. The planning district commissions aid local governments in increasing their resiliency and coordinating with each other but are subject to the voluntary participation of the locality. The Public Works department and Norfolk Department of Housing and Community Development (DHCD) are also in this quadrant due to their lack of policymaking ability and strong dependence on the adaptation work of facilitators and more dominant stakeholders.

DEQ, an independent stakeholder, is a state level department that issues permit and regulates pollutants and waste disposal. Their role is administrative and although agencies require their permission it does not have significant policy influence. The DEQ enforces the policy set forth by the EPA or General Assembly but does not create policy within itself. The independent category in this case is more a reflection of the role those stakeholders take in coastal adaptation policymaking. VDEM, DEQ, FHA are all regulatory agencies that enforce policy and may take an important role in projects but are not leaders in coastal adaptation policymaking.

The Norfolk City Manager is a facilitating stakeholder along with the city council and the Mayor; however, the position of the city manager is elevated in independence and dependence relative to the others. This is because the city council hires the city manager and has the power to terminate their employment. Both the mayor and city council are elected and therefore if residents were included in the study these positions would be closer to the city manager because the voters could terminate their employment with either a recall motion or by choosing a different representative at the next election. But the role of the city manager is significant and acts almost as a proxy to implement the agenda of elected officials. The city manager along with the planning department oversee the vision of the community, their decisions are directly shaping the future of Norfolk.

Not surprisingly, a lot of federal agencies and policymakers, such as the general assembly (GA) and governor are dominant stakeholders. The hierarchy of government in the US makes federal law the most influential followed by state and local law. This influence does not work in reverse, so that local law has limited influence over state law, which in term has limited influence over federal law. None of the local level stakeholders fell into this category. It may also be a reflection of the Dillon Rule which effectively limits the ability of local stakeholders to shape policymaking in their state, as they must work within the confines of the powers explicitly granted to their local government by the state government (Russell & Bostrom, 2016).

Multilevel Policy Graph

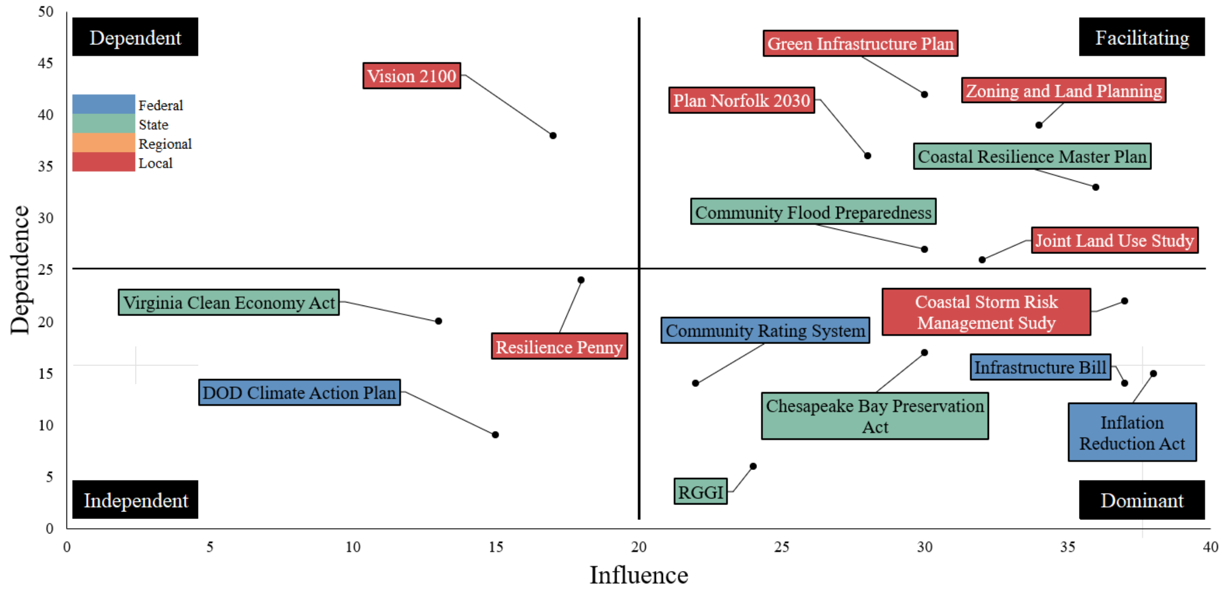

Figure 6 is the same graph but instead shows the display of policies against the same scale. The quadrants here are relabeled to apply to policies rather than people. The **conditional** quadrant is highly dependent on other people and policies. Vision 2100 for example is Norfolk's local plan that looks ahead to 2100, which will change based on the adaptation plans executed today. The **collaborate** section are policies that receive and give influence, they have many collaborators or are dependent on the policies in this study. For example, the state's Coastal Resilience Master Plan was a huge collaborative effort from federal, state, regional, and local stakeholders. It was even more influenced by actors not included in this study such as academic institutions and non-governmental organizations. It is also highly influential as the state's first comprehensive coastal resilience plan. The **leading** quadrant contains policies that either fund, regulate, or plan in a highly influential way. For example, two recent pieces of federal legislation will fund multiple federal agencies to study climate risk and give grants for local resilience projects. The last category remains labeled as **independent** since these policies are less influenced by the stakeholders in this study. However, it should be noted that the Virginia Clean Economy Act and RGGI would both be pushed to the leading or collaborative quadrant if private industry stakeholders such as energy companies were included in the analysis. It is important to remember that this is all relative to the entities and policies chosen for analysis. As an example of influencing government, the RGGI policy does provide funds for low-income communities to build their resiliency. The planning district commissions, and local governments work together to apply for those funds to support their proposed projects.

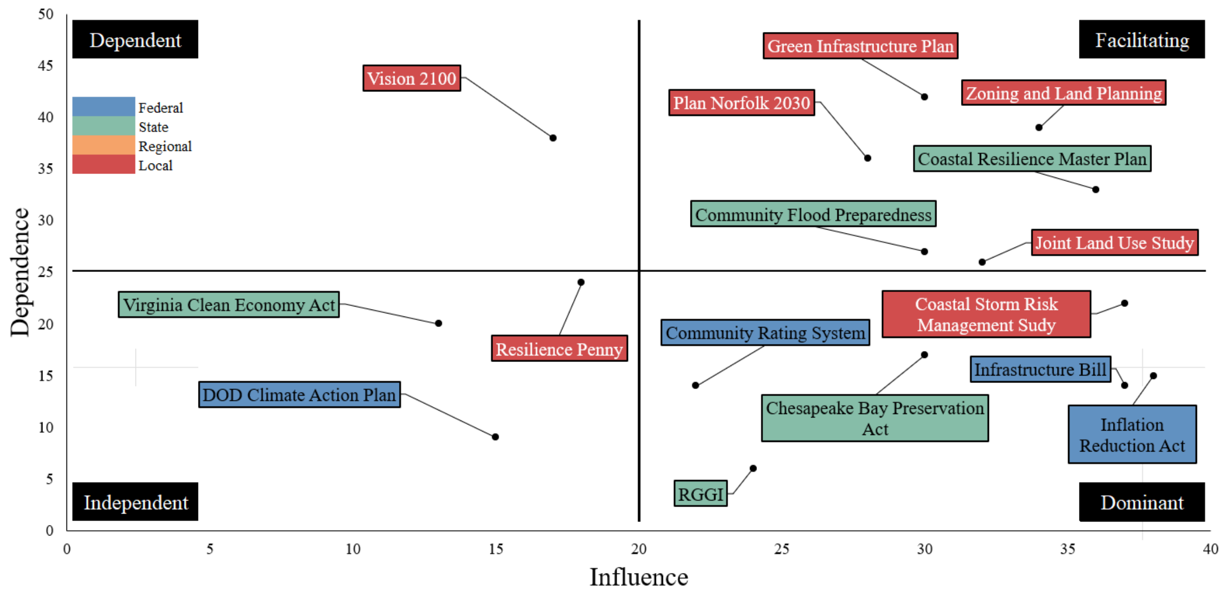

Figure 6: The Policy Interaction Map by Power/Influence and Dependence for Federal, State, Regional, and Local Government regarding Coastal Climate Risk Management

Comparisons at a Local Level

A unique flexibility of the influence and dependence matrix design is that the user can extract those policies or people that are relevant to a localized application. For example, Table 4 demonstrates this method where only Norfolk's local stakeholders and policies are shown. This recalibrated the summation of rows and columns therefore reaching a different result entirely.

This method can be a useful tool to breakdown relationships and know who the major actors in localized policymaking are. It also can expose an unequal distribution of power in the choices available to dependent stakeholders in CCRM. This method can be scaled globally or applied to a variety of climate and resource management issues. Researchers can also expand or narrow the boundaries of the problem or modify the scale to manage more quantifiable relationships such as flow of money.

Table 4: Influence Dependence Matrix of Local Stakeholders and Policies

		18	19	20	21	22	23	24	34	35	36	37	38	39	40	
18	**Mayor**		2	1	1	1	1	1	1	1	1	1	0	1	1	13
19	**City Council**	1		2	1	2	2	2	1	1	1	2	0	2	2	19
20	**City Manager**	0	1		2	2	2	2	1	2	2	2	0	2	2	20
21	**Chief Resilience Officer**	0	1	1		1	1	1	1	1	1	0	2	1	2	13
22	**Norfolk Housing and Redevelopment Authority**	0	0	2	1		2	2	1	1	1	1	0	1	2	14
23	**Department of City Planning**	1	1	2	2	2		2	1	2	2	2	1	2	2	22
24	**Public Works**	0	0	2	1	2	2		0	0	1	1	1	1	1	12
34	**Joint Land Use Study**	1	1	2	2	1	2	0		1	1	2	2	1	0	16
35	**Plan Norfolk 2030**	2	2	2	2	2	2	1	1		2	2	1	2	2	23
36	**Vision 2100**	1	1	2	2	2	2	0	0	2		1	0	2	1	16
37	**Zoning and Land Planning**	1	1	2	2	2	2	1	2	2	2		1	2	1	21
38	**Coastal Storm Risk Management Sudy**	1	1	2	2	1	2	1	1	2	2	2		2	2	21
39	**Green Infrastructure Plan**	1	1	2	2	1	2	1	1	2	2	2	1		1	19
40	**Resilience Penny**	1	1	2	2	2	2	0	0	1	1	1	0	2		15
	Dependence	10	13	24	22	21	24	14	11	18	19	19	9	21	19	

The Sankey diagram in Figure 7 offers a cohesive visualization of the connections between local government stakeholders and local public policies and programs in the context of coastal climate risk management. By focusing on local governance and removing federal, state, and regional stakeholders and policies from the influence-dependence matrix, we can analyze the complex interconnections between local stakeholders and policies.

In this analysis, the Planning Department, City Manager, and Chief Resilience Officer emerge as the most influential at the local level due to their significant control over coastal adaptation planning and risk management. The Planning Department receives substantial influence from the Mayor, City Council, City Manager, and other community leaders.

Each stakeholder in the Sankey diagram is a shade of blue while the policies are shade of green. This is apart from the Coastal Storm Risk Management Study influence to highlight it for analysis. Direct influence (2) is represented by a line twice as thick as an indirect influence connection (1). The diagram also displays the given influence (power) of each stakeholder and policy on the left, while the right side represents the received influence (dependence) on each stakeholder and policy.

By narrowing the scope to local governance, the Sankey diagram reveals a balance between most stakeholders and policies in terms of given and received influence. A notable exception is the Coastal Storm Risk Management Study, which has more influence than dependence due to its impact on other planning policies and guidance for the city's resiliency efforts. Another interesting observation is the difference between the Mayor and City Manager, highlighting the City Manager's crucial role in decision-making despite being appointed rather than elected. The City Planner stands out for having significant influence and dependence as they are at the center of resilience planning in the city.

The Sankey diagram demonstrates the flexibility and meaningful insights provided by the influence-dependence matrix when focusing on specific aspects, such as local governance in this case. This allows for a clearer understanding of the intricate relationships between stakeholders and policies even at a localized level.

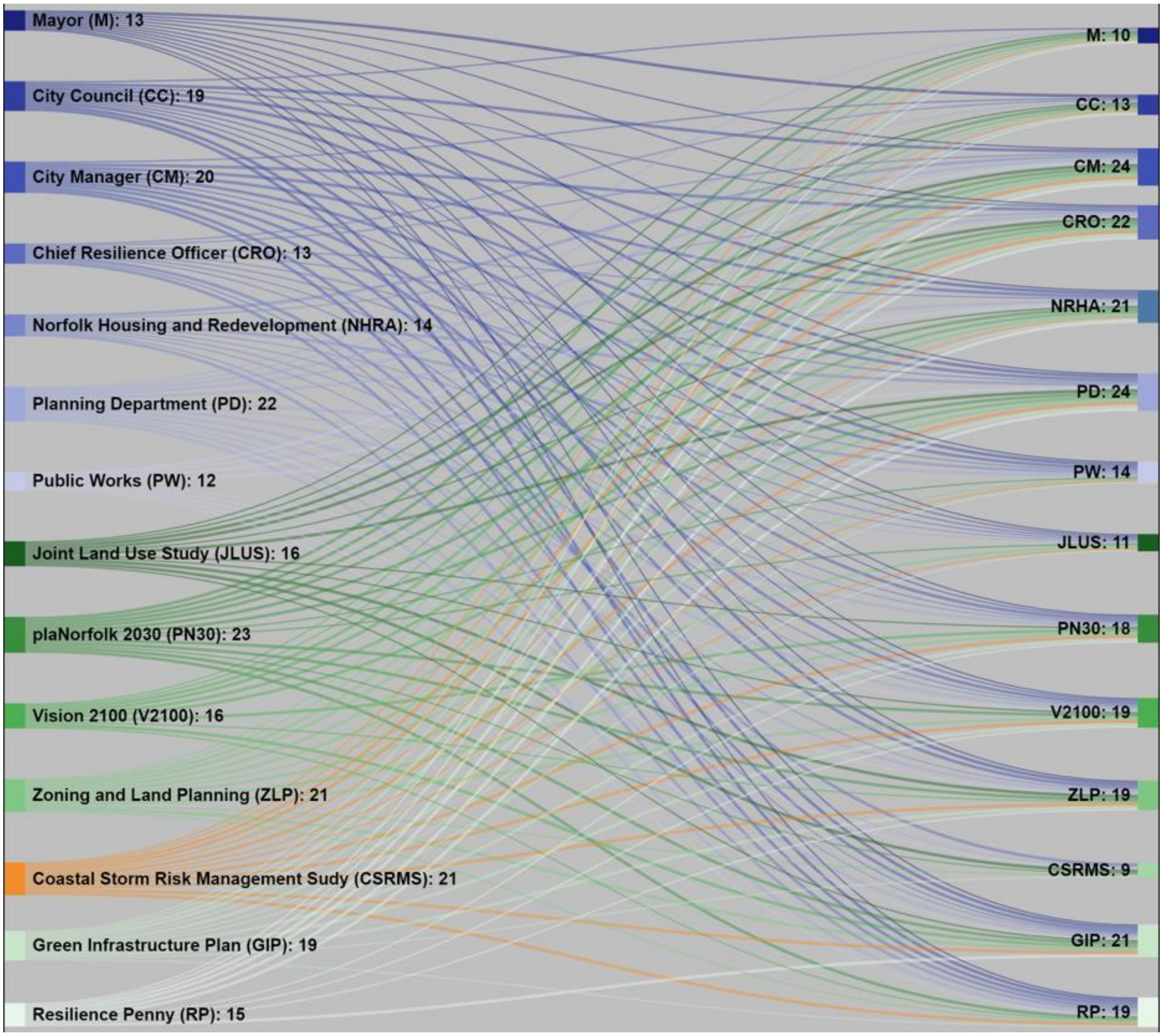

Figure 7: A Sankey Diagram of Local Stakeholders and Policies and their respective given (right) and received (left) influence.

2.5 Discussion and Concluding Remarks

The matrix analysis offers valuable insights into the relationships between stakeholders and policies in coastal climate risk management. It reveals that the most influential stakeholders in the network are federal and state agencies such as FEMA, EPA, NOAA, VDEM, and DEQ. These agencies maintain direct and indirect connections with numerous policies, highlighting their essential role in the implementation and enforcement of coastal climate risk management.

Moreover, the analysis identifies the most influential policies as the Infrastructure Bill, the Regional Greenhouse Gas Initiative (RGGI), and the Chesapeake Bay Preservation Act. These policies directly impact various stakeholders across different levels of government and serve as crucial drivers for climate change adaptation and mitigation efforts.

Local stakeholders, including the City Manager, Chief Resilience Officers, and Planning Departments, play a critical role in coordinating and implementing the various policies and initiatives within their jurisdiction. They serve as a bridge between federal and state policies and local community needs. Cross-boundary policies, such as the Joint Land Use Study and the Coastal Climate Risk Management Study, demonstrate the need for collaboration between different levels of government to address the complex challenges posed by climate change.

However, the study also acknowledges limitations, such as the simplification of complex relationships and its snapshot nature. The matrix analysis is a simplification of a complex network of relationships between stakeholders and policies, and it does not capture the full range of connections and interactions between these actors. The analysis is based on a snapshot in time (Fall 2022), and the relationships between stakeholders and policies may evolve over time as political priorities and policy landscapes shift.

Future research should focus on refining the matrix analysis methodology to capture more nuanced relationships between stakeholders and policies. Additionally, longitudinal studies should be conducted to assess how the network of relationships evolves over time in response to changing political and environmental conditions.

3. An Assessment of How Stakeholders Incorporate Social Inequity into Coastal Climate Resilience Planning

3.1 Introduction

Coastal areas face a growing risk from climate-driven sea level rise, which can result in permanent land submergence, severe storm surges and pluvial flooding, coastal erosion, and salinization of soils and groundwater (Begum et al., 2022). These impacts can have serious economic and health implications, with disadvantaged communities being disproportionately affected. Specifically, low-income and marginalized communities are disproportionately impacted due to their limited access to resources and infrastructure, higher exposure to environmental hazards, and greater social vulnerability (Cappelli et al., 2021). As such, including social equity in coastal climate adaptation planning efforts is crucial to increasing community resilience (Amorim-Maia et al., 2022; Morrow, 2008).

Despite the importance of social equity in adaptation planning, it is not yet clear how this issue is being incorporated into practice. This research aims to address this gap by examining how social equity is incorporated into urban, coastal adaptation planning efforts, using the case study of Norfolk, Virginia. Specifically, this study will focus on how stakeholders in Norfolk define and measure social equity and identify disadvantaged populations. The following research questions will guide the analysis: 1) how is social equity defined by stakeholders in terms of social vulnerability in coastal climate risk adaptation? 2) how do stakeholders incorporate social inequities into their project, program, or organization objectives? and 3) how does the context of social equity in coastal climate adaptation change for recurring flooding, severe storm events, and excessive heat By addressing these questions, this research contributes to the understanding of how social equity is incorporated into coastal adaptation planning efforts, using the case study of Norfolk, Virginia. Additionally, by identifying best practices for addressing social inequities, this research aims to inform future coastal adaptation planning efforts and increase community resilience to the impacts of sea level rise.

This paper is organized as follows. First, we provide a brief literature review of the current state of knowledge on social equity in coastal climate adaptation planning and identify key research gaps and priorities for future research. We then describe the methodology we used to conduct the study outlining the research design, interviews with stakeholders, and an analysis of their responses. Then, in the results section, findings from the stakeholder interviews are provided and current methods and practices for addressing social inequities in coastal adaptation planning are identified. Finally, the discussion and conclusion sections provide an analysis of the findings and discuss the implications for future research and policy development. To provide context for the study, the literature review explores the impacts of social inequities on coastal adaptation planning efforts and identifies different strategies for adapting to the risks of sea level rise. However, these strategies have tradeoffs for their effectiveness in reducing risk: the cost of implementation and the resulting social impact.

3.2 Literature Review

A wide range of different adaptation measures are typically considered in planning for coastal climate adaptation sea level rise (Siders, 2019b). Preventative adaptation measures include grey infrastructure, such as sea walls and dams, and green infrastructure, which uses methods like wetlands and marshes to create a buffer (Lee, 2014). Some examples of smaller scale adaptation strategies include raising homes, drainage, and alarm systems to focus on human systems rather than the environmental (Nicholls, 2011). Managed retreat is another adaptation strategy that relocates people to higher ground or further inland through political strategies such as a buyout program in areas that are high risk for recurring flooding events (Hino et al., 2017). While social equity has increasingly become an important component in assessing the effectiveness of adaptation strategies, there can be significant tradeoffs, and the differential impacts of these strategies on different communities are not well understood (Amorim-Maia et al., 2022; Araos et al., 2021).

The impact on social equity in adaptation planning is in part dependent on how stakeholders define and measure social vulnerability and identify disadvantaged populations (Swanson, 2021).

However, despite recent efforts by government agencies to hire diversity, equity, and inclusion officers and develop relevant indices, achieving a shared definition of social equity remains challenging, especially in the context of coastal adaptation planning, where vulnerabilities vary across communities and no standardized metrics exist to assess vulnerability. Therefore, this literature review aims to examine how stakeholders are defining social equity in coastal climate adaptation planning and the need for localized case studies to address unique challenges and opportunities for promoting social equity in different coastal communities.

Equity has been characterized in two elements: horizontal and vertical categories (Karakoc et al., 2020). Horizontal equity is when an individual or group has their needs met through access to the same resources as other communities (Joseph et al., 2016). Vertical equity is when an individual or group has their needs met by varying amounts of resources proportional to their needs and vulnerabilities. The National Academy of Public Administration defines social equity as, “the fair, just and equitable management of all institutions serving the public directly or by contract; and the fair and equitable distribution of public services, and implementation of public policy; and the commitment to promote fairness, justice, and equity in the formation of public policy” (Wooldridge & Bilharz, 2017).

One approach to defining social equity is through the use of vulnerability assessments, which identify populations that are at risk of being disproportionately impacted by climate change (Adger et al., 2004). Many studies have identified the need to consider social vulnerability, or the susceptibility of different groups to harm from climate impacts, in adaptation planning (Barnett et al., 2008; Cutter et al., 2003). For example, in a study of the Gulf Coast region, researchers used vulnerability assessments to identify vulnerable populations and developed strategies for enhancing social equity in climate adaptation planning (Brody et al., 2008). Some researchers have proposed using specific indicators, such as income, race, or access to healthcare, to measure social vulnerability (Fussell et al., 2010).

Due to the differential impacts that climate change risks have on different communities, there has been a call for more inclusive and equitable approaches to coastal resilience planning and project implementation. Flooding and severe storm events disproportionately affect low-income communities and communities of color, which may lack the resources to prepare for and recover from such events (Cutter et al., 2003). One study revealed that while urban climate change adaptation planning aims to reduce vulnerability and fosters new collaborations and coordination, it often overlooks equity issues, social vulnerability, and the influence of non-climatic factors (Hughes, 2015).One such approach is the Resilience Adaptation Feasibility Tool (RAFT), which seeks to incorporate equity into coastal resilience planning (Yusuf et al., 2022). The authors argue that a more inclusive and equitable approach to resilience planning can lead to more effective and sustainable outcomes that benefit all communities.

Occasionally, climate adaptation solutions can further the resource divide and exacerbate social inequities. Siders (2019) analyzed the social justice implications of managed retreat buyout programs in the United States, finding that these programs can perpetuate social inequalities and displacement, particularly for low-income and marginalized communities. The study highlights the need for more equitable approaches to managed retreat that prioritize social justice, community participation, and empowerment. A subsequent follow up study by Mach and Siders (2021) emphasizes the need for a transformative approach to managed retreat that addresses social injustices associated with climate change and promotes community participation and empowerment. The authors call for policy interventions and support to ensure that managed retreat is socially just and equitable for vulnerable communities (Mach & Siders, 2021). Araos et al. (2021) found that the lack of standardization and clarity on how equity is defined and measured in adaptation research hinders efforts to promote equitable outcomes. The review highlighted the need for more precise and context-specific definitions of equity and greater participation from marginalized communities in the decision-making process to address systemic inequities in adaptation planning and implementation (Araos et al., 2021). Another significant gap in research, limited conceptualization of equity, results in several barriers to promoting equity in urban adaptation planning (Swanson, 2021). The author called for more research on the intersection of equity and urban climate adaptation, as well as more inclusive and participatory approaches to planning and implementation that address the multiple dimensions of equity.

A study in Hampton Roads, Virginia highlights the importance of recognizing the subjective and value-laden nature of adaptation decision-making in the context of climate change. The study emphasizes the need for critical engagement with power dynamics and the inclusion of diverse perspectives in the decision-making process to promote equitable outcomes in adaptation planning (Haverkamp, 2017). Considine et al.'s (2017) case study of Hampton Roads, Virginia, emphasizes the importance of incorporating local knowledge, promoting cross-sectoral collaboration and adaptive governance structures, and fostering social learning and innovation to build resilience to sea level rise and climate change impacts (Considine et al., 2017). In Coastal Virginia, low-income and minority communities are more vulnerable to climate change impacts and there is a need for more equitable and inclusive approaches to climate adaptation that prioritize vulnerable communities and promote social justice and resilience (Eghdami et al., 2023).

Overall, the literature on social equity in coastal climate adaptation research highlights several key gaps and research needs: 1) lack of standardization and clarity on how social equity is defined and measured in the context of adaptation planning; 2) the need for more research on assessing the effectiveness of different adaptation strategies in promoting equity and ensuring that they do not perpetuate social inequalities; 3) the need for more inclusive and equitable approaches to climate adaptation that prioritize social justice and resilience to ensure the needs and perspectives of vulnerable communities are taken into account; and 4) the need for more localized case studies in climate adaptation research, particularly in the context of vulnerable coastal communities, to provide valuable insights into the context-specific social, economic, and cultural factors that could influence the outcomes of climate adaptation strategies. Considering the identified gaps and research needs, our study aims to contribute to the understanding of social equity in coastal climate adaptation by examining the definition and application of social equity in government decision-making, focusing on localized case studies, and promoting inclusive and equitable approaches to better address the unique challenges and opportunities faced by vulnerable coastal communities.

3.3 Methodology

3.3.1 Case Study Selection

We chose the City of Norfolk in Southeast Virginia as our case study. Out of all coastal cities in the United States, the climate change issues faced by Norfolk are among the most challenging. Norfolk is a low-lying city that has been facing rapid sea level rise, accelerated land subsidence, and more intense rainfall patterns. Flooding, therefore, has become a chronic problem in Norfolk, disrupting residents' lives and threating their livelihoods more than ever (Goodall et al., 2021; US EPA, 2021c). But recurrent flooding is not the only climate-related issue in Norfolk. As an overdeveloped city, Norfolk has also been facing heat island effect that would render some areas in the city increasingly unbearable with the temperature extremes produced by climate change (Hoffman et al., 2020). Additionally, Norfolk has a high vulnerable population, with 17.8% of people living in poverty, 10.6% of people under 65 living with a disability, and 12.9% of people lacking health insurance (U.S. Census Bureau, 2021a). Historically, the vulnerable populations in Norfolk have suffered from being neglected in public policy considerations (Boyer & Penn, 2013). In the meantime, Norfolk has been identified as one of the most proactive cities in coastal climate adaptation planning (Eghdami et al., 2023). Therefore, Norfolk is a prime candidate to represent urban, coastal communities addressing social inequities during coastal climate adaptation planning.

3.3.2 Interviewing Stakeholders

Semi-structured interviews were conducted with influential stakeholders from various sectors, including environmental and economic development NGOs, academic research institutions, local, regional, state, and federal government agencies, and community organizations, to understand the impact of coastal climate change in their community. Influential stakeholders were defined as agencies or other entities with political authority, financial means, power in planning, or community influence on coastal climate change adaptation and mitigation efforts in the state of Virginia. A total of forty-four interviews were conducted out of the 110 people in 64 agencies contacted, including multiple representatives from certain agencies. The interviewees were selected based on their work either directly or indirectly related to coastal climate change adaptation policy. Half of the interviewees were from various levels of government, and the other half were from academia and NGOs. The breakdown of interviewees by sector is as follows: thirteen from Environmental NGOs, 3 from Economic Development NGOs, 5 from Academic Research Institutions, 10 from Local Government, 2 from Regional Government, 7 from State Government, and 2 from the Federal Government. Two of the interviewees had to be interviewed in two sessions. The interviews took place between August 2021 and January 2022 and were conducted virtually. The saturation point for the data occurred when information in interviews became redundant (Guest et al., 2017). At a certain point, we asked each stakeholder for recommendations on additional interviewees, and some of the names provided were individuals we had already contacted or interviewed.

3.3.3 Conducting the Interviews

Semi-structured interviews were chosen as the method of data collection as they elicit authentic responses, and each question was meant to be a prompt that encouraged engagement. The primary focus of the interviews was to understand who and what influences coastal adaptation policymaking, the conflict or reinforcement points that are observed by stakeholders, and how they incorporate social equity in decision-making qualitatively and/or quantitatively. Each interviewee was researched prior to the interview to highlight the most relevant questions. Although many interview subjects mentioned social equity unprompted, the specific questions surrounding social equity were: *How do you define social equity? How does social equity relate to your organization's goals and objectives? How do you measure or understand the organization's impact on social equity?*

3.3.4 Qualitative Analysis

All interviews were initially transcribed using Otter.ai, an artificial intelligence software that transcribes audio to text. The transcriptions were reviewed while listening to the audio recording to address any errors. Transcriptions were then analyzed for social equity relevance content using Dedoose, a software developed for mixed methods research that includes both qualitative and quantitative indicators (*Dedoose*, 2021). In Dedoose, text was coded by highlighting a phrase or a word that was significant and assigning it a label. The labels were then categorized and sorted by themes and subjects. The data was organized and could be analyzed. After the initial coding, we conducted a thorough review of the codes and sorted them into major themes related to the research questions. For example, codes related to how organizations defined social equity were sorted into the broader theme of "definitions of social equity." Similarly, codes related to how organizations measured social equity were sorted into the broader theme of "measurement of social equity." The final step in the analysis was to synthesize the findings and draw conclusions based on the patterns and trends identified in the data. This process involved comparing the themes to identify similarities and differences in how different stakeholders approached social equity and climate adaptation policymaking.

3.4 Findings

3.4.1 Stakeholders' Defining Social Equity

The stakeholder interviews highlighted key themes, such as "environmental justice," "sustainability," "diversity, equity, and inclusion," "resilience," and "sustainability," when discussing social equity. However, some interviewees did not provide a definition for social equity, while others discussed related issues without providing a clear definition. Table 3 presents a small sample of direct responses from the interviewees. We found that the stakeholders in Norfolk's coastal climate adaptation planning have diverse perspectives on social equity. The most frequently used words within their definitions included opportunity, support, ability, resources, voices, different, and vulnerable. Specifically, the definitions highlighted the following aspects: providing equal opportunities and awareness; ensuring voice and control; understanding vulnerability and historical factors; reaching traditionally underserved communities; enabling equitable responses to challenges; addressing past wrongs; ensuring post-disaster recovery for low-income communities; and considering the fair distribution of impacts and benefits. While most interview participants agreed that fairness, equal opportunity, and justice are key components of social equity, only a few identified systemic vulnerabilities as a factor. These diverse viewpoints emphasize the importance of a multifaceted approach to social equity in coastal climate adaptation planning.

Table 5: Definitions for social equity provided by the interviewees.

Stakeholder Sector	**The Definition of Social Equity Provided by Stakeholders**
Environmental NGO	"Social equity means that everybody is given an opportunity, regardless of where they are, that there is the opportunity, and everybody is at least aware of the opportunities."
Environmental NGO	"Social equity is having a voice and control in those factors that affect your life, whether they're in the private sector or the government sector."
Local Government	"Social equity is creating opportunities for those who need different resources and support to be successful. And the reason that they need those different resources and support are because of the historical events that have happened that have led to disinvestment and lack of support resources."
Local Government	"Social equity is first looking at who are the most vulnerable residents and what makes their situation as vulnerable as it is. Not just looking at their specific income, or employment, or school system, but looking at all the contributing factors that play into their ability to be successful or their ability to be as vulnerable as they are."
Environmental NGO	"Social equity is trying to reach pockets of the city that traditionally do not have access and don't get attention from greening projects.
Environmental NGO	"Social equity is the ability for people to respond in a similar way, if as though everyone was operating from the same playing field, or at the same plane level."
Local Government	"Social equity is addressing the wrongs of the past and trying to create a more equitable opportunity for all addressing environmental issues, ensuring that all of our kids have access to a great education, safe neighborhoods, clean air, and jobs."
State Government	"Social equity is the ability for a [low-income] community to come back after a disaster."
State Government	"Social equity means that people have been fairly treated in the context of the options that they have to make decisions about their future when flooding begins to overtake their communities."
Research Institution	"Social equity is thinking about impacts on different groups, and making sure those impacts aren't disproportionately spread around, just having some concept of how those impacts are and how kind of benefits are spread too"

3.4.2 Metrics for Social Equity Assessment

When asked how they incorporate social equity into their objectives, stakeholders provided a range of responses. Some gave concrete examples, such as helping people vote, using relatable language, focusing on mixed-income communities, and providing equitable volunteer support. One environmental NGO stakeholder even shared an acronym they use to incorporate equity and inclusion into their program goals: SMARTIE goals. “SMART goals are Specific, Measurable, Achievable, Realistic, and anchored within a Time frame, but with the addition of ‘I’ for inclusion and ‘E’ for equity, they become SMARTIE goals.”

Metrics are essential for assessing progress and determining whether objectives have been met. By providing quantitative and/or qualitative measures, metrics can help establish clear criteria for success and enable the accurate evaluation of the effectiveness of the project. Stakeholders were asked how they measure social equity. Some admitted that they do not measure it at all, while others mentioned using social vulnerability metrics and tools. This indicates a gap between recognizing the importance of social equity and being able to measure progress towards achieving it.

Several sources were repeatedly identified as useful tools by the stakeholders interviewed for assessing social equity in coastal climate adaptation planning. These were: Social Vulnerability Index, Poverty Ratio, and Environmental Justice Tool. Notably, none of these resources were specifically developed for Norfolk. The Social Vulnerability Index is a statewide index developed by the Virginia Institute of Marine Science, while the Poverty Ratio and Environmental Justice Index are both federal resources. Table 4 presents a breakdown of these three tools, including their definitions as provided by the institutions that developed them, and an overview of their metric components.

Table 6: Metrics for social equity defined by stakeholders.

Tool/Index	Definition	Metric Breakdown

VIMS Social Vulnerability Index	Social vulnerability is the ability of an individual or group to anticipate, cope with, and resist and recover from natural or human made hazards. We used socio-economic data to classify census tracts in Virginia based on their social vulnerability.	• Income per capita • % population that is Black • % population that is Hispanic • % population that is Native American • % population that is over 65 years of age • % civilian labor force sixteen and over that is unemployed • % population for whom poverty status is established that is living in poverty • % population twenty-five and older with no high school degree or equivalent • % population in nursing homes • % females sixteen and over in civilian labor force • % households with female head • % households with social security income
Poverty Ratio	If a family's total income is less than the family's threshold, then that family and every individual in it is considered in poverty.	Before taxes: • Earnings • Unemployment compensation • Workers' compensation • Social Security • Supplemental Security Income • Public assistance • Veterans' payments • Survivor benefits • Pension or retirement income • Interest • Dividends • Rents • Royalties • Income from estates • Trusts • Educational assistance • Alimony • Child support • Assistance from outside the household • Other miscellaneous sources

Environmental Justice Tool	Environmental justice is the fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income, with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies.	• Twelve environmental indicators comprised of air, waste, water quality metrics.
		• Seven demographic indicators:
		    ○ people of color
		    ○ low-income
		    ○ unemployment rate
		    ○ linguistic isolation
		    ○ less than high school education
		    ○ under age 5
		    ○ over age 64
		    ○ demographic index (low-income and people of color
		• 12 EJ indexes including a variety of environmental hazards and proximity to hazards and superfund

Table Citations: VIMS Vulnerability Index metadata described the metrics and methodology (VIMS, 2016a). The VIMS mapping tool included the definition of social vulnerability under the classification overview (VIMS, 2016b). The metrics were described in a metadata sheet along with the methodology. The poverty ratio is both described and the metrics are described by the US Census Bureau (U.S. Census Bureau, 2021b). The Environmental Justice Tool which is provided by the US Environmental Protection Agency defines Environmental Justice in their page (US EPA, 2022a), the EJ indexes (US EPA, 2014a), the demographic indicators (US EPA, 2014b), and the environmental indicators (US EPA, 2014c).

One approach to measuring social equity, as shared by a local government stakeholder, focuses on analyzing the vulnerability of residents and considering all contributing factors that impact their ability to succeed or face vulnerability. Their climate adaptation strategy follows a multi-pronged approach, which begins with understanding the community's vision for the future and documenting it, as in Norfolk's Vision 2100. The community is divided into four distinct areas, and they have implemented tools within their zoning and floodplain ordinances to help realize their vision. The local government has also adopted a resilience quotient, which is a point system that encourages market participation in a voluntary exchange to reduce risk and improve flood and stormwater management. The community plays a significant role in this process, and the local government has incorporated these tools into their ordinances to ensure the community is invested in the success of their managed retreat efforts. However, the interviewee did not provide specific details on the zoning plan's release or the community's involvement in the process.

A federal government stakeholder emphasized that cost benefit analysis is a crucial factor in evaluating proposed solutions to protect against environmental challenges. They acknowledged the challenges of balancing economic benefits against costs, particularly when considering underserved low-income communities and social factors. However, they asserted that cost benefit analysis is a fair and consistent way to measure the effectiveness of proposed solutions. In their own words, "at the end of the day, it's very much an engineering answer, which is not necessarily the right way, but, at least, it's fair and consistent across the board, so it's measurable, and we can go back and reproduce it." The stakeholder mentioned that using cost benefit analysis can present challenges when considering underserved low-income communities and environmental justice issues. They acknowledged that damage prevented by expensive properties that would get flooded is given higher priority in the cost benefit analysis calculus, whereas damage prevented by low-income neighborhoods with low-value homes is minimal. The stakeholder also indicated that there is no quantitative number for social factors and analyses, making it more challenging to consider the impacts of cost benefit analysis on vulnerable communities. They acknowledged that this could make it difficult to justify building solutions that may cost a significant amount to protect a relatively small amount of property. Overall, the stakeholder recognized the challenges of balancing economic benefits with protecting vulnerable communities, particularly when using cost benefit analysis.

3.4.3 Connecting Climate Risks with Social Inequities

As climate change poses an increasing threat to our cities, it is necessary to examine how the resulting risks are distributed among different communities and why. In this section, we explore the relationship between social inequalities and the primary climate risks confronting the City of Norfolk, as identified by the stakeholders. These are recurrent and compound flooding and excessive heat. We examine how the perception of risks related to social equity is reflected in the narratives that link climate change threats to socially vulnerable communities. To gain a deeper understanding of how these risks are perceived through the lens of stakeholders, we explore the narratives that connect climate change threats to socially vulnerable communities. Through this analysis we aim to highlight the intersections of climate change and social justice and identify potential solutions to mitigate the disproportionate impacts on marginalized communities.

Equity and Inclusion in Climate Resilience: Stakeholder Perspectives on Flood and Severe Storms

In Norfolk, recurrent flooding has become a near-daily occurrence, with high tide or nuisance flooding often resulting from rising sea levels rather than storms or rainfall (NOAA, 2023). Nuisance flooding, which occurs during high tide, can have minor but disruptive impacts on daily life (NOAA, 2015). As two different stakeholders noted, the flooding is far from a mere nuisance when it prevents access to jobs, schools, or healthcare services, and it can significantly disrupt people's lives.

An exacerbating event such as heavy rainfall, tropical storms, hurricanes, and tornados can lead to extensive damage and flooding, which is predicted to become more frequent and intense due to climate change (Wuebbles et al., 2017). "We hold our breath every year, between September and October. That is our hurricane season. Another low hurricane year for us. But we are always worried about the big one. We think about storm surges and recurrent flooding due to sea level rise. Those are most present in our minds here locally" said an environmental NGO stakeholder.

Social inequalities can intensify the effects of flooding and create obstacles to equitable resilience-building efforts, such as engaging diverse stakeholders and fostering community participation among disadvantaged and vulnerable populations (Yusuf et al., 2015). An environmental NGO interviewee emphasized the importance of community-driven solutions and using data from various sources to identify the most vulnerable populations. According to the interviewee, "We use a lot of different organizations' data, research and studies, as well as just anecdotal data to figure out where those most vulnerable populations lie." An academic stakeholder emphasized the need for both mitigation and adaptation measures to address severe storm events' impacts. They also highlighted the importance of considering multiple funding sources for resilience projects and planning for storm events' consequences, such as flooding, storm surge, and compound flooding.

A local government stakeholder discussed their city's efforts to address social equity in planning, including allocating FEMA funds to communities in greatest need and reducing barriers for obtaining conditional use permits. However, they also mentioned challenges, such as the lack of diversity in the planning department and the need for a formal process to ensure equity is considered in all decisions.

Academic stakeholders offered differing perspectives on the role of social equity in addressing flooding and building resilience. One emphasized the need for difficult choices about long-term priorities, adopting measures to generate funding, and planning to preserve marshes as flood buffers. Another suggested that social equity should not be the focus, as natural migration away from risk will occur, and encouraging people to remain in high-risk areas could lead to more suffering and economic losses. As the stakeholder put it, "Let the free market, the free flows of forces migrate. Don't slow it down. In the long haul you're better off abandoning."

In contrast, environmental NGO stakeholders argued that social equity must be central to addressing flooding and other environmental issues, as climate change affects everyone. They stressed the importance of considering marginalized communities' needs and supporting their transition to sustainable practices. Additionally, they highlighted the challenges of addressing flood risks and climate change while grappling with systemic racism, acknowledging that protecting vulnerable communities without exacerbating existing inequalities is a complex task. As one noted, "If the city decides to buy out the most at-risk people, then the city is removing people of color from a risk. And when they do that, then it's politically charged because they're removing people." However, they emphasized the importance of finding solutions to safeguard all communities at risk from flooding and other climate-related hazards.

Equitable Tree Canopy Distribution and Excessive Heat in Norfolk

Interviewees expressed concerns about excessive heat waves impacting communities that have been historically neglected in green development efforts, such as tree canopies. In the face of this growing threat, extreme heat remains a cause of preventable death in the US, with health risks expected to rise due to factors such as an increasing urban population, an aging population, and the presence of urban heat islands (Centers for Disease Control and Prevention, 2020; Vose et al., 2017).

Urban heat islands are areas hotter than their surrounding communities due to a lack of natural land cover and a preponderance of urban infrastructure like pavement, buildings, and other heat-absorbing structures (American Forests, 2020). A recurring theme in the interviews was that heat is considered a neglected climate risk, often overshadowed by flood and storm adaptation efforts. A state stakeholder acknowledged that heat is a significant issue in places like Richmond, Virginia, but their primary focus is on flooding. They believe that heat, along with flooding, is a root cause of many climate-related problems in the Commonwealth.

An interviewee from an environmental NGO highlighted the issue of urban heat islands and the lack of investment in natural resources to address climate change. They noted that there is a partisan divide on how to prioritize and invest in disadvantaged communities and communities of color, which are disproportionately impacted by certain policy choices. The interviewee described the impact of unsustainable development practices on urban heat islands, stating, “when it can be 30 degrees, my neighborhood is 30 degrees cooler than an area that does not have trees, was not developed in a way that is sustainable. The type of plantings that were chosen to put in, we’re seeing those long-term health impacts of those policy choices.”

A local government stakeholder explained that historically redlined neighborhoods, usually populated by people of color or Jewish people, still face challenges such as higher temperatures due to fewer trees and increased energy burden. They emphasized the importance of heat resiliency and addressing energy burden by implementing measures such as home weatherization programs and other small adjustments to help residents cope with extreme temperatures, which are not mentioned in the Climate Action Plan.

The interviewees also discussed the impact of redlining on present-day neighborhood conditions, such as tree coverage and heat vulnerability. Redlining was a practice in the 1930s and 40s where banks and mortgage companies would decide not to give mortgages to neighborhoods deemed “bad,” often where people of color or Jewish people lived. These neighborhoods were considered “hazardous” or “definitely declining.” These antiquated maps have generational impacts and have created systemic oppressive housing practices.

Figure 8 compares two neighborhoods in Norfolk with different tree equity scores. The Tree Equity Score is a metric that helps cities assess equitable tree canopy cover to all residents, calculated at the neighborhood level and aggregated to the municipal level. It involves four steps: establishing a neighborhood goal, calculating the canopy gap, developing a priority index, and calculating the Tree Equity Score by multiplying the baseline gap score by the priority index. Achieving Tree Equity has numerous lifesaving and quality of life benefits, such as creating jobs and providing ecosystem services. In Figure 1 lower score of 44 corresponds to worse health outcomes, a larger population of people of color, unemployment, youth population, and poverty. The higher score of 94 has nearly met their tree canopy goal. The tree canopy goal is a target for equitable tree coverage that considers the population density of an area, adjusted from generalized natural biome baseline targets selected with the assistance of the United States Department of Agriculture Forest Service.

Figure 8 additionally incorporates Norfolk's redlining map, with different grades. The different grades represent the Homeowners' Loan Corporation's (HOLC) judgement on a neighborhood's risk level. Grade A (green outline) is "Best," grade B (yellow outline) is "still desirable", grade C (orange) is "definitely declining", and grade D (red) is "hazardous". The figure provides a visual representation of the disparities between neighborhoods and highlights the connection between historical redlining practices and current tree canopy coverage.

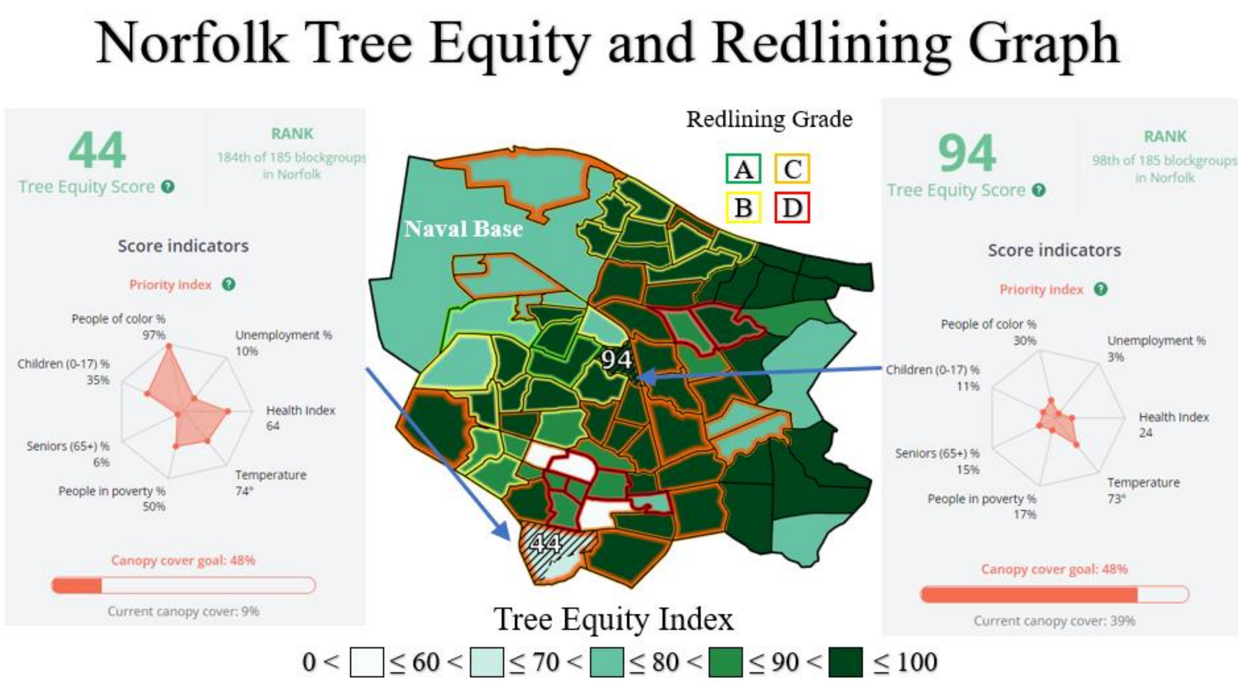

Figure 8: This graphic is a comparison of two census block groups in Norfolk, Virginia. Included in the figure is the tree equity score and a breakdown of the score indicators for the two communities. The whole city of Norfolk is mapped and broken into census block groups with a color indicator for tree equity score (American Forests, 2021) and the redline map (Nelson et al., 2022).

An academic stakeholder expressed their belief that investing in resilience to combat excessive heat is not a sustainable long-term solution and instead encourages migration away from high-risk areas. They argued that the costs of investing in resilience are immense and do not substantially reduce the risk of excessive heat. Another academic stakeholder highlights the importance of addressing heat-related issues and energy burden, which are often overlooked. They summarized their position by stating, "The bottom line is, there's not enough money. And you have to rely on all of those sources and figure out wisely how to use them."

3.5 Discussion & Concluding Remarks

This study investigates the challenges stakeholders face when integrating social equity into coastal climate adaptation policy, planning, and program implementation, focusing on Norfolk, Virginia. One key challenge is the variation in perspectives on social equity, which is evident in the range of definitions, understandings of its significance, and approaches for incorporating it into planning. While communities and governments attempt to address social equity, difficulties in defining and measuring it hinder decision-makers' ability to justify its inclusion and implementation. As one academic stakeholder described, "When it comes to white papers, I don't really have a way to measure [social equity], but we try to address it."

The challenges coastal cities face is exacerbated by the growing wealth gap in the United States, which outpaces state welfare or other social safety nets like flood insurance subsidies (Gotham & Greenberg, 2014). When decision-makers lack adequate metrics to support their objectives then the resulting policies and programs may further drive inequity in the community. The interviews revealed a reliance on indices developed at the state and federal levels to measure and evaluate social equity at a local level. These indices lack the local and regional social context needed to assess equity for a specific community, climate risk, and adaptation solution. As aggregates of metrics, the composite indices can be useful tools for recognizing patterns and identifying vulnerable communities; however, they may obscure important tradeoffs in decision-making and coastal climate adaptation planning.

This paper critically reflects on how social equity is currently incorporated in coastal adaptation planning, not to discredit or discourage efforts, but to improve the foundation that has been laid. There is no absolute result; environmental justice is an ideology that a climate-conscious society can strive for, similar to how democracy strives towards an idealized union. To bridge the gap between recognizing the importance of social equity and measuring progress towards achieving it, stakeholders must develop clear, measurable goals for social equity, along with tools and metrics to assess progress.

Addressing the impacts of climate risks requires a sustained commitment to social equity and sustainability. This involves tackling underlying drivers of environmental and social injustices, such as historical disinvestment in certain communities or limited access to resources and opportunities. Engaging diverse stakeholders, including community members, policymakers, and industry leaders, ensures inclusive and equitable decision-making processes. This is important in all sectors, but interviewees mention the impracticality of academic research solutions. One local government stakeholder describes several barriers when collaborating with academic partners for academic help, including preconceived solutions, short course durations, difficult academic experts, and a shortage of professionals with specialized expertise. As the interviewee says, "We have been very hesitant to work with academic organizations or outside stakeholders on buyout projects, because of the deep history that we have in Norfolk for urban renewal projects that have had a similar sort of 'this is what's best' approach." It is recommended that academic research for coastal climate adaptation engage those most impacted, understand the goals of the community, and apply research findings in a manner that ensures projects are socially and politically feasible and have community support.

There are however several recent efforts that aim to address the challenges of coastal climate adaptation more effectively while incorporating social equity concerns and community support. The Resilience Adaptation Feasibility Tool (RAFT) is one such initiative that helps to ensure that projects are equitable, sustainable, and have the support of the community. It engages stakeholders, identifies, and addresses equity concerns, and considers the goals and needs of the community to apply research findings in a socially and politically feasible manner. The tool facilitates the participation of those most impacted by the projects in the planning and decision-making process, thereby ensuring that projects align with the practical needs and goals of the organization seeking help (Wie Yusuf et al., 2022). Another initiative is the Resilient and Adaptable Communities Partnership launched by Old Dominion University’s Institute for

Coastal Adaptation and Resilience and the Chesapeake Bay Foundation. The partnership aims to fill gaps in resources for communities in Virginia dealing with increased flooding linked to climate change by fostering collaboration across various departments, training a workforce to design and build projects that protect homes and businesses while benefiting the Bay, and introducing resiliency concepts to students at the elementary school level (Paullin et al., 2023).

Interviewees provided direct recommendations for communities, such as investing more money in coastal resiliency, initiating strategic retreat, and coordinating regionally. Equitable allocation of investments requires regulation and measurement, while strategic retreat should be approached sensitively in vulnerable communities. Regional coordination is essential for ensuring mutually beneficial solutions. As demonstrated in a comparative study of two different regional coastal communities, cohesive regional coordination can increase local communities' adaptive capacity by bridging gaps, providing resources, and facilitating action (Birchall et al., 2023).

Heat as a climate risk garners less attention in policy, programs, and projects, It was identified during the interviews as having a direct link to historical inequities within Norfolk connecting heat to tree canopy development and policy injustices like redlining. Heat is the primary climate-related killer in the US, disproportionately impacting socially vulnerable communities. Statistical evidence shows a connection between redlining practices that deemed areas "hazardous" and consistently hotter land surface temperatures (Wilson, 2020). Investing in tree canopy development for lower-income neighborhoods and communities will have the added benefit of removing carbon dioxide from the atmosphere through plant carbon uptake. Adaptation strategies that have multiple benefits and focus on low-income neighborhoods can be considered equitable solutions, but it is important to keep in mind the risk of green infrastructure gentrification, which can be reduced by engaging local stakeholders from trusted community organizations (Anguelovski et al., 2019).

One of the key challenges facing stakeholders in the field of climate adaptation planning is the diverse perspectives on the role of social equity in resilience-building efforts. While some emphasize the need to prioritize long-term goals, generate funding, and preserve natural buffers against floods, others stress the importance of centering social equity in planning and decision-making processes, particularly for marginalized communities. Finding common ground and developing effective strategies to address both environmental risks and systemic inequalities remains a crucial area for future research and collaboration.

This study has several limitations. While the extended interview sample size is large, it is small compared to the vast network of stakeholders in the area. A stakeholder network analysis could contribute to this body of work supporting coastal climate adaptation in Norfolk and the Hampton Roads area. Furthermore, crucial components of the coastal climate adaptation system, such as private industry stakeholders, utilities, and citizens, were not included in the interviews. Future research should incorporate these groups to gain insight into how they address social equity problems in their communities and the impact on residents To address the lack of coherent definitions and measurement of social equity in coastal climate risk management, future studies could benefit from taking a more participatory approach to decision-making that engages diverse stakeholders, including community members, policymakers, and industry leaders, to ensure inclusive and equitable processes. Additionally, using a mixed-methods research methodology that includes both qualitative and quantitative indicators could provide a more comprehensive understanding of the issue. Finally, to ensure the generalizability of research findings, it may be beneficial to conduct case studies in multiple communities facing similar challenges to those in Norfolk, Virginia, and compare the results to identify common themes and best practices for addressing social equity in coastal climate adaptation planning. By applying these lessons, coastal communities can promote equitable and sustainable solutions for climate risk management.

4. Developing a Scorecard to Evaluate Social Equity-Related Indices

4.1 Introduction

Social vulnerability indices (SVIs) have gained popularity as a means of measuring the susceptibility of communities to natural hazards, social inequalities, and environmental changes (Cutter et al., 2003; Schmidtlein et al., 2008). These indices often aggregate numerous socio-demographic, economic, and environmental variables to rank communities based on their relative vulnerability. Two prominent SVIs are the Centers for Disease Control and Prevention's Social Vulnerability Index (CDC SVI) and the Virginia Institute of Marine Science's Social Vulnerability Index (VIMS SVI), which have been applied in various fields, such as disaster risk management, public health, and environmental planning (Borden et al., 2007; Flanagan et al., 2011).

Despite their growing popularity, concerns have been raised about SVIs' ability to accurately measure social equity (Borden et al., 2007; Tate, 2012). Major limitations include the lack of understanding tradeoffs, as these indices often do not account for how one metric may be affected by another, potentially leading to misleading interpretations of vulnerability (Tate, 2013). Furthermore, SVIs are often criticized for their insensitivity to local changes and issues, as they typically rely on national or regional data and may not adequately capture the specific vulnerabilities of individual communities (Cutter et al., 2003; Holand et al., 2011).

Social vulnerability to floods is a crucial issue in disaster risk management, necessitating a comprehensive understanding of impacted communities, including factors such as socioeconomic status, resource and infrastructure access, and social networks (Rufat et al., 2015). Incorporating context-specific indicators that capture the complex nature of social vulnerability is essential for effective disaster management strategies (Wood et al., 2021).

This chapter aims to review the application of social equity-related indices, their effectiveness in planning, and their limitations, particularly focusing on the case study of the federally developed

CDC SVI and the state-level VIMS SVI. Through literature and case-based studies, critical components that make a quality planning tool can be identified. Additionally, stakeholder feedback can help inform the quality of certain indices in application. Once identified, this chapter proposes a scorecard to evaluate the efficacy of an SVI tool.

4.2 Literature Review

4.2.1 Applications of SVIs

To comprehend the broad scope of SVI applications, it is instructive to examine studies that offer insights into their effectiveness and limitations. Lee (2014) provides a framework for the development of context-specific SVIs, emphasizing the importance of incorporating community engagement and stakeholder feedback in the planning process (Lee, 2014). De Oliveira Mendes (2009) advocates for the use of SVIs to promote social equity and resilience, stressing the need for context-specific indices that reflect the complex and dynamic nature of social vulnerability (de Oliveira Mendes, 2009).

SVIs have been utilized in various sectors, such as healthcare, to enhance care access and reduce health disparities for vulnerable populations (Roy et al., 2022). Studies have found associations between social vulnerability and increased mortality risk in elderly populations (Andrew et al., 2008), and the use of CDC's Social Vulnerability Index (SVI) to identify areas with a higher risk of heat-related health impacts (Lehnert et al., 2020). Fekete (2009) demonstrated SVIs' effectiveness in predicting river flood impacts on vulnerable populations, underlining the need for context-specific indices that capture regional characteristics and incorporate a range of socio-demographic, economic, and environmental factors (Fekete, 2009).

4.2.2 Critiques and Limitations

Despite their extensive applications, several critiques have been raised about the limitations of SVIs. One concern is their inability to accurately capture the complex and multidimensional nature of development, as noted by (Aziz et al., 2015) and (Babcicky, 2013). Tate (2012) found that the choice of index can significantly affect vulnerability assessment results, emphasizing the importance of carefully selecting appropriate indices (Tate, 2012). Tate (2013) further stressed the need for caution when interpreting and using SVIs, as input data and normalization methods could significantly impact vulnerability assessments (Tate, 2013).

Flanagan et al. (2011) identified limitations such as the reliance on aggregate data at a relatively coarse geographic scale, which may not accurately capture individual community vulnerabilities (Flanagan et al., 2011). Additionally, static data sources used in SVIs do not reflect changes over time. The authors suggested that refinement and improvement of SVIs, informed by stakeholder feedback and local data, could address these limitations.

Su et al. (2015) acknowledged the limitations of SVIs, such as their lack of sensitivity to local issues and the potential for oversimplification of vulnerability (Su et al., 2015). Ignacio et al. (2015) emphasized the need for more comprehensive and nuanced approaches to vulnerability assessment to improve disaster risk reduction strategies (Ignacio et al., 2015). Koks et al. (2015) supported the incorporation of social vulnerability alongside traditional hazard and exposure assessments for effective risk reduction strategies (Koks et al., 2015). Spielman et al. (2020) highlighted the importance of selecting appropriate social vulnerability indicators based on local context and specific hazard types (Spielman et al., 2020).

In summary, this literature review provides a broad and nuanced examination of the potential benefits and limitations of SVIs in measuring social vulnerability and promoting social equity. The review emphasizes the importance of carefully selecting and refining SVIs based on their sensitivity to local context and specific hazard types. Furthermore, it identifies gaps in the existing literature, such as the need for context-specific, comprehensive, and dynamic vulnerability assessments, and suggests directions for future research to improve disaster risk reduction strategies and promote more equitable outcomes across various applications.

4.3 Connecting Methodologies of SVI to Literature

Social vulnerability indices (SVIs) are essential tools for policymakers and planners to identify areas with high social vulnerability and direct resources and interventions accordingly (Cutter et al., 2003). Two widely used SVIs are the Centers for Disease Control and Prevention (CDC) SVI and the Virginia Institute of Marine Science (VIMS) SVI. This section provides an in-depth comparison of the methodologies and indicators used in each index, highlighting their differences and applications in localized planning, while connecting the discussion to the relevant literature.

The CDC SVI comprises fifteen indicators, which are organized into four themes: socioeconomic status, household composition and disability, minority status and language, and housing and transportation (CDC, 2022). VIMS SVI focuses specifically on coastal communities in Virginia and includes indicators such as poverty, age, education, and disability status (VIMS, 2016a). Both indices rely on data from the US Census Bureau, but they differ in the specific indicators used and the weighting of these indicators, as noted in the literature (Sarah Stafford & Schyler Vander Schaaf, 2021).

The differences between these indices can be visually observed by comparing Figure 9 and Figure 10. Figure 9 depicts the VIMS SVI map, while Figure 10 displays the CDC SVI map in Norfolk, Virginia. A comparison of the two maps reveals significant differences in their ability to identify areas with "very high social vulnerability." For instance, the downtown area in Norfolk, which has been identified as a prime example of social vulnerability in other chapters, is classified as "very high social vulnerability" in the VIMS SVI (Figure 9) but not in the CDC SVI (Figure 10).

The VIMS SVI was developed using a multivariate statistical approach to identify the most important social and environmental variables and weight them based on their relative influence on social vulnerability (VIMS, 2016a). This approach is consistent with the recommendations in the literature for developing robust vulnerability indices (Fekete, 2009). Additionally, VIMS collaborated with the Center for Coastal Resource Management, Wetlands Watch, and the Virginia Coastal Policy Center at William & Mary Law School to develop an online mapping tool, AdaptVA, which integrates SVI data with information on climate change impacts such as sea-level rise, flooding, and storm surge (Stafford & Abramowitz, 2017). This tool helps communities identify areas most at risk and develop adaptation strategies, thus addressing the need for localized planning highlighted in the literature (Adger et al., 2005).

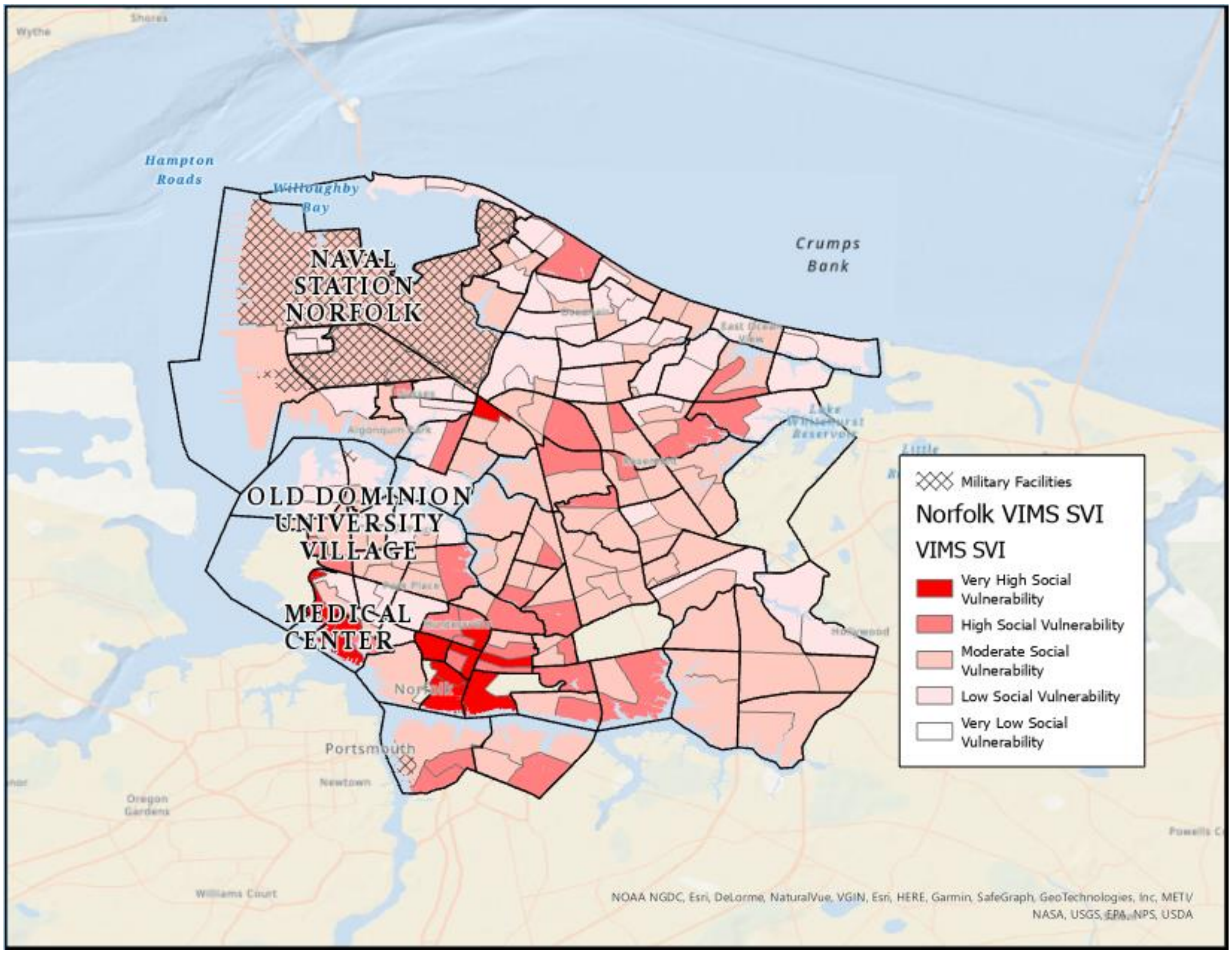

Figure 9: VIMS SVI for Norfolk, Virginia providing the scale of very low to very high social vulnerability (VIMS, 2016b). This graph includes military facilities mapped using the Hampton Roads Planning District Commission open source data (*Maps*, 2021)

The CDC SVI, in contrast, is developed at the federal level using census tract information (CDC, 2022). As noted in the literature, this methodology involves constructing an index that measures the social vulnerability of a given population or geographic area based on various socio-demographic, economic, and environmental factors (Flanagan et al., 2011). While the CDC SVI methodology is more standardized and widely used, with data available for all U.S. counties, it may not capture the unique characteristics of different regions and may not be sensitive to local issues that are specific to certain communities (Cutter et al., 2003). The VIMS SVI, conversely, was specifically designed for Virginia's coastal communities and incorporates local data and knowledge to capture the unique social vulnerability characteristics of the region (VIMS, 2016a)

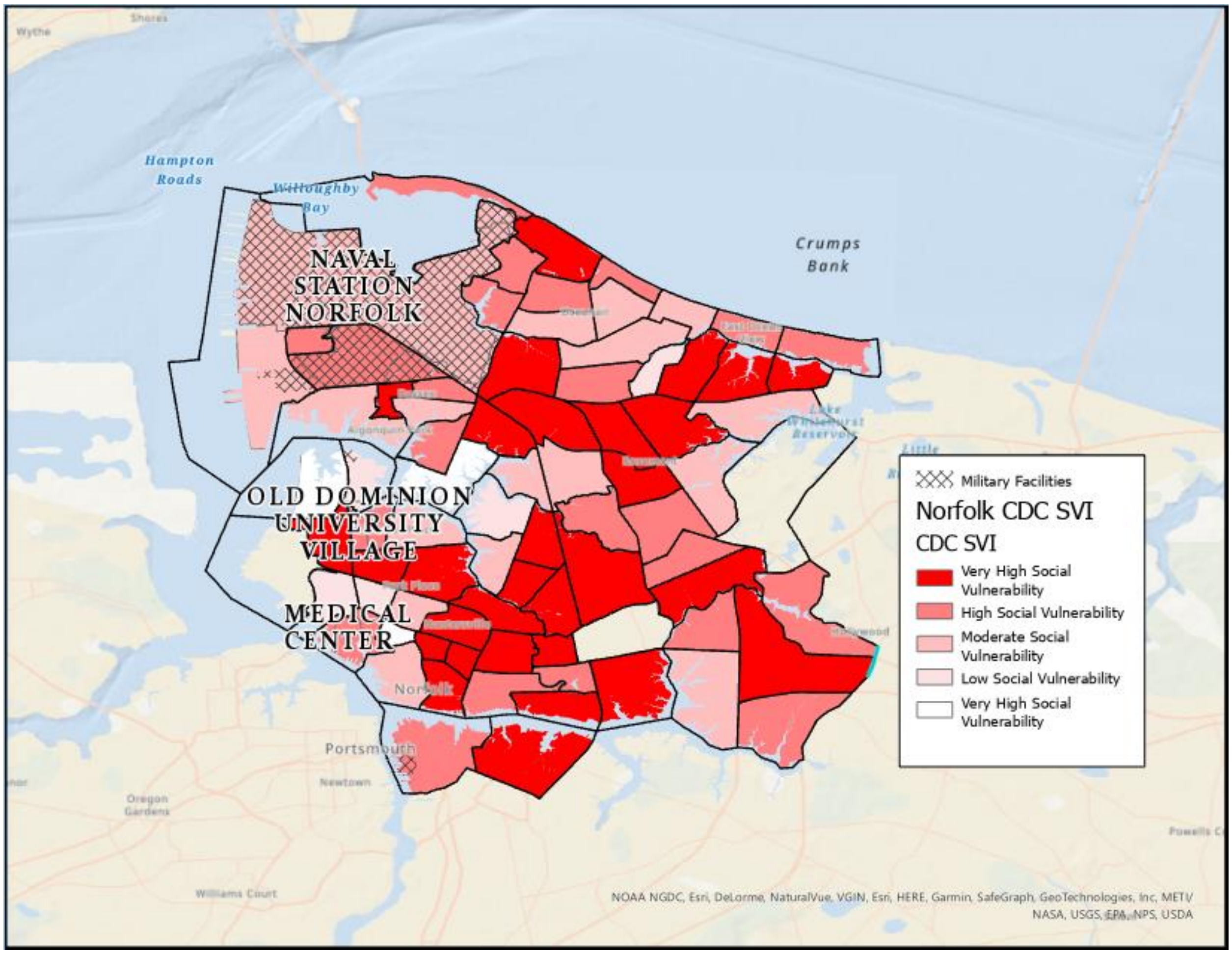

Figure 10: CDC SVI for Norfolk, Virginia providing the scale of very low to very high social vulnerability (CDC, 2022). his graph includes military facilities mapped using the Hampton Roads Planning District Commission open source data (*Maps*, 2021)

This analysis highlights the strengths and weaknesses of the CDC and VIMS SVIs in localized planning, offering insights into the implications of their methodological choices. Connecting the discussion to the literature review ensures that the analysis is grounded in existing research and contributes to the understanding of social vulnerability indices in localized planning contexts.

The CDC and VIMS SVIs offer different approaches to assessing social vulnerability, with the VIMS SVI being more tailored to Virginia's coastal communities and the CDC SVI providing a standardized approach for the entire United States. The choice of index for localized planning will depend on the specific context and goals of the assessment. The literature suggests that it is crucial for policymakers and planners to consider the unique characteristics of the communities they serve and the specific vulnerabilities they face (Cutter et al., 2003; Adger et al., 2005). In the case of coastal communities in Virginia, the VIMS SVI might be more appropriate due to its focus on local data and context-specific factors. However, for broader applications or comparisons between different regions, the CDC SVI may be more suitable.

Ultimately, the use of social vulnerability indices, such as the CDC and VIMS SVIs, can help inform localized planning efforts and guide resource allocation to reduce disparities and promote social equity. By critically evaluating the methodologies and indicators used in these indices, and connecting the discussion to the literature, this section contributes to a deeper understanding of the role of social vulnerability indices in localized planning and their potential applications in addressing social equity challenges.

4.4 Evaluation of Social-Equity Related Indices Scorecard

4.4.1 Developing the Scorecard

Social equity-related indices play a critical role in informing policy and decision-making processes aimed at reducing disparities and promoting inclusiveness, which underscores the importance of evaluating them (Organization for Economic Co-operation and Development, 2011). This comprehensive scorecard has been developed to assess the effectiveness of these indices, considering six key components: Data Quality, Variable Selection, Tradeoff Understanding, Local Sensitivity, Cultural and Social Norm Considerations, and Usability. Each component is supported by research and expert recommendations, ensuring that the scorecard provides a robust framework for evaluating social equity indices.

1. Data Quality: Reliable, relevant, and timely data is crucial for accurately assessing social equity (Jolliffe & Prydz, 2016). Ensuring that indices use reliable sources, relevant data for the specific context, and the most up-to-date information strengthens the accuracy and validity of the assessment (World Bank, 2014).

2. Variable Selection: Comprehensiveness and appropriateness of the selected variables directly impact the quality of the index (Alkire & Foster, 2011). By including diverse socio-demographic, economic, environmental, and cultural variables relevant to the

specific context, the index can better capture the nuances of social equity challenges (Ghislandi et al., 2019).

3. Tradeoff Understanding: Addressing complex interactions between different dimensions of vulnerability requires careful consideration of aggregation methods, non-linear relationships, and appropriate weighting and normalization techniques (Ferreira et al., 2016). A robust understanding of these tradeoffs can improve the accuracy and usefulness of the index (Nardo et al., n.d.)

4. Local Sensitivity: Capturing local-scale variations and context-specific factors is crucial for ensuring that social equity indices are relevant and actionable (Reed et al., 2006). Incorporating local data sources and up-to-date information enables a more targeted and effective approach to addressing social equity challenges (Cutter et al., 2003).

5. Cultural and Social Norm Considerations: Accounting for cultural diversity, social norms, and local knowledge in indices is essential for promoting inclusiveness and understanding the impact of these factors on vulnerability (Adger et al., 2009). By incorporating these considerations, the index can better inform policies and programs that respect and support diverse communities (Smit & Wandel, 2006).

6. Usability: Ensuring that indices are interpretable, accessible, and actionable is key to their usefulness for policymakers, practitioners, and community members (Ravallion, 2011). A user-friendly index can facilitate better communication of results and promote informed decision-making to address social equity challenges (Munda & Nardo, 2009).

Table 7 explains the aspects of each of the index evaluation components and the corresponding research questions they answer. Each aspect is given a score of one through five, one being the very poor performance, and five being very high performance. Although based on the user’s application the score is adjustable. For example, consider the case of disaster relief, where the aid administrator wants to allocate the aid in a socially equitable manner. They may use a housing social vulnerability index and may want to use this scorecard to select the most appropriate index. In this situation, understanding the relevant tradeoffs, variable selection, and data quality might be twice as important as local sensitivity, while usability might not matter at all. Users can adjust the scale, drop out a component that has no value to the application, and apply relative weights to indicate the factor by which one component is more important than another, rather than weighing all the scores evenly.

Table 7: Social Equity Related Index Efficacy Scorecard

Index Evaluation Component	**Aspects of Each Component**	**Description of Aspects**
Data Quality	Reliability	Does the index use reliable data sources?
	Relevance	Are the data sources relevant to the specific context being analyzed?
	Timeliness	Does the index use the most up-to-date data available?
Variable selection	Comprehensiveness	Does the index include a diverse range of socio-demographic, economic, environmental, and cultural variables?
	Appropriateness	Are the selected variables relevant to the specific context and goals of the social equity assessment?
Tradeoff understanding	Aggregation method	Does the index use an appropriate aggregation method that considers the complex interactions between different dimensions of vulnerability?
	Non-linear relationship	Does the index account for potential non-linear relationships between vulnerability variables?
	Weighting and normalization	Are the weighting and normalization techniques used in the index appropriate and robust?
Local sensitivity	Spatial resolution	Does the index capture local-scale variations in vulnerability?
	Context-specific factors	Does the index account for context-specific factors that influence vulnerability?
	Local data integration	Does the index incorporate local data sources and up-to-date information?
Cultural and social norm considerations	Cultural diversity	Does the index account for diverse cultural practices and values?
	Social norms and behaviors	Does the index consider the impact of social norms and behaviors on vulnerability?
	Local knowledge and adaptation strategies	Does the index capture local knowledge and community-based adaptation strategies?
Usability	Interpretability	Is the index easy to understand and interpret
	Accessibility	Is the index accessible to a wide range of users, including policymakers, practitioners, and community members?
	Actionability	Does the index provide actionable insights to inform policy and planning decisions?

Appendix A includes a breakdown of each component aspect and the description of each score 1/5 to 5/5 to describe how a score may be evaluated. Appendix B are various examples of a score for each component aspect.

4.4.2 Examples in Practice

The score card will be discussed in detail for the two examples used previously in this case, the VIMS SVI, and the CDC SVI. In Appendix C, there are three other indices used for comparison including the CDC Environmental Justice Index (EJI), the VIMS EJI, and the American Forests Tree Equity Score (TES) which was applied in Chapter 3.

CDC SVI Scorecard Evaluation

Table 8: CDC SVI Scorecard Performance

Index Evaluation Component	**Aspects of Each Component**	**Description of Aspects**
Data Quality	Reliability	4/5 The SVI primarily uses data from the U.S. Census Bureau, which is generally reliable but might have some biases
	Relevance	5/5 The data sources are relevant to the communities being analyzed, focusing on fifteen social factors across four themes.
	Timeliness	4/5 The SVI is updated annually using the latest American Community Survey (ACS) 5-year estimates, ensuring relatively up-to-date data.
Variable selection	Comprehensiveness	5/5 The SVI includes a diverse range of socio-demographic, economic, and environmental variables across four themes, covering a wide spectrum of social factors.
	Appropriateness	5/5 The selected variables are relevant to the specific context and goals of the social equity assessment for coastal communities
Tradeoff understanding	Aggregation method	4/5 The SVI uses percentile ranking for each of the fifteen social factors, which is an appropriate method for capturing patterns among multiple dimensions of vulnerability but might not fully capture complex interactions between dimensions.
	Non-linear relationship	3/5 It is unclear whether the index accounts for potential non-linear relationships between vulnerability variables
	Weighting and normalization	5/5 The SVI uses percentile ranking, which is a robust normalization technique, and equal weighting for the four

		themes, providing a transparent and straightforward approach.
Local sensitivity	Spatial resolution	3/5 The SVI does not capture local-scale variations and is done on a tract level rather than a block level
	Context-specific factors	4/5 The index accounts for some context-specific factors influencing vulnerability, but might not cover all relevant factors
	Local data integration	3/5 The index uses federal data sources and does not include local sources
Cultural and social norm considerations	Cultural diversity	3/5 It is unclear whether the index considers the impact of social norms and behaviors on vulnerability.
	Social norms and behaviors	1/5 It does not consider the impact of social norms and behaviors on vulnerability
	Local knowledge and adaptation strategies	3/5 The index does not incorporate the preference of community-based adaptation strategies.
Usability	Interpretability	5/5 The index is easy to understand and interpret, with clear explanations and visualizations available on the CDC website.
	Accessibility	5/5 The index is accessible to a wide range of users, including policymakers, practitioners, and community members, with data available through the CDC website and the GeoPlatform.
	Actionability	4/5 The index provides actionable insights to inform policy and planning decisions, though its effectiveness in practice may depend on the specific context and implementation

Please note that the scores provided are only an approximate assessment.

For the Data Quality component, the CDC SVI uses data from the U.S. Census Bureau (Flanagan et al., 2011) and the American Community Survey (ACS) 5-year estimates (CDC, 2022) which are well-established and widely used data sources for social vulnerability research (Cutter et al., 2003; Schmidtlein et al., 2008). The data is generally reliable, but it is essential to recognize potential biases in the data accuracy like mixed race and ethnicity (Zhang et al., 2022).

In terms of Variable Selection, the CDC SVI has been evaluated in numerous studies (Emrich et al., 2020; Horney et al., 2015), with researchers praising the comprehensiveness and appropriateness of the variables included in the index. The selected variables are relevant to the specific context and goals of the social equity assessment for coastal communities.

For the Tradeoff Understanding component, the CDC SVI uses percentile ranking and equal weighting for its variables (Flanagan et al., 2011). This approach has been widely used in social vulnerability research (Cutter et al., 2003; Cutter & Finch, 2008), and it has been considered a transparent and straightforward method. However, concerns have been raised about the potential for oversimplification when using this approach (Tate, 2012).

When combining the aspects of each component the total component score from Table 8 are as follows:

- Data Quality: 13/15
- Variable Selection: 10/10
- Tradeoff Understanding: 12/15
- Local Sensitivity: 10/15
- Cultural and Social Norm Considerations: 7/15
- Usability: 14/15

CDC SVI Scorecard Application

When using the CDC SVI in coastal climate resilience planning, the comparative scores can help planners understand the index's strengths and limitations. By examining the scores across different components, planners can assess how well the CDC SVI aligns with their goals and priorities.

For example, the CDC SVI scores well in data quality (13/15), variable selection (10/10), and usability (14/15). This indicates that the index relies on reliable and relevant data sources and is easy to interpret, accessible, and actionable for decision-makers. As a result, planners focusing on these aspects would find the CDC SVI particularly useful when assessing social vulnerability in coastal communities.

However, the CDC SVI has lower scores in local sensitivity (10/15) and cultural and social norm considerations (7/15). This suggests that the index might not be the best choice for assessing social vulnerability in communities with unique cultural practices, values, or social norms, or for small or remote communities where federal data sources may not accurately capture local conditions.

By comparing these scores, coastal climate resilience planners can determine if the CDC SVI meets their specific needs and priorities. If the high scores in data quality, variable selection, and usability are more important than the lower scores in local sensitivity and cultural considerations, then the CDC SVI would be a suitable choice for their resilience planning efforts.

VIMS SVI Scorecard Evaluation

Table 9: VIMS SVI Scorecard Performance

Index Evaluation Component	**Aspects of Each Component**	**Description of Aspects**
Data Quality	Reliability	4/5 The SVI primarily uses data from the U.S. Census Bureau, which is generally reliable but might have some biases.
	Relevance	5/5 The data sources are relevant to the communities being analyzed.
	Timeliness	4/5 The index should be assessed to ensure that it uses the most recent Census data available, as the data is updated every 10 years
Variable selection	Comprehensiveness	4/5 The SVI includes a diverse range of socio-demographic, economic, and environmental variables, but it could potentially include more cultural variables
	Appropriateness	5/5 The selected variables are relevant to the specific context and goals of the social equity assessment for coastal communities
Tradeoff understanding	Aggregation method	4/5 The SVI uses PCA and cluster analysis, which are appropriate methods for capturing patterns among multiple dimensions of vulnerability but might still not fully capture all complex interactions between dimensions.
	Non-linear relationship	3/5 It is unclear whether the index accounts for potential non-linear relationships between vulnerability variables
	Weighting and normalization	4/5 Weighting and normalization techniques are used, but their appropriateness and robustness might need further assessment
Local sensitivity	Spatial resolution	4/5 The SVI captures local-scale variations in vulnerability but could benefit from finer resolution data
	Context-specific factors	4/5 The index accounts for some context-specific factors influencing vulnerability, but might not cover all relevant factors
	Local data integration	3/5 The index uses federal data sources and although recently updated for AdaptVA it previously was dated for nearly eight years.

Cultural and social norm considerations	Cultural diversity	3/5 The SVI might not fully account for diverse cultural practices and values like Indigenous populations or religious diversity
	Social norms and behaviors	1/5 It does not consider the impact of social norms and behaviors on vulnerability
	Local knowledge and adaptation strategies	3/5 The index for Virginia does not incorporate the preference of green or grey adaptation strategies
Usability	Interpretability	4/5 The index is relatively easy to understand and interpret
	Accessibility	4/5 The index is accessible to a wide range of users, although it may be challenging for non-experts to fully comprehend
	Actionability	4/5 The index provides actionable insights to inform policy and planning decisions however there are few examples in literature of it being applied in practice.

Please note that the scores provided are only an approximate assessment.

The scores for the VIMS SVI evaluation were derived through a systematic analysis of the index's documentation, methodology, and relevant literature. In doing so, key factors were considered in the evaluation process.

Variable selection involves an assessment of the comprehensiveness and appropriateness of the selected variables. For example, the SVI includes a diverse range of socio-demographic, economic, and environmental variables but could potentially include more cultural variables (Cutter et al., 2003).

Tradeoff understanding was evaluated by examining the index's aggregation method, non-linear relationship handling, and weighting and normalization techniques. The SVI uses cluster analysis, an appropriate method for capturing patterns among multiple dimensions of vulnerability, but it might not fully capture all complex interactions between dimensions (Aldrich & Meyer, 2015). In addition to cluster analysis, the VIMS SVI also employs Principal Component Analysis (PCA) for aggregating and reducing the dimensionality of the data. PCA is a widely used technique that helps identify key patterns and relationships within large datasets, which can be particularly useful for multidimensional indices like the VIMS SVI (“Principal Component Analysis for Special Types of Data,” 2002)

PCA has limitations in both social indicators and hyperspectral target recognition in remote sensing (Libório et al., 2022). In social indicators, PCA is limited by the assumption of linearity, sensitivity to outliers, the choice of the number of components to retain, and its inability to capture unobserved variables (Prasad & Bruce, 2008). In remote sensing, the assumption of linearity, spectral variability, sensitivity to noise, and the need to select the optimal number of components are the main limitations of PCA (Libório et al., 2022). However, researchers have proposed various techniques to address these limitations, including robust PCA, truncated PCA, and kernel PCA. It is important to use PCA in conjunction with other methods for more reliable data analysis and target recognition (Libório et al., 2022; Prasad & Bruce, 2008; "Principal Component Analysis for Special Types of Data," 2002).

Local sensitivity was assessed by looking at the spatial resolution, context-specific factors, and local data integration. The index captures local-scale variations in vulnerability but could benefit from finer resolution data and more recent updates to the data sources (Center for Coastal Resources Management et al., 2022)

Cultural and social norm considerations were analyzed by reviewing the extent to which the index accounts for cultural diversity, social norms and behaviors, and local knowledge and adaptation strategies. For example, the index might not fully account for diverse cultural practices and values like Indigenous populations or religious diversity (Adger, 2006).

Usability was assessed by evaluating the index's interpretability, accessibility, and actionability. The index is relatively easy to understand and interpret, accessible to a wide range of users, and provides actionable insights to inform policy and planning decisions (Füssel & Klein, 2006)

VIMS SVI Scorecard Application

When combining the aspects of each component the total component scores from Table 9 are as follows:

- Data Quality: 13/15
- Variable Selection: 9/10
- Tradeoff Understanding: 11/15
- Local Sensitivity: 11/15

- Cultural and Social Norm Considerations: 7/15
- Usability: 12/15

In the context of coastal climate resilience planning, using the VIMS SVI can help planners determine the social vulnerability of communities and prioritize resources accordingly. The comparative scores provide insights into the strengths and areas for improvement of the index, assisting planners in evaluating its suitability for their specific goals and priorities.

For instance, the VIMS SVI demonstrates strong performance in data quality (13/15) and variable selection (9/10), suggesting that the index utilizes dependable and pertinent data sources, such as the U.S. Census Bureau. The index encompasses a comprehensive range of socio-demographic, economic, and environmental variables, including income, education, and housing, making it well-suited for evaluating social vulnerability in coastal communities.

However, there may be room for improvement in capturing cultural diversity and social norms (7/15). For example, the VIMS SVI could further consider factors like language barriers, Indigenous practices, or religious diversity when assessing vulnerability. This would help ensure a more comprehensive understanding of the unique challenges faced by diverse populations.

The VIMS SVI also performs moderately in local sensitivity (11/15) and tradeoff understanding (11/15). Although it captures some context-specific factors, such as coastal flooding risks and sea-level rise, it may not account for all relevant local factors, like specific land-use patterns or community-based adaptation strategies. Additionally, while the VIMS SVI employs cluster analysis for aggregation, it may not fully capture complex interactions between dimensions of vulnerability or potential non-linear relationships between variables.

When using the VIMS SVI for coastal climate resilience planning, decision-makers can leverage its strengths in data quality and variable selection while being aware of its limitations in capturing cultural diversity, social norms, and certain local factors. Planners can then consider supplementing the VIMS SVI with additional information or alternative indices to address these limitations and create a more robust vulnerability assessment for informed decision-making.

Comparisons of Multiple Social Equity-Related Indices

While the CDC SVI and VIMS SVI are valuable in specific contexts, it is important to consider a range of social equity planning related indices to ensure a comprehensive understanding of vulnerability. In Table 10 there are a selection of social equity related indices are evaluated based on each component identified in the scorecard. This included the CDC EJI, Elizabeth River (ER) EJI, and the TES. For the individual evaluation of those not provided in the text of this chapter refer to Appendix C.

Table 10: Scorecard for Five Different Social Equity Related Indices

	CDC SVI	**VIMS SVI**	**CDC EJI**	**ER EJI**	**TES**
Data Quality (15)	13	13	13	12	13
Variable selection (10)	10	9	9	9	9
Tradeoff Understanding (15)	12	11	11	11	11
Local Sensitivity (15)	10	11	11	11	13
Cultural considerations (15)	7	7	9	9	9
Usability (15)	14	12	12	12	14
Final Score (85)	**66**	**63**	**65**	**64**	**69**

4.4.3 Interpreting Results

The results of the social equity scorecards for the CDC Social Vulnerability Index (SVI), VIMS Environmental Justice Index (EJI), and Tree Equity Score (TES) provide valuable insights into the strengths and weaknesses of each index, as well as guidance on when and where these indices may be most useful. Each index has its unique context and goals, and the scorecards can help users understand the potential applicability and limitations of each index in different scenarios.

The CDC SVI is a comprehensive index that focuses on the vulnerability of communities to various socio-demographic, economic, and environmental factors. It is particularly useful in assessing the vulnerability of populations to public health threats and natural disasters. The index is well-suited for informing policy and planning decisions that aim to enhance community resilience and reduce social disparities. However, it may not fully account for local knowledge, cultural diversity, or social norms and behaviors that can influence vulnerability. Thus, the CDC

SVI is most appropriate for broad-scale analyses and should be supplemented with local data and context-specific factors when used at a finer scale or in culturally diverse settings.

The VIMS EJI is specifically designed to assess environmental justice issues in the context of coastal communities, such as the Elizabeth River Watershed. Its strength lies in its ability to capture local-scale variations in vulnerability and consider context-specific factors. This makes the VIMS EJI particularly useful for addressing environmental justice concerns in coastal areas, where the impacts of climate change, pollution, and other environmental stressors are pronounced. However, like the CDC SVI, the VIMS EJI might not fully account for diverse cultural practices, social norms, or local knowledge and adaptation strategies. It is best used in coastal communities and should be supplemented with additional data and context when applied in other settings.

An example where the CDC SVI could be particularly useful, in contrast to the VIMS SVI, is in the context of public health emergencies and natural disasters. The CDC SVI could help identify communities with greater vulnerability to the impacts of such events, allowing for targeted allocation of resources and support to those most in need, ultimately enhancing community resilience and promoting social equity. The VIMS SVI may be more useful than the CDC SVI in situations where the focus is specifically on coastal communities and their vulnerability to climate change-related risks, such as sea-level rise, coastal flooding, and storm surges. The VIMS SVI is tailored to the unique challenges faced by these coastal communities, including their dependence on marine ecosystems and resources, as well as the specific environmental and socio-economic factors that contribute to their vulnerability. By providing a more context-specific assessment of vulnerability in coastal areas, the VIMS SVI can better inform targeted policies, planning, and adaptation strategies for coastal resilience and sustainable development, addressing the needs of these communities more effectively than the more generalized CDC SVI.

The Tree Equity Score (TES) is a unique index that assesses tree equity in urban areas, considering the distribution of tree canopy, socio-demographic factors, and potential benefits of trees for public health, climate resilience, and environmental quality. The TES is particularly valuable for informing urban forestry policy and planning decisions aimed at promoting tree equity and addressing environmental justice concerns in cities. However, the TES might not fully capture cultural diversity, social norms, or local knowledge related to tree planting and maintenance. The TES is most useful in urban settings, and its application in rural or non-urban contexts may require additional data and contextual information.

Each index serves a specific purpose and has its unique strengths and limitations. The CDC SVI is best suited for broad-scale vulnerability assessments, while the VIMS EJI is tailored for coastal communities and the TES focuses on urban tree equity. Users should carefully consider the context, goals, and available data when selecting an index for their analysis and supplement the chosen index with additional information as needed to ensure a comprehensive and accurate assessment of social equity and environmental justice issues.

Some shortcomings were observed in the evaluation of these indices. For instance, the CDC SVI and VIMS EJI might not fully account for cultural diversity, social norms, or local knowledge and adaptation strategies. Additionally, these indices may have limitations in capturing complex interactions between vulnerability variables or non-linear relationships. The VIMS EJI, while adept at capturing local-scale variations in vulnerability, may benefit from finer resolution data and better integration of local data sources. The Tree Equity Score (TES), though specifically designed for urban settings, might face similar limitations in capturing cultural nuances and the influence of social norms on tree planting and maintenance.

These limitations may be attributed to the inherent challenges in measuring social vulnerability and environmental justice issues using a single index. The complexity of these concepts and the numerous factors that contribute to vulnerability and equity require the use of multiple variables and data sources, which can be difficult to integrate into a single, comprehensive index. Additionally, the diversity of contexts, cultures, and social norms across different communities presents challenges in creating an index that is universally applicable and accurately captures the nuances of each unique setting. To address these limitations and improve the accuracy and applicability of these indices, it is crucial to supplement them with additional data, context-specific factors, and local knowledge when conducting assessments of social equity and environmental justice.

4.5 Discussion & Concluding Remarks

The evaluation of various social vulnerability and environmental justice indices highlights the importance of incorporating local data and context in assessments. A comprehensive understanding of the vulnerabilities and inequities within communities requires a more nuanced approach that takes into consideration the unique characteristics and circumstances of the populations being studied. This can be achieved by utilizing local data sources and collaborating with community stakeholders to ensure that their knowledge and perspectives are incorporated into the analysis.

Using multiple indicators for vulnerability is another key aspect of robust assessments. Vulnerability is a multi-dimensional concept, and relying on a single indicator or a limited set of indicators may not capture the complexity of the factors contributing to vulnerability. By employing a diverse range of socio-demographic, economic, environmental, cultural, and behavioral indicators, a more comprehensive understanding of the vulnerabilities within communities can be achieved.

Assessing spatial and temporal vulnerability dynamics is also crucial in understanding how vulnerabilities evolve over time and vary across different locations. Monitoring changes in vulnerability indices can provide valuable insights into the effectiveness of policies and interventions aimed at reducing disparities and enhancing resilience. Furthermore, analyzing spatial patterns of vulnerability can help identify areas or communities that are disproportionately affected and prioritize resources for those most in need.

Enhancing transparency and communication in indices is another important aspect of their development and application. Vulnerability indices should be designed in a way that makes them easily interpretable and accessible to various stakeholders, including policymakers, practitioners, and community members. Effective communication of index results can address underlying issues and facilitate informed decision-making. Additionally, transparency in the methods and data sources used in the development of these indices can help build trust and credibility among stakeholders.

Regularly updating and refining vulnerability indices is essential to ensure that they remain relevant and accurately reflect the changing dynamics of communities. As new data becomes available and our understanding of vulnerability factors evolves, it is important to incorporate these updates into the indices to maintain their accuracy and usefulness in guiding policy and planning decisions.

Transitioning to mapping particular social indicators with climate risks is a valuable approach to break down and prioritize the most important factors contributing to vulnerability. By overlaying social vulnerability data with climate risk data, such as flood zones, heat exposure, or storm surge areas, it becomes possible to identify the most pressing challenges faced by communities and allocate resources more effectively. This integrated approach can help create targeted, context-specific interventions that address both the social and environmental dimensions of vulnerability, ultimately leading to more resilient and equitable communities. In conclusion, the development and application of social vulnerability and environmental justice indices should be an ongoing, iterative process that incorporates local context, multiple indicators, spatial and temporal dynamics, transparency, and regular updates to ensure their effectiveness in addressing the complex challenges faced by communities in the face of a changing climate.

5. Demonstrating the Impacts of Incorporating Social Equity into Decision-Making through Scenario Planning

5.1 Introduction

In the context of climate change adaptation planning, understanding, and addressing social vulnerability is crucial to ensure that adaptation strategies are equitable and inclusive. Traditional social vulnerability indices provide valuable insights into the factors contributing to vulnerability, such as income, race, and age. However, these indices may not fully capture the complex interplay between various social, economic, and environmental dimensions that contribute to vulnerability and may overlook marginalized communities' needs and experiences (Schlör et al., 2018).

To overcome these limitations, this chapter proposes an approach that integrates social equity considerations into coastal adaptation planning through scenario analysis. Scenario planning is a powerful tool for exploring different future pathways and their associated risks, opportunities, and trade-offs (Moser & Ekstrom, 2010).

Using a broader range of metrics and factors is necessary to address traditional social vulnerability indices' limitations. Other relevant indices, such as environmental justice and social equity, can offer additional insights into social vulnerability complexities (Birkmann et al., 2013). Considering a wider range of metrics and factors, such as access to healthcare, transportation, and social services, as well as social and economic dynamics contributing to vulnerability, is also vital (Aldrich & Meyer, 2015).

Managed retreat refers to the strategic relocation of people, infrastructure, and assets away from vulnerable coastal areas (Hino et al., 2017). Green infrastructure involves using natural systems and processes to address climate change impacts, such as wetlands and green roofs (Benedict & McMahon, 2006). Grey infrastructure refers to traditional engineered structures like seawalls and levees (Folke et al., 2016).

Previous studies, such as Cutter et al. (2003) and Adger et al. (2004), have explored the integration of social equity considerations in coastal adaptation planning (Adger et al., 2004; Cutter et al., 2003). However, this chapter offers a novel approach by specifically focusing on scenario analysis as a means of incorporating social equity considerations in objective decision-making processes for managed retreat, green infrastructure, and grey infrastructure.

This chapter explores how scenario planning can be tailored to the specific needs and characteristics of local communities and the key considerations for scaling these approaches across different geographic contexts. The research questions addressed in this chapter are:

1. How does the incorporation of social equity into objective decision-making impact the outcomes of managed retreat?
2. How does the incorporation of social equity into objective decision-making impact the outcomes of green infrastructure?
3. How does the incorporation of social equity into objective decision-making impact the outcomes of grey infrastructure?

The goal of this chapter is to analyze the potential of scenario analysis in addressing the limitations of traditional social vulnerability indices, provide recommendations for incorporating social equity considerations in coastal adaptation planning, and explore the connections between scenario planning, decision-making, and social equity outcomes.

5.2 Literature Review

The integration of social equity metrics in flood risk management planning is an emerging area of research, as climate change disproportionately affects vulnerable populations (Intergovernmental Panel on Climate Change, 2014). One approach that has been increasingly used to incorporate social equity into flood risk management planning is scenario planning (Preston et al., 2011).

Scenario planning is a structured process for exploring and preparing for multiple plausible future conditions (Swart et al., 2004). It helps identify potential impacts of flood risk management strategies on different subpopulations and social systems (Moser & Ekstrom, 2010). By engaging a diverse range of stakeholders, including community members, policymakers, and experts, adaptation planners can better comprehend the social, economic, and environmental dynamics contributing to vulnerability (Tompkins et al., 2008).

Green infrastructure and grey infrastructure are two contrasting approaches to flood risk management. Green infrastructure focuses on utilizing natural or nature-based solutions, such as wetlands, dunes, and green roofs, to reduce flood risks (Barbosa et al., 2012; Benedict & McMahon, 2006). These solutions are known to provide additional ecosystem services and public health benefits (Kabisch et al., 2016; Narayan et al., 2017; Temmerman et al., 2013). In contrast, grey infrastructure comprises traditional engineering approaches, such as flood walls, levees, and drainage systems (Aerts et al., 2018). Grey infrastructure projects can effectively reduce flood risks but may also have negative impacts on public health and the environment (Wamsler et al., 2014).

Gentrification and climate gentrification are important factors to consider when incorporating social equity metrics into flood risk management planning. Gentrification refers to the process by which low-income communities are displaced by higher-income residents due to rising property values and neighborhood improvements (Lees et al., 2013). Climate gentrification is a specific form of gentrification resulting from the implementation of climate adaptation measures, such as green infrastructure or managed retreat (Anguelovski et al., 2019; Keenan et al., 2018).

Implementing green infrastructure projects can lead to gentrification and displacement of vulnerable populations if not done equitably (Cole et al., 2017; Rigolon et al., 2018). Similarly, managed retreat strategies may disproportionately affect low-income communities and marginalized populations, exacerbating existing inequalities (Graham et al., 2016; Siders, 2019c). To ensure equitable outcomes, decision-makers must consider the potential social equity implications of green and grey infrastructure projects and develop strategies to mitigate these impacts (Chakraborty et al., 2019).

The literature reveals an increasing interest in incorporating social equity metrics into flood risk management planning using scenario planning. More research is needed to understand the potential trade-offs and implications of different flood risk management strategies, such as green and grey infrastructure, managed retreat, and nature-based solutions, on vulnerable populations and social systems (Pelling & Garschagen, 2019). Addressing gentrification and climate gentrification is essential for ensuring that flood risk management strategies promote social equity and protect the most vulnerable communities (Meerow et al., 2016, 2019)

5.3 Methodology

5.3.1 Scenario Planning

This study employs scenario planning and analysis as a key methodological approach for evaluating the potential outcomes of different coastal adaptation strategies, with a focus on social equity considerations. The following six scenarios were chosen to provide a comprehensive understanding of how social equity considerations can influence the outcomes of various coastal adaptation strategies:

- Scenario 1: Managed retreat without specific social equity considerations.
- Scenario 2: Managed retreat with social equity considerations.
- Scenario 3: Green infrastructure without specific social equity considerations.
- Scenario 4: Green infrastructure with specific social equity considerations.
- Scenario 5: Grey infrastructure without social equity considerations.
- Scenario 6: Grey infrastructure with social equity considerations.

The scenario planning process involves several steps:

1. Identification of key drivers of change: The study will identify the main factors that could influence the outcomes of the different scenarios, such as socio-economic conditions (e.g., income levels, educational attainment), governance structures (e.g., local policies, decision-making processes), and environmental factors (e.g., sea level rise, land use changes) (Preston et al., 2011; Swart et al., 2004).

2. Impact assessment: The potential consequences of each scenario will be assessed, focusing on social equity implications using specific metrics or indicators (e.g., distribution of costs

and benefits, access to resources, and exposure to risks). The assessment will also consider potential unintended consequences, such as gentrification and displacementact assessment: The potential consequences of each scenario will be assessed, focusing on social equity implications, the distribution of costs and benefits, and potential unintended consequences, such as gentrification and displacement (Anguelovski et al., 2019; Moser & Ekstrom, 2010).

3. Comparison of scenarios: The results of the impact assessments will be compared across the different scenarios to identify the most desirable or appropriate adaptation strategy, considering social equity and other relevant criteria.

5.3.2 Data

Geographic Information Systems (GIS) will be used to analyze spatial data on flood risks, social vulnerability, and the distribution of infrastructure projects in the study area. The GIS analysis will include data layers on housing vulnerability, asthma rates, redlining districts, flood zones, and infrastructure projects to help identify potential areas of concern and inform the impact assessments of the different scenarios (Moser & Ekstrom, 2010).

The Hampton Roads Planning District Commission (HRPDC) Coastal Resiliency Program provides a database of past, present, and future projects. The Flood Risk Dashboard offers a useful tool for evaluating flood risk in the Hampton Roads region of Virginia. The dashboard includes a variety of interactive maps and tools that allow users to explore flood zones, historical flood events, and flood insurance information. Although this resource is not comprehensive of all projects taking place in Virginia, it provides a basis for current and planned major grey and green infrastructure projects.

5.4 Scenario Analysis

5.4.1 Scenario Details

Scenario 1: Managed retreat without specific social equity considerations.

Scenario 2: Managed retreat with social equity considerations.

Scenarios 1 and 2 pertain to managed retreat, which is a planning effort that focuses on human behavior for adaptation solutions and relocates individuals away from high-risk areas. Managed retreat can be implemented through various approaches, such as land-use regulations, voluntary buyouts, and community-led relocation effort (Siders, 2019c).

Scenario 3: Green infrastructure without specific social equity considerations.

Scenario 4: Green infrastructure with specific social equity considerations.

Scenarios 3 and 4 are concerned with green infrastructure, an adaptation solution that integrates environmental design into infrastructure. Examples include incorporating green roofs, rain gardens, and other green spaces to mitigate urban heat island effects and flooding risks (Monteiro et al., 2020).

Scenario 5: Grey infrastructure without social equity considerations.

Scenario 6: Grey infrastructure with social equity considerations.

Scenarios 5 and 6 address the use of gray infrastructure, which may provide more protection against flooding but lacks environmental benefits. Examples of grey infrastructure include traditional flood management systems like deep tunnels, pipe networks, dams, levees, and stormwater drainage systems (Chen et al., 2021).

5.4.2 Objectives

The following objectives serve as general goals for coastal climate change adaptation solutions. The social equity component is addressed in parenthesis and is only considered for scenarios 2, 4, and 6.

1. Reduce the impacts of climate risks on infrastructure and communities (while prioritizing support for the most socially vulnerable).
2. Minimize future costs of climate impacts (by addressing systemic issues that perpetuate social inequities).
3. Protect and restore ecosystems and their services (ensuring equitable distribution of ecosystem services and benefits for vulnerable communities).
4. Enhance public health and safety (by targeting the specific needs and vulnerabilities of marginalized communities).

5. Encourage community participation and empowerment in adaptation planning (through inclusive engagement of vulnerable and marginalized groups).

5.4.3 Scenario 1 and 2: Managed Retreat

Managed retreat is a complex process that involves assessing vulnerable areas, engaging with affected communities, implementing the relocation process, and monitoring and evaluating its effectiveness. Scenario 2 aims to reduce vulnerability to climate-related hazards while ensuring equity and justice for affected communities (Siders, 2019c). Coastal areas are particularly susceptible to the impacts of climate change, making flood risk management essential for reducing vulnerability to climate-related hazards.

Table 11 outlines four key objectives and associated actions for implementing managed retreat, a strategy to protect vulnerable communities from the impacts of climate change by relocating or resettling them away from high-risk areas. The table includes measurable metrics for each objective and action to track progress and ensure effectiveness in achieving the desired outcomes.

Table 11: Managed Retreat Objectives, Actions, and Measurable Metrics for Climate Change Adaptation and Resilience Planning.

Primary Objective	**Scenario Actions**	**Scenario 1 Metrics**	**Scenario 2 Metrics**
Reduce the impacts of climate risks on infrastructure and communities (while prioritizing support for the most socially vulnerable).	Implement buyout programs; relocate communities	Number of households relocated, percent participation of eligible candidates, and insurance claim payouts	Number of socially vulnerable households relocated, percentage of participation based on demographics, ratio of renters to owners relocated
Minimize future costs of climate impacts (by addressing systemic issues that perpetuate social inequities).	Limit new development in high-risk areas	Percentage of wetlands preserved, acreage of high-risk land acquired, tree canopy coverage percentage	Percentage of wetlands preserved, number of displaced individuals, disparities in median household income, small business growth and development, tree canopy growth in redlined communities.

Protect and restore ecosystems and their services (ensuring equitable distribution of ecosystem services and benefits for vulnerable communities).	Reforest areas; restore wetlands locally	Number of trees planted, reforestation rate per year, forest canopy coverage percentage, wetland acreage restored, wetland functional assessments conducted	Trees planted in underserved areas, reforestation rate based on need, forest canopy coverage by community demographics, wetland restoration in underserved areas, wetland functional assessments by community demographics
Enhance public health and safety (by targeting the specific needs and vulnerabilities of marginalized communities).	Create buffer zones to prevent hazardous exposure for public health	Buffer zone width in feet/meters, pollutant levels within buffer zones, groundwater quality presence or absence of hazardous substances or concentration levels, number of hazardous waste violations within buffer zones, completion of emergency response plans and number of drills or exercises conducted	Increased buffer zone width in socially vulnerable communities, lowered pollutant levels accepted in areas with high social vulnerability, increased groundwater quality testing in underserved communities, increased hazardous waste oversight in marginalized communities, community-involved emergency response planning in socially vulnerable communities
Encourage community participation and empowerment in adaptation planning (through inclusive engagement of vulnerable and marginalized groups).	Engage communities and develop a comprehensive plan for relocation, resettlement, and community empowerment	Number of community engagement events, number of households or individuals relocated, number of households or individuals resettled, number of community-led initiatives or programs implemented	Engagement events for marginalized groups, relocation of people by demographics, resettlement by demographics, programs developed for vulnerable communities

Managed retreat is a complex and challenging strategy that requires collaboration and engagement with vulnerable communities to ensure equitable outcomes. The objectives and associated actions outlined in the table focus on minimizing the costs of climate impacts, protecting and restoring ecosystems, enhancing public health and safety, and encouraging community participation and empowerment in adaptation planning. The metrics chosen for each objective and action are designed to measure progress and effectiveness, with a focus on social equity and community engagement.

Scenario 1 focuses on reducing climate risks on infrastructure and communities by implementing buyout programs and relocating communities. The scenario 1 metrics primarily measures the number of households relocated, percent participation of eligible candidates, and insurance claim payouts. In contrast, scenario 2 aims to minimize future costs of climate impacts by addressing systemic issues that perpetuate social inequities. The scenario 2 metrics include the percentage of wetlands preserved, acreage of high-risk land acquired, and tree canopy coverage percentage, as well as metrics that measure the disparities in median household income and small business growth and development in redlined communities. The metrics for scenario 2 incorporate a social equity lens, which is not as explicitly present in scenario 1. Detailed descriptions of the metrics can be found in Appendix D for scenario 1 and Appendix E for scenario 2.

Exploring Social Equity in Managed Retreat in Norfolk, Virginia

The city of Norfolk, Virginia, is implementing a managed retreat strategy as part of its larger climate change adaptation plan, which includes identifying vulnerable areas and acquiring properties in those areas through voluntary buyouts (US Housing and Urban Development, 2022).

To understand the implications of managed retreat in Norfolk, it is essential to consider the intersection of flood risk and social equity. Managed retreat includes moving families away from their homes and social networks. If managed retreat is implemented in areas near hospitals and schools, decision-makers must consider the potential impacts of relocation on access to healthcare and education. Without access to these essential services, vulnerable populations may be further disadvantaged by managed retreat.

Figure 11 presents a flood risk insurance map (FIRM) of Norfolk, Virginia, overlaid with schools and hospitals. This map helps decision-makers identify areas where managed retreat may have significant impacts on critical infrastructure and vulnerable populations, which is vital for assessing the potential social equity implications of managed retreat.

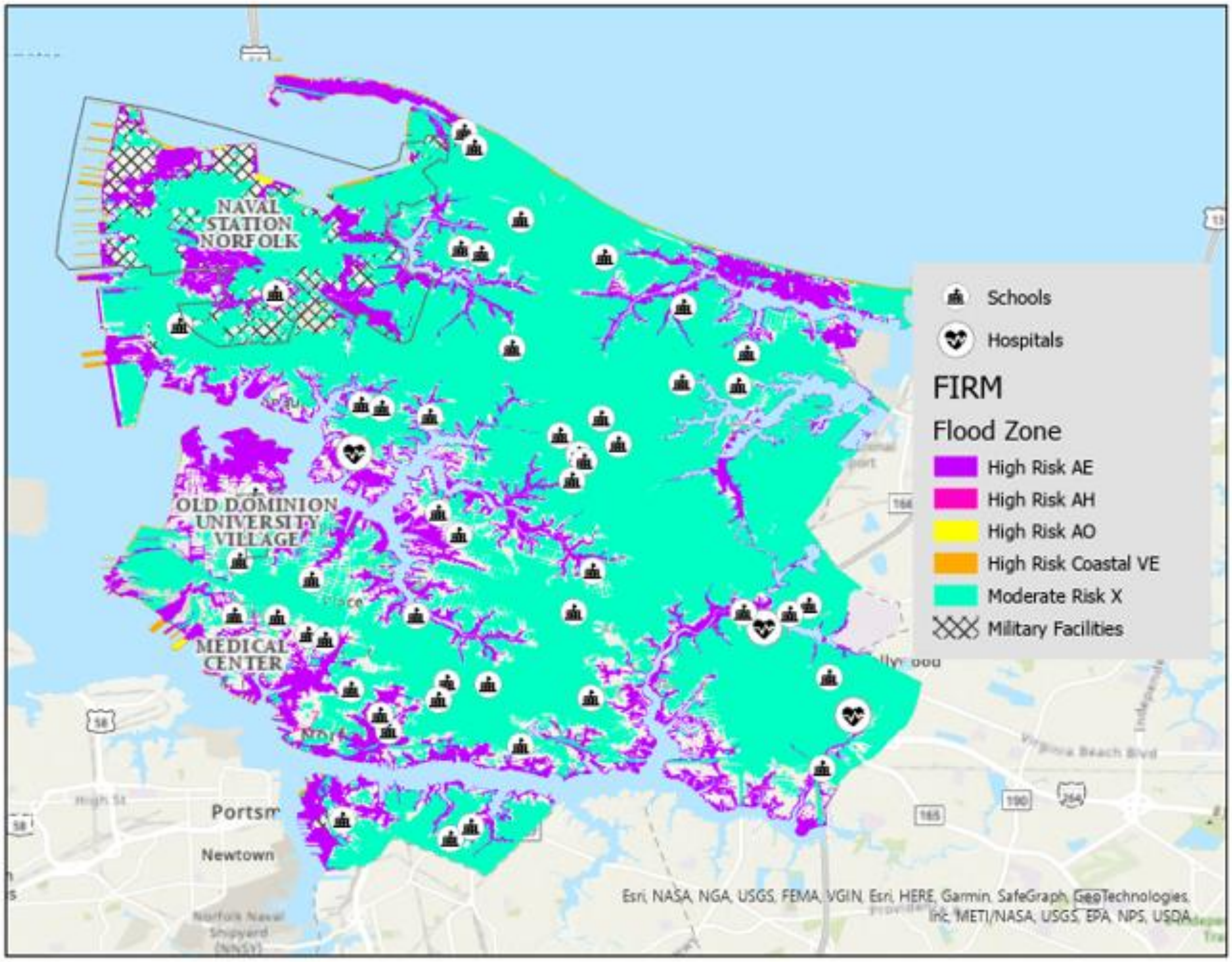

Figure 11: Flood Insurance Risk Map of Norfolk with Schools and Hospitals (*FIRM Flood Insurance Rate Map*, 2022; The City of Norfolk, 2018)

Norfolk's managed retreat policy must face cultural considerations. Practices like redlining have created generational distrust from communities towards the government (Li & Yuan, 2022). Incorporating a redline map of a flood insurance risk map is a crucial component of social equity indicator breakdown analysis of flood risk management in Norfolk, Virginia.

Figure 12 provides historical context for the current distribution of flood risk in the city and highlights the intersection of flood risk and social equity. The historically marginalized neighborhoods are indicated in orange and red on the map. The Homeowners' Loan Corporation (HOLC) rated these properties as "hazardous' (D, red), "definitely declining" (C, orange), "still desirable" (B, yellow), and "best" (A, green).

Based on the new relocation of these families, there are financial costs to consider. Relocating to a less flood-prone area might reduce flood risk and flood insurance costs, but climate gentrification can cause an inflation of property values as low flood-prone areas become more desirable (Keenan et al., 2018).

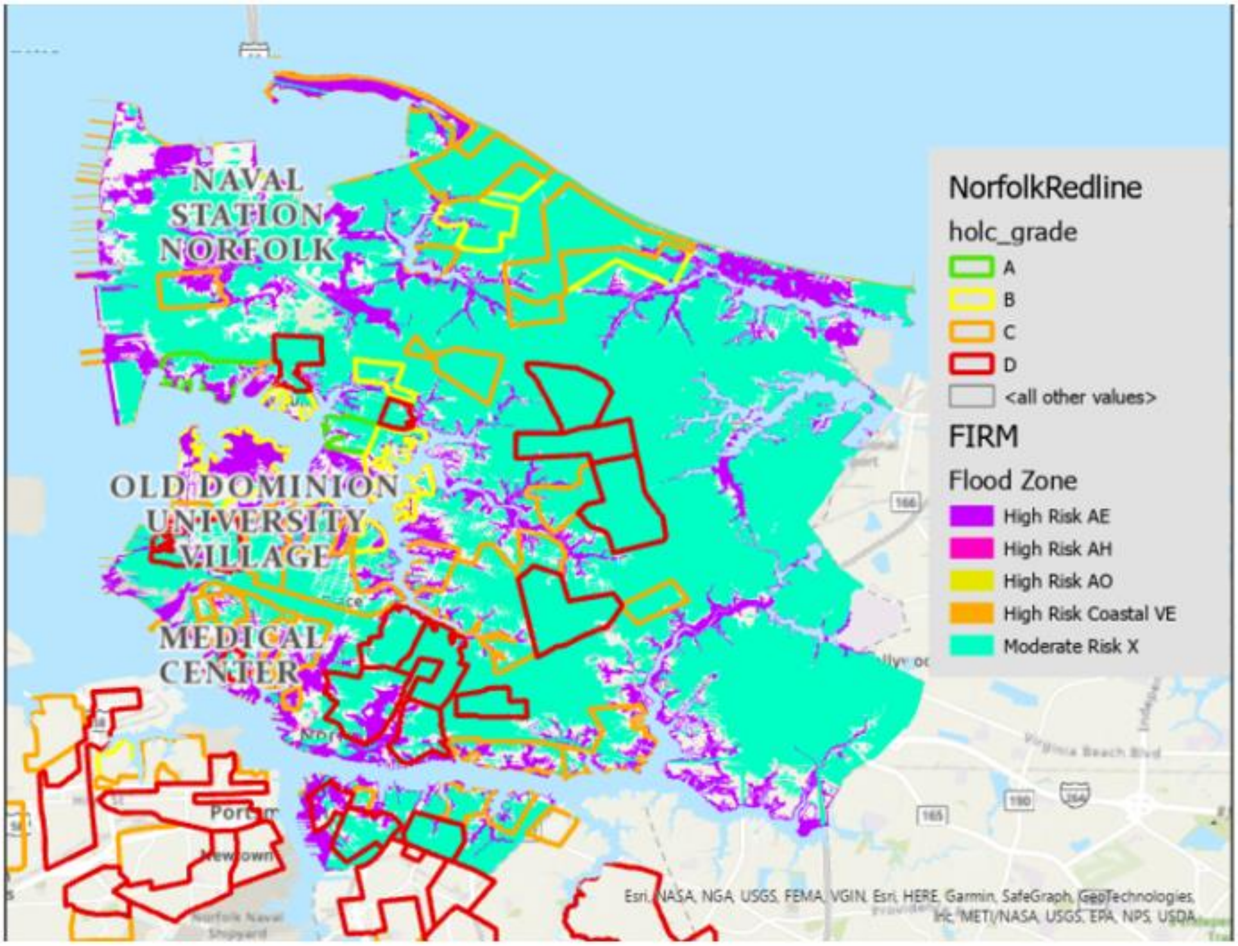

Figure 12: Norfolk Flood Insurance Risk Map with Redlining Map (*FIRM Flood Insurance Rate Map*, 2022; Nelson et al., 2022; The City of Norfolk, 2018)

Figure 13 shows a closer look at the downtown area of Norfolk, Virginia, including the major economic districts. Downtown Norfolk is particularly vulnerable to flooding due to its location in a low-lying coastal area. The historic practice of redlining has contributed to the concentration of low-income and marginalized communities in flood-prone areas in the downtown area (Li & Yuan, 2022).

Figure 13: Downtown Norfolk Flood Insurance Risk Map with Redlining Map (*FIRM Flood Insurance Rate Map*, 2022; Nelson et al., 2022; The City of Norfolk, 2018)

Vulnerable populations, such as low-income residents, elderly residents, and residents with disabilities, are more likely to experience negative impacts from flooding and may not have the resources to recover from flood damage. Protecting critical infrastructure such as hospitals and government offices is an important component for the city's economic resilience and sustainability.

Implementing managed retreat as part of climate change adaptation and resilience planning requires considering social equity implications and engaging with vulnerable communities. By combining objectives, actions, and metrics that prioritize social equity and community engagement, decision-makers can create more inclusive and effective strategies. Understanding the historical context of flood risk distribution, considering cultural factors, and addressing the potential consequences of relocation on access to essential services are crucial elements in developing a comprehensive and equitable managed retreat plan.

5.4.4 Scenario 3 and 4: Green Infrastructure

Green infrastructure refers to an approach to land use planning and management that emphasizes the preservation and restoration of natural systems and processes, with the goal of improving the ecological, social, and economic functions of urban and rural landscapes (Chen et al., 2021). Green infrastructure strategies often involve the use of natural or semi-natural features, such as parks, forests, wetlands, and green roofs, to manage stormwater, reduce the urban heat island effect, improve air quality, provide habitat for wildlife, and enhance recreational opportunities (Benedict & McMahon, 2006). By incorporating green infrastructure into urban design and development, communities can create more resilient and sustainable environments, while also improving the health and well-being of residents (Monteiro et al., 2020).

Table 12 presents the scenario actions and corresponding metrics for two different scenarios of green infrastructure implementation. Scenario 3 focuses on minimizing the future costs of climate impacts by using green infrastructure while scenario 4 aims to ensure equitable distribution of green infrastructure benefits for vulnerable communities. Green infrastructure refers to the use of natural systems, such as trees and wetlands, to manage stormwater, reduce urban heat island effects, and enhance biodiversity. It offers multiple benefits, including improved air and water quality, reduced flooding, and enhanced recreational opportunities. The actions proposed in these scenarios aim to maximize these benefits while minimizing the risks associated with climate change.

Table 12: Green Infrastructure Objectives, Actions, and Measurable Metrics for Climate Change Adaptation and Resilience Planning.

Scenario Objective	**Scenario Actions**	**Scenario 3 Metrics**	**Scenario 4 Metrics**

Minimize future costs of climate impacts (by addressing systemic issues that perpetuate social inequities).	Limit new development in high-risk areas, increase green infrastructure in vulnerable communities, and enforce building codes and standards.	Percentage of high-risk land acquired for conservation, green infrastructure coverage percentage in vulnerable communities, number of buildings retrofitted to meet higher standards.	Percentage of high-risk land acquired for conservation in underserved communities, green infrastructure coverage percentage in underserved communities, number of buildings retrofitted to meet higher standards in underserved communities, disparities in access to green infrastructure projects across demographic groups.
Protect and restore ecosystems and their services (ensuring equitable distribution of ecosystem services and benefits for vulnerable communities).	Plant trees, create green corridors, restore wetlands and habitats, and protect natural areas.	Number of green infrastructure projects installed that address specific ecosystem services, percentage of population living within a half-mile radius of a green infrastructure project, number of trees planted in green infrastructure projects, wetland acreage restored.	Number of green infrastructure projects installed in underserved communities that address specific ecosystem services, percentage of population living within a half-mile radius of a green infrastructure project in underserved communities, number of trees planted in green infrastructure projects in underserved communities, wetland acreage restored in underserved communities, disparities in access to green infrastructure projects across demographic groups.
Enhance public health and safety (by targeting the specific needs and vulnerabilities of marginalized communities).	Create buffer zones to prevent hazardous exposure for public health, develop emergency response plans, and improve access to green spaces.	Buffer zone width in feet/meters, pollutant levels within buffer zones, groundwater quality, number of hazardous waste violations within buffer zones, and completion of emergency response plans and drills/exercises.	Increased buffer zone width in socially vulnerable communities, lowered pollutant levels accepted in areas with high social vulnerability, increased groundwater quality testing in underserved communities, increased hazardous waste oversight in marginalized communities, community-involved emergency response planning in socially vulnerable communities, and percentage increase in green space access for vulnerable communities.

Encourage community participation and empowerment in adaptation planning (through inclusive engagement of vulnerable and marginalized groups).	Create a Managed Retreat Task Force to engage communities and develop a comprehensive plan for relocation, resettlement, and community empowerment.	Number of community engagement events, number of households or individuals relocated, number of households or individuals resettled, and number of community-led initiatives or programs implemented.	Engagement events for marginalized groups, relocation of people by demographics, resettlement by demographics, programs developed for vulnerable communities, and participation rates of vulnerable and marginalized communities in planning and decision-making.

Green infrastructure employs natural systems to manage stormwater, mitigate heat island effects, enhance air and water quality, and promote biodiversity. Scenarios 3 and 4 examine the potential benefits of green infrastructure for climate adaptation, with varying degrees of focus on social equity. Scenario 3 centers on conventional green infrastructure implementation, while Scenario 4 emphasizes the incorporation of social equity considerations in the planning process. The metrics selected for each scenario mirror these distinct objectives; Scenario 3 primarily measures environmental outcomes, while Scenario 4 stresses equity-focused metrics such as community engagement and reduced disparities in access to green space. The analysis of these scenarios underscores the importance of integrating social equity considerations in green infrastructure planning and implementation and the potential trade-offs between environmental and equity-centered outcomes. Detailed descriptions of the metrics are available in Appendix F for scenario 3 and Appendix G for scenario 4.

Exploring Social Equity in Green Infrastructure

Figure 14 displays a map of various green infrastructure projects in Norfolk, Virginia. The CDC SVI indicators for the Housing and Transportation theme, which assess social vulnerability concerning access to affordable and safe housing as well as transportation, are superimposed on the map. These indicators help pinpoint areas where residents might encounter substantial challenges related to housing and transportation, potentially affecting their overall resilience to climate change and other hazards.

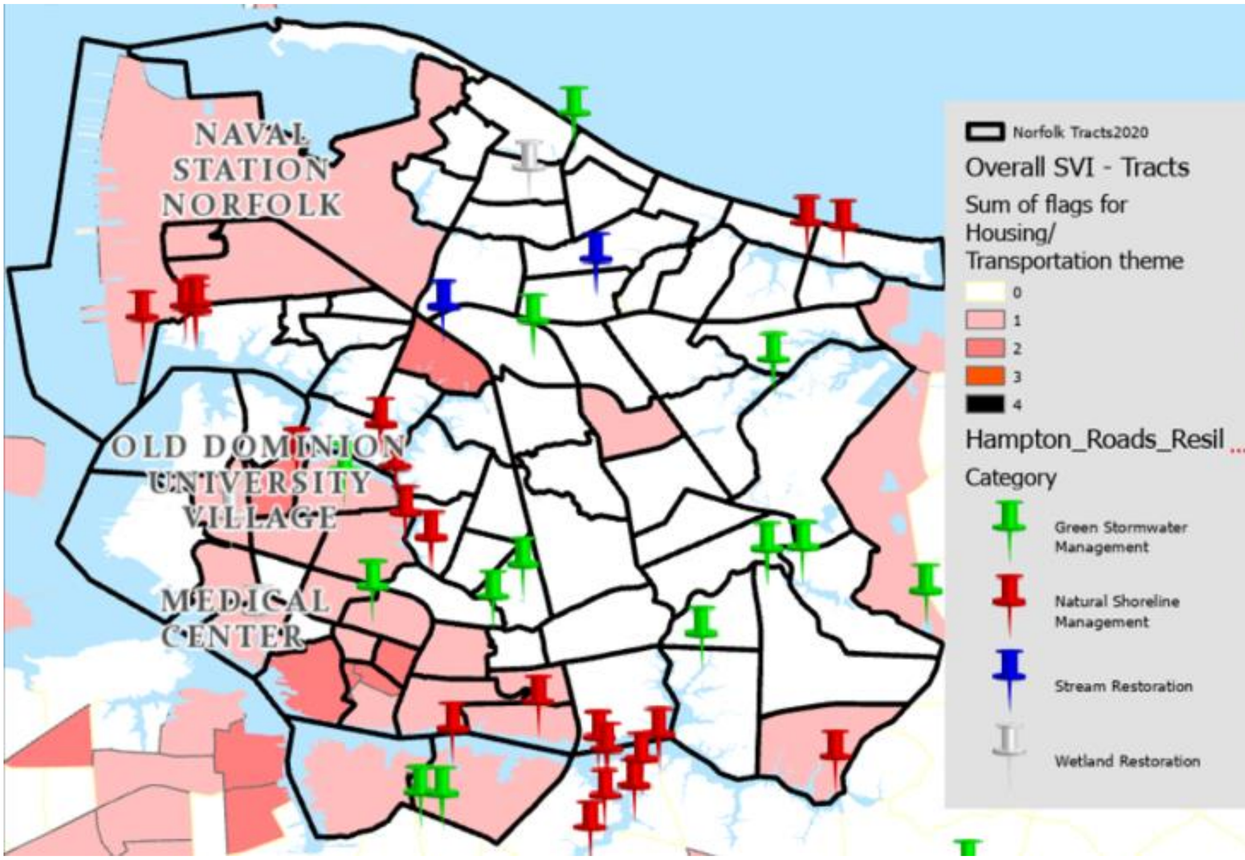

Figure 14: HRPDC Project Resilience Dashboard Green Infrastructure Projects and the Housing and Transportation Indicators from CDC SVI in Norfolk Virginia (CDC, 2022; HRPDC Coastal Resiliency Program, 2021).

The severity of climate change impacts on coastal real estate depends on an area's development level and geographic location. A study in Boston identified several injustices that socially vulnerable populations face due to green adaptation development, including the displacement of low-income residents, low prioritization of socially vulnerable communities, lack of representation in planning, and social and cultural exclusion of specific groups from developed green areas (Anguelovski et al., 2019).

5.4.5 Scenario 5 and 6: Grey Infrastructure

Grey infrastructure, such as flood walls or levees, is designed to protect against flooding and other climate-related hazards. However, the construction of these projects can also have negative impacts on public health, particularly for vulnerable populations such as children and the elderly (Brears, 2018).

Table 13 outlines two scenarios for grey infrastructure in the context of climate adaptation. Scenario 5 aims to reduce the risks of climate impacts on infrastructure and communities by improving grey infrastructure. Scenario 6 builds on this objective by addressing systemic issues that perpetuate social inequities, while minimizing future costs of climate impacts. The metrics listed in the table are intended to measure the effectiveness of the scenario actions in achieving these objectives.

Table 13: Grey Infrastructure Objectives, Actions, and Measurable Metrics for Climate Change Adaptation and Resilience Planning.

Scenario Objective	**Scenario Actions**	**Scenario 5 Metrics**	**Scenario 6 Metrics**
Minimize future costs of climate impacts (by addressing systemic issues that perpetuate social inequities).	Invest in grey infrastructure such as seawalls, levees, and drainage systems, upgrade existing infrastructure to withstand climate impacts, and implement land use regulations to reduce exposure to climate risks.	Number of critical infrastructure elements upgraded to meet higher standards, number of properties in low-lying areas protected from flooding and other hazards, and amount of land protected by infrastructure improvements.	Number of critical infrastructure elements upgraded to meet higher standards in vulnerable areas, number of vulnerable properties protected from flooding and other hazards, and percentage of vulnerable population living within the service area of infrastructure improvements.
Protect and restore ecosystems and their services (ensuring equitable distribution of ecosystem services and benefits for vulnerable communities).	Design grey infrastructure with green elements, implement low impact development techniques, and retrofit existing grey infrastructure with green infrastructure.	Percentage of green elements in grey infrastructure projects, amount of impervious surface retrofitted with green infrastructure, and amount of land protected by green infrastructure.	Percentage of infrastructure projects in vulnerable areas, amount of impervious surface retrofitted with green infrastructure in vulnerable areas, and percentage of vulnerable population living within the service area of grey infrastructure projects.

Enhance public health and safety (by targeting the specific needs and vulnerabilities of marginalized communities).	Design and implement infrastructure improvements to reduce health risks, such as air pollution, flooding, extreme heat, and water quality.	Reduction in air pollution levels, reduction in number of properties impacted by flooding, reduction in extreme heat days, improvement in water quality, and reduction in number of public health complaints.	Reduction in air pollution levels in vulnerable areas, reduction in number of properties impacted by flooding in vulnerable areas, reduction in extreme heat days in vulnerable areas, improvement in water quality in vulnerable areas, and percentage of vulnerable population living within the service area of infrastructure improvements that reduce health risks.
Encourage community participation and empowerment in adaptation planning (through inclusive engagement of vulnerable and marginalized groups).	Develop infrastructure plans and projects through community engagement and collaboration and establish mechanisms for ongoing communication and feedback.	Number of community engagement events, number of community-led initiatives or programs implemented, and percentage of vulnerable populations involved in planning and decision-making.	Number of community engagement events in vulnerable areas, number of community-led initiatives or programs implemented in vulnerable areas, percentage of vulnerable populations involved in planning and decision-making in vulnerable areas, and disparities in access to community engagement events and decision-making opportunities across demographic groups.

For scenario 5 and 6 of grey infrastructure, the primary objective is to reduce the impacts of climate risks on infrastructure and communities by implementing grey infrastructure solutions. The difference between scenario 5 and 6 is that scenario 6 incorporates social equity considerations into the objectives, whereas scenario 5 does not. The metrics for scenario 5 focus on risk reduction, health impacts, protected land, and property value protection. In contrast, scenario 6 includes metrics such as the reduction in air pollution levels in vulnerable areas and the percentage of low-income households served. By incorporating social equity considerations into the objectives, scenario 6 seeks to address systemic issues that perpetuate social inequities and ensure that vulnerable communities are not left behind in climate adaptation efforts. These metrics aim to promote equity in the distribution of benefits and services derived from grey infrastructure solutions. Detailed descriptions of the metrics can be found in Appendix H for scenario 5 and I for scenario 6.

Chapter 5: Demonstrating the Impacts of Incorporating Social Equity into Decision-Making through Scenario Planning

Exploring Social Equity in Grey Infrastructure

The city of Norfolk, Virginia is undertaking a major seawall project in partnership with the United States Army Corps of Engineers (USACE) to address rising sea levels and flooding. The $1.8 billion project aims to construct a comprehensive coastal storm risk management system spanning 10 miles along the city's waterfront, which will include flood walls, tide gates, and pump stations. It is designed to protect the city's downtown area, including its naval base, and is expected to be completed by 2035 (US Army Corp of Engineers, 2018).

Concerns have been raised about potential negative impacts of the seawall project. Asthma, a chronic respiratory condition that can be worsened by air pollution and construction-related dust, is highly prevalent in the same area as the concentration of grey infrastructure projects in downtown Norfolk (Kopnina, 2016). Additionally, seawalls can have significant ecological impacts on coastal ecosystems, including loss of habitat for marine organisms, alteration of natural coastal processes, and changes to the hydrodynamic and morphologic characteristics of the coastal zone (Hosseinzadeh et al., 2022).

Figure 15 shows a map of asthma rates in Norfolk with HRPDC projects overlayed. The grey infrastructure projects that include construction are highlighted as red boxes. The asthma rates are highest in the downtown area where construction will be heavily concentrated for the seawall construction.

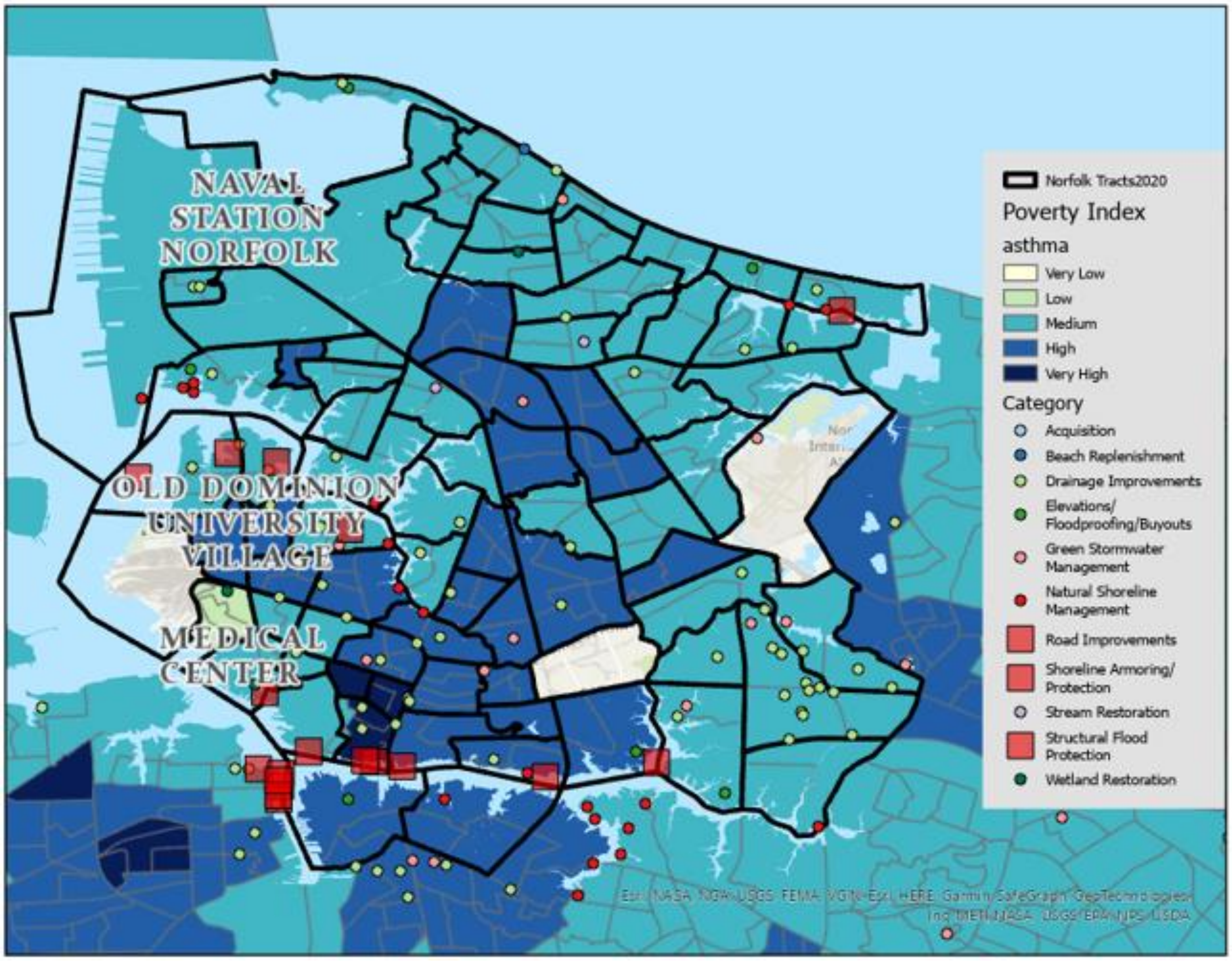

Figure 15: HRPDC Project Resilience Dashboard and the Asthma Rates in Norfolk, Virginia (American Forests, 2021; HRPDC Coastal Resiliency Program, 2021)

The high concentration of asthma rates in the downtown area, where the seawall construction will be heavily concentrated, raises concerns about potential negative health impacts on vulnerable populations, including children, the elderly, and those with respiratory conditions. These findings underscore the importance of incorporating social equity considerations into grey infrastructure planning and implementation to ensure that vulnerable populations are not disproportionately impacted by the negative consequences of climate adaptation measures. The following discussion will further explore the complex relationship between grey infrastructure, social equity, and climate adaptation, and provide recommendations for promoting equitable and effective climate adaptation planning.

A recent study analyzing user perceptions of the Pleasure Point Seawall in Santa Cruz County, California, USA, highlights the complex and nuanced perspectives of different stakeholder groups regarding the seawall's physical characteristics, environmental impacts, and socio-economic implications. This underscores the importance of considering the diverse perspectives and needs of stakeholders in coastal management and planning, particularly with respect to the potential consequences of coastal protection measures (Anderson et al., 2022).

5.5 Discussion and Concluding Remarks

This chapter analyzed different scenarios of adaptation planning solutions that do or do not incorporate social equity, highlighting the difference in metric selection and the importance of local social and cultural considerations in coastal adaptation planning. The analysis showed that decision-makers must prioritize the protection of vulnerable populations when implementing managed retreat strategies, including developing strategies to mitigate the impacts of relocation on access to healthcare and education. Green and nature-based solutions must be developed and implemented in an equitable and inclusive manner, prioritizing the protection of vulnerable populations and avoiding gentrification and displacement. Finally, the chapter discusses the consideration of potential negative impacts of grey infrastructure projects on public health and explores alternative flood risk management strategies that minimize these impacts.

To consider community needs and perspectives in coastal adaptation planning, a comprehensive, participatory approach can be helpful, incorporating a broader range of metrics and engaging community members in decision-making processes (Karakoc et al., 2020; Spielman et al., 2020). This approach should go beyond solely using social vulnerability indices, which may oversimplify social dynamics and lack data sufficiency for capturing the full spectrum of social vulnerabilities. Considering community needs and perspectives involves using a variety of metrics and factors alongside SVIs (Nguyen et al., 2017; Rufat et al., 2019). The scenario analysis presented in this chapter may be a useful tool for presenting how social equity considerations will impact metric selection. Future research should explore this approach in other regions to determine its transferability and should also consider the ecological and economic implications of flood risk management strategies.

The incorporation of social equity metrics into flood risk management planning is critical for developing effective and equitable strategies for reducing vulnerability to climate-related hazards. Decision-makers must consider the historical context of redlining, the potential impacts of managed retreat on access to healthcare and education, the negative impacts of grey infrastructure projects on public health, and the potential for green and nature-based solutions to lead to gentrification and displacement. By prioritizing the protection of vulnerable populations and implementing flood risk management strategies in an equitable and inclusive manner, it is possible to develop sustainable and effective strategies for reducing vulnerability to climate-related hazards

6. Thoughts, Conclusions, Future Direction

6.1 Revisiting the Original Problem

Coastal climate change adaptation is a complex challenge for policy makers as they strive to develop effective and equitable solutions for coastal communities facing the impacts of climate change. This research aimed to contribute to addressing this issue by focusing on the interactions among stakeholders and policies in coastal climate risk management and by identifying governance and policy recommendations to strengthen multilevel governance interactions.

The study employed a mixed-methods approach, including qualitative assessments and quantitative research, to provide insights into the complex network of people, programs, and policies involved in coastal climate change adaptation. The findings highlighted the importance of considering the interactions among stakeholders and policies, as well as the social inequities that occur, in coastal adaptation planning.

Incorporating social equity considerations into coastal climate adaptation planning is crucial to developing effective and equitable solutions. The study also emphasized the need for a comprehensive assessment framework that considers all relevant factors and indicators, including the potential impacts of climate change on infrastructure, ecosystems, and human communities.

Systems thinking plays a critical role in developing and implementing sustainable and equitable solutions to coastal climate change adaptation. A multidisciplinary approach, coupled with stakeholder engagement in the assessment process, can help mitigate the impacts of climate change on coastal communities and ensure that vulnerable populations are not left behind.

This research contributes to the growing body of knowledge on coastal climate change adaptation and provides a framework for systems engineers to develop and implement effective and equitable solutions. By doing so, we can help mitigate the impacts of climate change on coastal communities and ensure a sustainable and equitable future for all.

6.2 Methodologies

The methodologies employed in this dissertation reflect a mix of different analytical approaches that are tailored to address the complex systems questions surrounding coastal climate change adaptation. The research utilizes a range of qualitative methods to provide a comprehensive analysis of the network of people, programs, and policies involved in coastal climate change adaptation, as well as the social inequities that have occurred in coastal communities.

Chapter 2: This chapter employs a quantitative approach that uses the influence-dependence matrix methodology to analyze the relationships between stakeholders and policies in the context of coastal climate risk management (CCRM). The analysis is based on data collected through interviews with key stakeholders in Norfolk, Virginia, United States. The methodology provides a framework for quantifying and visualizing the interactions between stakeholders and policies.

Chapter 3: This chapter uses a qualitative research approach, specifically a series of stakeholder interviews, to explore the challenges and opportunities for integrating social equity into coastal climate adaptation planning in Norfolk, Virginia. The interviews provide valuable insights into the perspectives of stakeholders and the complexities involved in incorporating social equity considerations into planning efforts.

Chapter 4: This chapter employs a mixed methods approach that includes a literature review and the development of a scorecard for evaluating the efficacy of social equity-related indices. The analysis examines the limitations of various social vulnerability and environmental justice indices and their applicability in assessing the vulnerability and equity of communities in the face of a changing climate.

Chapter 5: This chapter uses scenario analysis and mapping as a tool to demonstrate how different social vulnerability indicators can be interpreted for different climate adaptation scenarios when social equity is involved. The methodology involves analyzing the potential impacts of informed social equity-based planning in different adaptation strategies, identifying appropriate indicators to measure the severity of the impacts. By breaking down SVI and mapping specific indicators against climate risks, policies, and programs decision-makers can identify strategies to minimize negative impacts and maximize positive outcomes.

The mix of methodologies in this dissertation provides a nuanced and multifaceted understanding of the complex network of people, programs, and policies involved in coastal climate change adaptation, as well as the social inequities that have occurred in coastal communities in Norfolk, Virginia.

6.3 Results

This research aimed to tackle complex questions related to coastal climate adaptation planning through a mixed methods approach that combines qualitative assessments with quantitative research. The objectives were to assess the complex network of actors and interactions in coastal climate adaptation using a case study of Norfolk, Virginia, evaluate how those agencies and actors incorporate social equity into coastal climate adaptation planning, and suggest alternative localized and regional approaches to meet the social equity goals in coastal climate adaptation planning.

Chapter 2 identified the most influential stakeholders and policies in the network, highlighting the essential role of federal and state agencies in implementing and enforcing coastal climate adaptation policies. Local stakeholders, including the City Manager, Chief Resilience Officers, and Planning Departments, played a crucial role in coordinating and implementing policies within their jurisdiction. The analysis revealed the need for collaboration between different levels of government to address the complex challenges posed by climate change.

Chapter 3 focused on how stakeholders incorporated social equity considerations into planning for Norfolk's climate change impacts. The research found that social equity was not well defined or measured in the context of coastal climate adaptation planning, and stakeholders had varying definitions and approaches to addressing social equity concerns. The chapter also explored the historical injustices in housing practices and their impacts on the social and political landscape today.

Chapter 4 evaluated the efficacy of social vulnerability indices commonly used among planners and suggested alternative localized and regional approaches to meet social equity goals in coastal climate adaptation planning. Multiple state and federally developed social vulnerability indices, environmental justice indices, and a non-profit developed tree equity index were evaluated and compared. The research identified limitations in the current indices and suggested improvements, including regular updates and refinement, integration with climate risk data, and the use of targeted, context-specific interventions to promote resilience and equity in communities.

Chapter 5 discussed how particular social equity metrics were of interest when employing policies that directly impact vulnerable communities. The chapter explored the scenarios when social equity is or is not included in goals and metrics for adaptation planning such as managed retreat, green and grey infrastructure. The resulting maps incorporated local-specific social and cultural considerations in Norfolk, Virginia, highlighting the importance of socially equitable decision-making that takes into account historically marginalized populations and social vulnerability mapping specific to climate risks.

Overall, this research provides valuable insights into the complex network of relationships between stakeholders and policies in coastal climate adaptation planning and contributes to the development of effective policy solutions for climate change adaptation and mitigation. The research also identifies the need for further refinement and improvement in the methods and approaches used for social equity and vulnerability assessments in the context of coastal climate adaptation planning.

6.4 Limitations

The current study faced several challenges and limitations that should be taken into account when interpreting the results. One of the major challenges was the complexity of modeling when and where managed retreat should take place. The numerous factors and uncertainties involved in this decision, such as sea level rise projections, social and economic impacts, and community preferences, made it difficult to develop a comprehensive and accurate model. Another limitation was the inability to perform bivariate mapping to explore nonlinear relationships between indicators of social vulnerability and climate risk due to limitations in the granularity of available data.

Furthermore, the effectiveness of federal programs like the Community Rating System (CRS) program on a local scale was difficult to determine, as it requires a large sample size to properly evaluate its efficacy. This limitation could have been addressed by conducting surveys with residents and small business owners to obtain more localized perspectives and better understand cultural differences in climate adaptation. Additionally, although the study provided valuable insights into the complex network of relationships between stakeholders and policies in coastal climate adaptation planning, further research is needed to refine the methodology and assess how the network of relationships evolves over time in response to changing political and environmental conditions.

The challenges and limitations highlight the need for continued research and innovation in the field of coastal climate adaptation planning, in order to develop more comprehensive and effective strategies for managing the complex challenges posed by climate change.

6.5 Contributions

This research has made several significant contributions to the field of coastal climate adaptation planning. First, by utilizing a mixed-methods approach combining qualitative assessments with quantitative research, this study has provided a more comprehensive understanding of the complex network of actors and interactions involved in coastal climate adaptation planning. Through the case study of Norfolk, Virginia, the research has demonstrated the need for collaboration between federal, state, and local government agencies, non-governmental organizations, and academic institutions in order to effectively address the challenges posed by climate change.

Secondly, this research has highlighted the importance of incorporating social equity considerations into coastal climate adaptation planning. By assessing how agencies and actors in the same urban area as Norfolk incorporate social equity into their planning, this research has demonstrated the need for more localized and regional approaches to meet the social equity goals in coastal climate adaptation planning. Additionally, this research has evaluated the efficacy of social vulnerability indices commonly used among planners and suggested alternative localized and regional approaches to promote social equity in coastal climate adaptation planning.

Thirdly, this research has proposed an enhanced framework for incorporating social equity analysis into existing social vulnerability and environmental justice indices. By examining the strengths and limitations of various indices, this research has provided recommendations for improving the effectiveness of these tools in promoting resilience and equity in coastal communities.

In conclusion, this research has contributed significantly to the field of coastal climate adaptation planning by providing a more comprehensive understanding of the complex network of actors and interactions involved, highlighting the importance of incorporating social equity considerations, and proposing an enhanced framework for promoting resilience and equity in coastal communities. The limitations encountered by this research provide opportunities for future research to refine the methodology and improve our understanding of the complexities of coastal climate adaptation planning.

6.6 Final Thoughts and Reflection

This dissertation highlights the intricate nature of coastal climate change adaptation and social equity and underscores the importance of evidence-based decision-making in policy implementation. While the research presented in this dissertation offers significant scientific contributions, it also sheds light on the challenges of translating academic findings into actionable policy initiatives. The cooperation and collaboration of stakeholders at all levels of governance are crucial for addressing the complex challenges posed by climate change and to implement effective policy solutions.

Various political groups and special interests may impede progress towards effective policy implementation. These challenges underscore the importance of increased collaboration and communication among stakeholders and a commitment to prioritizing the needs of coastal communities.

The research also demonstrates the challenges of conducting qualitative research in the context of coastal climate change adaptation and social equity. While qualitative research remains a powerful tool for understanding the social dynamics and complexities of coastal climate change adaptation and social equity, it can be time-consuming and resource-intensive, and analyzing the subjective nature of the data can be challenging. Despite these difficulties, continued qualitative research is essential to deepen our understanding of this pressing issue and to support effective policy development.

There is a need to address the challenges of integrating academic research into policy initiatives, navigating political and special interest barriers, and conducting qualitative research to support effective policy implementation. By doing so, we can better support coastal communities in adapting to the challenges posed by climate change while promoting social equity. Continued research is necessary to deepen our understanding of this complex issue and to develop policy solutions that meet the needs of all coastal communities.

6.7 Future Direction

The research presented in this dissertation provides a foundation for future research and policy development in the field of coastal climate change adaptation and social equity. Building upon the methodologies and analytical approaches presented in this dissertation, future research can expand upon various aspects of coastal climate change adaptation and social equity. For example, research can investigate the impact of climate change on coastal infrastructure, assess the effectiveness of adaptation strategies, and examine the intersection of social equity and other climate-related issues such as food security and migration.

Moreover, policy development can build on the recommendations presented in this dissertation to improve multilevel governance interactions and address social inequities in coastal communities. By prioritizing the needs of coastal communities, future policy initiatives can ensure that their voices are heard in the decision-making process. To bridge the gap between academic research and policy implementation, policy development can address the challenges of integrating academic research into policy initiatives.

The potential of emerging technologies such as artificial intelligence and machine learning can also be explored to address the complex systems questions surrounding coastal climate change adaptation and social equity. Leveraging these technologies, researchers can gain new insights into the complex relationships among stakeholders, policies, and coastal climate change adaptation, enabling decision-makers to identify vulnerable communities and develop effective adaptation strategies.

Additionally, upcoming research will be conducted to better understand the social network in sea level rise planning in Hampton Roads. The survey will engage stakeholders involved in coastal climate change adaptation, including government officials, non-governmental organizations, and academic researchers. By understanding the social network in sea level rise planning, this research can inform the development of effective policy initiatives and facilitate collaboration among stakeholders.

The future direction for this work involves continued research and policy development that builds on the scientific contributions of this dissertation, addresses the challenges of coastal climate change adaptation and social equity, and prioritizes the needs of coastal communities. By doing so, we can work towards a future where all coastal communities are resilient in the face of climate change, and social inequities are addressed through effective and equitable policy.

6.8 Publications and Ongoing Research

The following publication was primarily used for Chapter 1:

- Eghdami, S., Michel, V., Shafiee-Jood, M., & Louis, G. (2023). Gap Analysis of Climate Adaptation Policymaking in Coastal Virginia. *Climate Policy*, (Under Review)

This publication provides valuable insights into the gaps and challenges in climate adaptation policymaking in the Coastal Virginia region, which were used to provide context for the review of existing policies and stakeholders in Chapter 1. Chapter 1 reviewed the research on where the gaps in coastal policymaking currently exist, particularly with a case study of Coastal Virginia.

Although the publication is currently under review, it could be a valuable resource for future research and analysis related to climate adaptation policymaking in Coastal Virginia.

The publications below helped inform the research for Chapter 2.

- Eghdami, S., Michel, V., Shafiee-Jood, M., & Louis, G. (2023) Climate adaptation in Coastal Virginia: an analysis of existing policies and main stakeholders, *Climate Policy*, DOI:10.1080/14693062.2022.2152773
- Michel, V., Nazemi, N., & Eddy, T. (2018). Identifying Vulnerable Stakeholders from Dependent Relationships in California's Water System. In Proceedings of the International Annual Conference of the American Society for Engineering Management. (pp. 1-10). American Society for Engineering Management (ASEM).

The publication by Eghdami et al. (2023) on climate adaptation in Coastal Virginia was likely used in Chapter 2 as a reference for the policies and stakeholders involved in climate adaptation planning in Coastal Virginia. This publication provides valuable information about the existing policies and actors involved in coastal climate adaptation planning, which is an important context for understanding the vulnerability of stakeholders in the region. By understanding the policies and stakeholders involved in climate adaptation planning, Michel et al. (2018) methodology on identifying vulnerable stakeholders from dependent relationships in California's water system could be applied to identify vulnerable stakeholders in the context of coastal climate adaptation planning in Coastal Virginia. This methodology provides a framework for identifying stakeholders that are dependent on others for their resilience and can be used to identify areas where interventions may be needed to increase resilience among vulnerable populations. Therefore, both publications were likely used in tandem to provide context and methodology for identifying vulnerable stakeholders in the context of coastal climate adaptation planning.

Chapter 3 was entirely informed by the following publication, which is currently undergoing peer review in the Journal of Urban Climate:

- Michel, V., Eghdami, S., Shafiee-Jood, M, & Louis, G, (2023) Addressing Social Equity in Coastal Climate Adaptation Planning: A Case Study of Norfolk, Virginia, *Urban Climate*, (Under Review)

This publication provided a comprehensive case study on the challenges and opportunities for integrating social equity into coastal climate adaptation planning in Norfolk, Virginia. It helped to identify the perspectives of stakeholders and the complexities involved in incorporating social equity considerations into planning efforts. By analyzing the case study, Chapter 3 was able to identify the historical injustices in housing practices and their impacts on the social and political landscape, thus providing valuable insights into the ways in which social equity can be integrated into coastal climate adaptation planning.

Chapter 4 is ongoing work, a suitable journal for publication could be the Journal of Environmental Management. This journal is an interdisciplinary publication that covers a broad range of topics related to environmental management, including climate change adaptation, policy analysis, and environmental justice. The journal publishes original research articles, reviews, and case studies, making it an ideal platform to present research on evaluating the efficacy of social vulnerability indices and suggesting alternative localized and regional approaches to meet social equity goals in coastal climate adaptation planning. The journal's audience includes researchers, policymakers, and practitioners in environmental management and related fields, providing a broad reach for this work.

For Chapter 5, a suitable journal for publication could be the journal Climate Risk Management. This journal is dedicated to publishing research on the assessment and management of climate risks, including adaptation and mitigation strategies. The journal is particularly interested in interdisciplinary research that integrates climate science, social science, and engineering approaches to address climate risk. The focus of Chapter 5, which uses scenario analysis and mapping to demonstrate how different social vulnerability indicators can be interpreted for different climate adaptation scenarios when social equity is involved, aligns well with the scope of Climate Risk Management. The journal's readership includes researchers, policymakers, and practitioners working on climate risk management, making it an ideal platform to present these research findings.

The following conference paper was helpful in Chapter 5 for managed retreat:

- Eghdami, S., Anderson, T., Michel, V., & Louis, G. (2020). Policy Analysis for Community Retreat in Coastal Regions. In Proceedings of the International Annual Conference of the American Society for Engineering Management. (pp. 1-13). American Society for Engineering Management (ASEM)

By drawing on this publication, Chapter 5 was able to apply similar principles and considerations to the context of Coastal Virginia and analyze the potential impacts of managed retreat. Although Chapter 5 emphasized the importance of including social vulnerability and equity in the region. The publication also highlighted the importance of engaging with and incorporating the perspectives of stakeholders in the development and implementation of climate adaptation policies, which was a key consideration in Chapter 5's analysis.

Other publications:

- Michel, V., Eghdami, S., Hadley, K, & Louis, G. (2020). A Framework for Characterizing Multilevel Water Governance: A Case Study of Baltimore Maryland. In Proceedings of the International Annual Conference of the American Society for Engineering Management. (pp. 1-10). American Society for Engineering Management (ASEM).

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Appendix

A. Table 14 is a breakdown of each component aspect and the description of each score 1/5 to 5/5 to describe how a score may be evaluated.

Table 14: Social-Equity Index Efficacy Scorecard Breakdown

Component Aspect		Description
Data Quality		
Reliability	1/5	Data sources are known to contain significant errors or biases.
	2/5	Data sources have occasional inaccuracies or inconsistencies.
	3/5	Data sources are generally accurate but may contain some minor errors.
	4/5	Data sources are consistently accurate and have minimal errors.
	5/5	Data sources are from highly reputable organizations and have undergone rigorous validation.
Relevance	1/5	Data sources do not reflect the specific context or social equity concerns.
	2/5	Data sources somewhat reflect the specific context or social equity concerns but may be lacking in certain aspects.
	3/5	Data sources moderately reflect the specific context and social equity concerns, with some room for improvement.
	4/5	Data sources mostly reflect the specific context and social equity concerns, with only minor gaps.
	5/5	Data sources are highly tailored to the specific context and directly address the social equity concerns.
Timeliness	1/5	Data sources are outdated, potentially leading to inaccurate assessments.
	2/5	Data sources are somewhat outdated, with more recent data available.
	3/5	Data sources are fairly up-to-date, but there may be slightly more recent data available.
	4/5	Data sources are up-to-date, with only minimal delays in data availability.
	5/5	Data sources are the most recent available, ensuring accurate assessments.
Variable Selection		

Comprehensiveness	1/5	Index includes only a few variables, providing a limited perspective on social equity.
	2/5	Index includes a limited range of variables, covering some aspects of social equity but leaving gaps.
	3/5	Index includes a moderate range of variables, providing a balanced view of social equity but may lack depth in certain areas.
	4/5	Index includes a wide range of variables, offering a comprehensive view of social equity with only minor gaps.
	5/5	Index includes a diverse set of socio-demographic, economic, environmental, and cultural variables, providing a holistic view of social equity.
Appropriateness	1/5	Selected variables are not relevant to the specific context or social equity goals.
	2/5	Selected variables are somewhat relevant but may not fully capture the context or social equity goals.
	3/5	Selected variables are moderately relevant, reflecting the context and social equity goals fairly well.
	4/5	Selected variables are mostly relevant, accurately reflecting the context and social equity goals with only minor shortcomings.
	5/5	Selected variables are highly relevant and tailored to the specific context and social equity goals.
Tradeoff Understanding		
Aggregation method	1/5	Aggregation method oversimplifies the interactions between dimensions of vulnerability, potentially leading to inaccuracies.
	2/5	Aggregation method considers some interactions between dimensions of vulnerability but may still have shortcomings.
	3/5	Aggregation method moderately accounts for interactions between dimensions of vulnerability, with some room for improvement.
	4/5	Aggregation method mostly accounts for interactions between dimensions of vulnerability, providing a robust assessment.
	5/5	Aggregation method comprehensively considers complex interactions between dimensions of vulnerability and provides a highly accurate assessment.
Non-linear relationship	1/5	Index does not account for potential non-linear relationships between vulnerability variables, leading to oversimplification.
	2/5	Index accounts for some non-linear relationships, but may still miss important interactions.
	3/5	Index moderately accounts for non-linear relationships, providing a fairly accurate assessment.
	4/5	Index mostly accounts for non-linear relationships, capturing key interactions between vulnerability variables.

	5/5	Index comprehensively accounts for non-linear relationships, ensuring a highly accurate assessment.
Weighting and normalization	1/5	Inappropriate weighting and normalization techniques may lead to significant inaccuracies or biases.
	2/5	Weighting and normalization techniques are somewhat appropriate but may have some shortcomings.
	3/5	Weighting and normalization techniques are moderately appropriate and robust, with some room for improvement.
	4/5	Weighting and normalization techniques are mostly appropriate and robust, providing a reliable assessment.
	5/5	Weighting and normalization techniques are highly appropriate and robust, ensuring an accurate and unbiased assessment.
Local Sensitivity		
Spatial resolution	1/5	Index does not capture local-scale variations in vulnerability, potentially masking important differences.
	2/5	Index captures some local-scale variations, but may still overlook key differences.
	3/5	Index moderately captures local-scale variations, providing a fairly accurate assessment.
	4/5	Index mostly captures local-scale variations, providing a detailed assessment of vulnerability differences.
	5/5	Index comprehensively captures local-scale variations, ensuring a highly accurate assessment.
Context-specific factors	1/5	Index does not account for context-specific factors that influence vulnerability, leading to oversimplification.
	2/5	Index accounts for some context-specific factors but may still miss important elements.
	3/5	Index moderately accounts for context-specific factors, providing a fairly accurate assessment.
	4/5	Index mostly accounts for context-specific factors, accurately reflecting the unique characteristics of the area.
	5/5	Index comprehensively accounts for context-specific factors, ensuring a highly accurate assessment.
Local data integration	1/5	Index does not incorporate local data sources or up-to-date information, potentially leading to inaccuracies.
	2/5	Index incorporates some local data sources and up-to-date information but may still have gaps.
	3/5	Index moderately incorporates local data sources and up-to-date information, providing a fairly accurate assessment.
	4/5	Index mostly incorporates local data sources and up-to-date information, providing a detailed and accurate assessment.

	5/5	Index comprehensively incorporates local data sources and the most up-to-date information, ensuring a highly accurate assessment.
Cultural and Social Norm Considerations		
Cultural diversity	1/5	Index does not account for diverse cultural practices and values, potentially leading to biases and inaccuracies.
	2/5	Index accounts for some cultural diversity but may still overlook key differences.
	3/5	Index moderately accounts for cultural diversity, providing a fairly accurate assessment.
	4/5	Index mostly accounts for cultural diversity, accurately reflecting diverse practices and values.
	5/5	Index comprehensively accounts for cultural diversity, ensuring a highly accurate and inclusive assessment.
Social norms and behaviors	1/5	Index does not consider the impact of social norms and behaviors on vulnerability, potentially leading to oversimplification.
	2/5	Index accounts for some impacts of social norms and behaviors but may still miss important elements.
	3/5	Index moderately accounts for the impact of social norms and behaviors, providing a fairly accurate assessment.
	4/5	Index mostly accounts for the impact of social norms and behaviors, accurately reflecting their influence on vulnerability.
	5/5	Index comprehensively accounts for the impact of social norms and behaviors, ensuring a highly accurate assessment.
Local knowledge and adaptation strategies	1/5	Index does not capture local knowledge or community-based adaptation strategies, potentially overlooking important factors.
	2/5	Index captures some local knowledge and adaptation strategies but may still have gaps.
	3/5	Index moderately captures local knowledge and adaptation strategies, providing a fairly accurate assessment.
	4/5	Index mostly captures local knowledge and adaptation strategies, providing a detailed assessment of community resilience.
	5/5	Index comprehensively captures local knowledge and community-based adaptation strategies, ensuring a highly accurate assessment.
Usability		
Interpretability	1/5	Index is difficult to understand and interpret, hindering its usefulness for decision-making.
	2/5	Index is somewhat difficult to understand, potentially limiting its effectiveness for decision-making.
	3/5	Index is moderately easy to understand and interpret, providing a fairly accessible assessment.

	4/5	Index is mostly easy to understand and interpret, facilitating informed decision-making.
	5/5	Index is highly interpretable and easy to understand, promoting informed decision-making for a wide range of users.
Accessibility	1/5	Index is not accessible to a wide range of users, limiting its usefulness for policy and planning.
	2/5	Index is somewhat accessible but may still be difficult for some users to access or understand.
	3/5	Index is moderately accessible, providing a fairly inclusive tool for policy and planning.
	4/5	Index is mostly accessible, making it easy for a wide range of users to access and understand.
	5/5	Index is highly accessible, ensuring its usefulness for policymakers, practitioners, and community members alike.
Actionability	1/5	Index does not provide actionable insights, limiting its usefulness for policy and planning decisions.
	2/5	Index provides some actionable insights but may still have shortcomings in informing decision-making.
	3/5	Index provides moderately actionable insights, offering a fairly useful tool for policy and planning decisions.
	4/5	Index provides mostly actionable insights, facilitating effective decision-making to address social equity challenges.
	5/5	Index provides highly actionable insights, ensuring its usefulness for policy and planning decisions to address social equity challenges effectively.

B. Detailed example scores of each component aspect:

Data Quality

Reliability (4/5): An index evaluating gender equality uses data from well-established sources such as the World Bank, United Nations, or national statistical agencies for variables like literacy rates, employment rates, and political representation. However, the index also includes data on gender-based violence from less-established sources, which might be less reliable.

Relevance (3/5): An index measuring economic inequality includes data on income, education, and health but lacks information on other relevant dimensions, such as access to services, housing, or social capital, leading to an incomplete picture of the issue.

Timeliness (2/5): An index assessing access to education uses data from 2019, while more recent data from 2021 is available, potentially not reflecting the current situation and recent developments.

Variable Selection

Comprehensiveness (5/5): An index evaluating environmental justice includes a wide range of socio-demographic, economic, environmental, and cultural variables, such as income distribution, pollution exposure, access to green spaces, and Indigenous rights, effectively capturing various dimensions of environmental equity.

Appropriateness (1/5): An index assessing urban poverty uses variables like agricultural production and rural-to-urban migration, which are not directly relevant to the urban context, leading to an inaccurate representation of urban poverty.

Tradeoff Understanding

Aggregation method (3/5): An index measuring social vulnerability to natural disasters uses a simple additive method to aggregate variables such as population density, poverty, and infrastructure quality. This method may not adequately capture complex interactions between dimensions of vulnerability, such as how poverty may exacerbate the effects of poor infrastructure.

Non-linear relationship (4/5): An index evaluating access to healthcare considers the nonlinear relationship between distance to healthcare facilities and healthcare utilization, accurately reflecting that the relationship may change at different distances (e.g., utilization drops more rapidly beyond a certain distance threshold).

Local Sensitivity

Spatial resolution (5/5): An index assessing urban air quality measures pollution levels at a neighborhood level, capturing local variations in air quality and providing targeted insights for policymakers to address air pollution hotspots.

Context-specific factors (2/5): An index evaluating economic opportunities for minority populations fails to consider the unique challenges faced by specific minority groups, such as discrimination or language barriers, leading to an oversimplified assessment of the issue.

Local data integration (3/5): An index measuring food security incorporates some local data sources, such as local agricultural production and retail food prices, but lacks information on community-level factors, such as food distribution networks and cultural food preferences.

Cultural and Social Norm Considerations

Cultural diversity (4/5): An index assessing social cohesion takes into account diverse cultural practices and values by including variables such as religious diversity, cultural events, and representation in local government, but may not fully capture all aspects of cultural diversity.

Social norms and behaviors (5/5): An index evaluating gender equity comprehensively accounts for the impact of social norms and behaviors by including variables like gender roles in the household, attitudes towards women's education and employment, and representation in decision-making processes.

Local knowledge and adaptation strategies (1/5): An index assessing community resilience to climate change fails to consider local knowledge and community-based adaptation strategies, overlooking important factors that contribute to local resilience.

Usability

Interpretability (3/5): An index measuring income inequality uses the Gini coefficient, which is moderately easy to understand and interpret for users familiar with the concept but may be challenging for non-experts.

Accessibility (5/5): An index evaluating access to public transportation is presented in an interactive online map, making it highly accessible and easy to understand for a wide range of users, including policymakers, urban planners, and community members.

Actionability (4/5): An index assessing housing affordability provides mostly actionable insights, such as average rent prices, availability of affordable housing units, and income distribution. These insights facilitate effective decision-making to address housing affordability challenges but may still have some limitations in informing specific policy interventions.

C. Completed scorecards for each social equity related index provided in Table 10. Table 15 is the CDC EJI scorecard. Table 16 shows the VIMS EJI. And Table 17 is the American Forests TES.

Table 15: CDC Environmental Justice Index

Index Evaluation Component	Aspects of Each Component	Description of Aspects
Data Quality	Reliability	4/5 - The EJI primarily uses data from the U.S. Census Bureau and the U.S. Environmental Protection Agency, which are generally reliable but might have some biases.
	Relevance	5/5 - The data sources are relevant to assessing environmental justice in communities.
	Timeliness	5/5 – The index uses the most up to date data available
Variable selection	Comprehensiveness	4/5 - The EJI includes a diverse range of socio-demographic, economic, and environmental variables, but it could potentially include more cultural variables.
	Appropriateness	5/5 - The selected variables are relevant to the specific context and goals of the environmental justice assessment.
Tradeoff understanding	Aggregation method	4/5 - The EJI uses an appropriate method for capturing patterns among multiple dimensions of vulnerability but might not fully capture complex interactions between dimensions.
	Non-linear relationship	3/5 - It is unclear whether the index accounts for potential non-linear relationships between vulnerability variables.
	Weighting and normalization	4/5 - Weighting and normalization techniques are used, but their appropriateness and robustness might need further assessment.
Local sensitivity	Spatial resolution	4/5 - The EJI captures local-scale variations in vulnerability but could benefit from finer resolution data.
	Context-specific factors	4/5 - The index accounts for some context-specific factors influencing vulnerability, but might not cover all relevant factors.
	Local data integration	2/5 – The index does capture local variation but does not include local data sources
	Cultural diversity	3/5 - The EJI might not fully account for diverse cultural practices and values.

Cultural and social norm considerations	Social norms and behaviors	3/5 - It is unclear whether the index considers the impact of social norms and behaviors on vulnerability.
	Local knowledge and adaptation strategies	3/5 - The index might not capture local knowledge and community-based adaptation strategies.
Usability	Interpretability	4/5 - The index is relatively easy to understand and interpret.
	Accessibility	4/5 - The index is accessible to a wide range of users, although it may be challenging for non-experts to fully comprehend.
	Actionability	4/5 - The index provides actionable insights to inform policy and planning decisions.

Table 16: Elizabeth River Environmental Justice Index

Index Evaluation Component	**Aspects of Each Component**	**Description of Aspects**
Data Quality	Reliability	4/5 - The EJI primarily uses data from the EPA EJSCREEN and U.S. Census Bureau, which are generally reliable but might have some biases.
	Relevance	5/5 - The data sources are relevant to assessing environmental justice in the Elizabeth River Watershed.
	Timeliness	3/5 - The index uses data from the 2015-2019 American Community Survey (ACS), which may not be the most recent data available.
Variable selection	Comprehensiveness	4/5 - The EJI includes a diverse range of socio-demographic and environmental variables, but it could potentially include more cultural variables.
	Appropriateness	5/5 - The selected variables are relevant to the specific context and goals of the environmental justice assessment for the Elizabeth River Watershed.
Tradeoff understanding	Aggregation method	4/5 - The EJI uses principal component analysis (PCA), which is an appropriate method for capturing patterns among multiple dimensions of vulnerability but might not fully capture complex interactions between dimensions.
	Non-linear relationship	3/5 - It is unclear whether the index accounts for potential non-linear relationships between vulnerability variables.
	Weighting and normalization	4/5 - Weighting and normalization techniques are used, but their appropriateness and robustness might need further assessment.
Local sensitivity	Spatial resolution	4/5 - The EJI captures local-scale variations in vulnerability but could benefit from finer resolution data.
	Context-specific factors	4/5 - The index accounts for some context-specific factors influencing vulnerability but might not cover all relevant factors.

	Local data integration	3/5 - It is unclear whether the index incorporates local data sources and up-to-date information.
Cultural and social norm considerations	Cultural diversity	3/5 - The EJI might not fully account for diverse cultural practices and values.
	Social norms and behaviors	3/5 - It is unclear whether the index considers the impact of social norms and behaviors on vulnerability.
	Local knowledge and adaptation strategies	3/5 - The index might not capture local knowledge and community-based adaptation strategies.
Usability	Interpretability	4/5 - The index is relatively easy to understand and interpret.
	Accessibility	4/5 - The index is accessible to a wide range of users, although it may be challenging for non-experts to fully comprehend.
	Actionability	4/5 - The index provides actionable insights to inform policy and planning decisions for the Elizabeth River Watershed.

Table 17: American Forests Tree Equity Score

Index Evaluation Component	**Aspects of Each Component**	**Description of Aspects**
Data Quality	Reliability	4/5 - The TES primarily uses data from the National Land Cover Database, U.S. Census Bureau, and other reliable sources, but there might be some biases.
	Relevance	5/5 - The data sources are relevant to assessing tree equity in urban areas.
	Timeliness	4/5 - The index should be assessed to ensure that it uses the most recent data available, as some data sources might be updated more frequently than others.
Variable selection	Comprehensiveness	4/5 - The TES includes a range of socio-demographic, economic, and environmental variables, but it could potentially include more cultural variables.
	Appropriateness	5/5 - The selected variables are relevant to the specific context and goals of the tree equity assessment for urban areas.
Tradeoff understanding	Aggregation method	4/5 - The TES uses various methods to combine data, which is appropriate for capturing patterns among multiple dimensions of tree equity but might not fully capture complex interactions between dimensions.
	Non-linear relationship	3/5 - It is unclear whether the index accounts for potential non-linear relationships between vulnerability variables.
	Weighting and normalization	4/5 - Weighting and normalization techniques are used, but their appropriateness and robustness might need further assessment.

Local sensitivity	Spatial resolution	4/5 - The TES captures local-scale variations in tree equity but could benefit from finer resolution data.
	Context-specific factors	4/5 - The index accounts for some context-specific factors influencing tree equity but might not cover all relevant factors.
	Local data integration	5/5 – The index provides the most up to date information and provides easy to access change logs to show when changes are made to the TES
Cultural and social norm considerations	Cultural diversity	3/5 - The TES might not fully account for diverse cultural practices and values related to urban tree distribution.
	Social norms and behaviors	3/5 - It is unclear whether the index considers the impact of social norms and behaviors on tree equity.
	Local knowledge and adaptation strategies	3/5 - The index might not capture local knowledge and community-based tree planting and maintenance strategies.
Usability	Interpretability	5/5 - The index is vey easy to understand and interpret.
	Accessibility	5/5 - The index is accessible to a wide range of users
	Actionability	4/5 - The index provides actionable insights to inform policy and planning decisions related to urban tree equity but may lack local insights.

D. Scenario 1 metric descriptions:

- Percentage of wetlands preserved: This metric measures the percentage of wetlands that are protected or preserved in a given area. An example metric could be the percentage of wetlands preserved in a specific county. A potential data source for this metric could be the National Wetland Inventory (NWI) provided by the U.S. Fish and Wildlife Service.
- Acreage of high-risk land acquired: This metric measures the total acreage of high-risk land that has been acquired for conservation or protection purposes. An example metric could be the total acreage of land acquired in a specific region prone to flooding. A potential data source for this metric could be the National Flood Hazard Layer (NFHL) provided by the Federal Emergency Management Agency (FEMA).
- Tree canopy coverage percentage: This metric measures the percentage of a given area covered by trees. An example metric could be the percentage of tree canopy coverage in a specific city. A potential data source for this metric could be the National Land Cover Database (NLCD) provided by the U.S. Geological Survey.
- Number of trees planted: This metric measures the total number of trees planted in a specific area during a given time period. An example metric could be the number of trees

planted in a city park during a spring planting event. A potential data source for this metric could be records kept by local parks and recreation departments or conservation organizations.

- Reforestation rate per year: This metric measures the rate at which forests are being re-established in a specific area. An example metric could be the number of acres of forest that were successfully reforested in a specific county over the course of a year. A potential data source for this metric could be the Forest Inventory and Analysis (FIA) program provided by the U.S. Forest Service.
- Forest canopy coverage percentage: This metric measures the percentage of forest canopy coverage in a given area. An example metric could be the percentage of forest canopy coverage in a specific national forest. A potential data source for this metric could be the National Forest Inventory (NFI) provided by the U.S. Forest Service.
- Wetland acreage restored: This metric measures the total acreage of wetlands that have been restored in a given area. An example metric could be the total acreage of wetlands restored in a specific county. A potential data source for this metric could be the National Wetland Condition Assessment (NWCA) provided by the Environmental Protection Agency (EPA).
- Wetland functional assessments conducted: This metric measures the number of functional assessments conducted to evaluate the health and condition of wetlands in a specific area. An example metric could be the number of wetland functional assessments conducted in a specific state. A potential data source for this metric could be state or federal agencies responsible for wetland management.
- Buffer zone width in feet/meters: This metric measures the width of a buffer zone between a specific site and adjacent land uses. An example metric could be the width of a buffer zone between a factory and nearby residential properties. A potential data source for this metric could be local zoning ordinances or land use regulations.
- Pollutant levels within buffer zones: This metric measures the levels of pollutants within a buffer zone. An example metric could be the concentration of heavy metals in a buffer zone

between a landfill and nearby waterways. A potential data source for this metric could be environmental monitoring data collected by local or state agencies.

- Groundwater quality presence or absence of hazardous substances or concentration levels: This metric measures the quality of groundwater in a specific area by evaluating the presence or absence of hazardous substances or the concentration levels of various contaminants. An example metric could be the presence of arsenic in groundwater in a specific county. A potential data source for this metric could be the Ground Water Rule provided by the EPA.
- Number of hazardous waste violations within buffer zones: This metric measures
- Number of hazardous waste violations within buffer zones: This metric measures the number of violations related to hazardous waste within buffer zones. It can provide insight into the effectiveness of regulations and enforcement related to hazardous waste management within buffer zones. A potential data source for this metric could be regulatory agencies such as the Environmental Protection Agency (EPA) or state environmental agencies.
- Completion of emergency response plans and number of drills or exercises conducted: This metric measures the completion of emergency response plans within buffer zones and the number of drills or exercises conducted to test the plans. It can provide insight into the preparedness of buffer zones for emergencies such as chemical spills or natural disasters. A potential data source for this metric could be the local emergency management agency or the buffer zone management organization.
- Number of community engagement events: This metric measures the number of events or activities that engage the community within buffer zones. It can provide insight into the level of community involvement and participation in buffer zone management and decision-making. A potential data source for this metric could be the buffer zone management organization or community organizations within the buffer zone.
- Number of households or individuals relocated: This metric measures the number of households or individuals that have been relocated from buffer zones due to environmental hazards or other factors. It can provide insight into the effectiveness of relocation programs

and the impact of buffer zone management on local communities. A potential data source for this metric could be the buffer zone management organization or local government agencies responsible for relocation programs.

- Number of households or individuals resettled: This metric measures the number of households or individuals that have been resettled in buffer zones after relocation. It can provide insight into the effectiveness of resettlement programs and the impact of buffer zone management on local communities. A potential data source for this metric could be the buffer zone management organization or local government agencies responsible for resettlement programs.
- Number of community-led initiatives or programs implemented: This metric measures the number of initiatives or programs implemented by the community within buffer zones. It can provide insight into the level of community involvement and participation in buffer zone management and decision-making. A potential data source for this metric could be community organizations within the buffer zone or the buffer zone management organization.

E. Scenario 2 metric descriptions:

- Number of socially vulnerable households relocated: The total number of households that were relocated due to social vulnerability, which could be caused by factors such as low income, lack of access to transportation, or inadequate housing. Example metric: "500 households relocated due to social vulnerability in 2022." Potential data source: Local government records or reports.
- Percentage of participation in relocation programs based on demographics: The proportion of individuals who participated in relocation programs, broken down by demographic factors such as age, race, or income level. Example metric: "60% of eligible low-income households participated in the relocation program." Potential data source: Survey data collected by the organization responsible for the relocation program.
- Ratio of renters to owners relocated: The ratio of renters to owners among households that were relocated. Example metric: "70% of relocated households were renters." Potential data source: Data collected by the organization responsible for the relocation program.

- Percentage of wetlands preserved: The percentage of wetlands that were protected from development or other human activities that could harm their ecological value. Example metric: "95% of wetlands in the conservation area were preserved." Potential data source: Wetland inventory data from a government agency or nonprofit organization.
- Number of individuals displaced due to wetland preservation efforts: The number of people who were forced to relocate due to the preservation of wetlands. Example metric: "25 households were displaced due to wetland preservation efforts." Potential data source: Local government records or reports.
- Disparities in median household income among different demographic groups: The differences in median household income between different demographic groups, such as white and non-white residents or those with and without a college degree. Example metric: "The median household income for white residents was $80,000, while for non-white residents it was $40,000." Potential data source: Census Bureau data or survey data collected by a nonprofit organization.
- Small business growth and development in marginalized communities: The increase in the number or success of small businesses in communities that are marginalized due to factors such as low income or lack of access to resources. Example metric: "The number of small businesses in the community increased by 20% in the past year." Potential data source: Business license data from the local government or survey data collected by a nonprofit organization.
- Tree canopy growth in redlined communities: The increase in tree canopy coverage in communities that were historically redlined and have experienced disinvestment and neglect. Example metric: "Tree canopy coverage in the redlined community increased by 5% over the past five years." Potential data source: Satellite imagery data or local government tree inventory data.
- Number of trees planted in underserved areas: The total number of trees planted in areas that are underserved due to factors such as low income or lack of access to resources. Example metric: "1,000 trees were planted in underserved areas in the past year." Potential data source: Tree planting program records or local government tree inventory data.

- Reforestation rate based on need in different communities: The rate at which forests are being restored in different communities, based on the ecological need for reforestation in each area. Example metric: "The reforestation rate in the heavily degraded forest was 10,000 trees per year." Potential data source: Forest inventory data or ecological restoration project records.
- Forest canopy coverage by community demographics: The percentage of forest canopy coverage in different communities, broken down by demographic factors such as race or income level. Example metric: "The community with the highest forest canopy coverage had a median household income of $100,000." Potential data source: Satellite imagery data or local government tree inventory data.
- Wetland restoration in underserved areas: The restoration of wetlands in areas that are underserved due to factors such as low income or lack of access to resources. Example metric: "5 acres of wetlands were restored in the underserved community." Potential data source: Wetland restoration program records or ecological survey data.
- Wetland functional assessments by community demographics: The functional status of wetlands in different communities, broken down by demographic factors such as race or income level. Example metric: "The wetlands in the low-income community had lower functional status due to pollution and erosion." Potential data source: Wetland functional assessment reports from a government agency or nonprofit organization.
- Increased buffer zone width in socially vulnerable communities: The width of the buffer zones around environmentally hazardous facilities increased in socially vulnerable communities to reduce the risk of exposure to pollutants. Example metric: "The buffer zone around the chemical plant was increased to 2 miles in the socially vulnerable community." Potential data source: Buffer zone regulation records from a government agency or environmental advocacy group.
- Lowered pollutant levels accepted in areas with high social vulnerability: The maximum acceptable level of pollutants allowed in areas with high social vulnerability, decreased to reduce the risk of exposure to harmful substances. Example metric: "The maximum acceptable level of lead in the air was lowered in the high-poverty community." Potential

data source: Environmental regulation records from a government agency or environmental advocacy group.

- Increased groundwater quality testing in underserved communities: The frequency and scope of groundwater quality testing increased in underserved communities to identify and mitigate contamination risks. Example metric: "Groundwater quality testing was conducted monthly in the low-income community." Potential data source: Groundwater testing records from a government agency or environmental advocacy group.
- Increased hazardous waste oversight in marginalized communities: The level of oversight and regulation of hazardous waste disposal and storage increased in marginalized communities to reduce the risk of environmental harm. Example metric: "The number of hazardous waste inspections increased by 50% in the historically marginalized community." Potential data source: Hazardous waste regulation records from a government agency or environmental advocacy group.
- Community-involved emergency response planning in socially vulnerable communities: The level of community involvement and participation in emergency response planning increased in socially vulnerable communities to ensure that the unique needs and perspectives of these communities are taken into account. Example metric: "A community-led emergency response plan was developed and implemented in the low-income community." Potential data source: Emergency response planning documents from a government agency or community organization.
- Engagement events for marginalized groups: Events and activities designed to engage and empower marginalized communities, promote environmental awareness and education, and encourage participation in environmental initiatives. Example metric: "100 residents attended the environmental justice workshop in the immigrant community." Potential data source: Attendance records from an environmental education organization or community group.
- Relocation programs developed for vulnerable communities, categorized by demographics: The development of relocation programs tailored to the specific needs and challenges faced by different vulnerable communities, such as low-income renters or elderly homeowners. Example metric: "The relocation program for low-income renters

included financial assistance and transportation support." Potential data source: Relocation program documents from a government agency or community organization.

F. Scenario 3 metric descriptions:

- Percentage of high-risk land acquired for conservation: This refers to the amount of ecologically important land that has been acquired for conservation purposes, particularly those areas that are at risk of development or other forms of human disturbance. Example metric: Percentage of total high-risk land acquired for conservation. Potential data source: Land Trust Alliance's LandScope America.
- Green infrastructure coverage percentage in vulnerable communities: This refers to the proportion of green infrastructure, such as parks, green roofs, and rain gardens, in communities that are vulnerable to environmental hazards or socio-economic disadvantages. Example metric: Percentage of green infrastructure coverage in low-income communities. Potential data source: U.S. Environmental Protection Agency's (EPA) Environmental Justice Screening and Mapping Tool.
- Number of buildings retrofitted to meet higher standards: This refers to the number of existing buildings that have undergone retrofitting or renovation to improve their energy efficiency and reduce their carbon footprint. Example metric: Number of commercial buildings retrofitted to meet LEED Platinum standards. Potential data source: U.S. Green Building Council's LEED certification database.
- Number of green infrastructure projects installed that address specific ecosystem services: This refers to the number of projects that have been implemented to provide specific environmental benefits, such as stormwater management, air quality improvement, or wildlife habitat creation. Example metric: Number of green roofs installed for stormwater retention. Potential data source: Green Infrastructure Center's Project Database.
- Percentage of population living within a half-mile radius of a green infrastructure project: This refers to the proportion of people who live close to green infrastructure projects, which can provide a range of environmental, health, and social benefits. Example metric: Percentage of population living within a half-mile radius of a community garden. Potential data source: National Recreation and Park Association's Park Metrics.

- Number of trees planted in green infrastructure projects: This refers to the number of trees that have been planted in green infrastructure projects, which can help reduce urban heat island effects, improve air quality, and provide wildlife habitat. Example metric: Number of trees planted in city parks in a given year. Potential data source: Urban Forestry Inventory and Analysis program by the USDA Forest Service.
- Wetland acreage restored: This refers to the number of wetlands that have been restored to their original state, or improved to function more effectively as habitat and ecosystem services providers. Example metric: Acres of wetlands restored in a given year. Potential data source: U.S. Fish and Wildlife Service's National Wetlands Inventory.
- Buffer zone width in feet/meters: This refers to the width of the buffer zone around sensitive areas, such as water bodies or wetlands, which is designed to protect them from pollution and other forms of disturbance. Example metric: Average width of buffer zones around streams in a given watershed. Potential data source: EPA's Stream and River Monitoring and Assessment.
- Pollutant levels within buffer zones: This refers to the levels of pollutants, such as nitrogen, phosphorus, or sediment, which are present within the buffer zone, which can indicate the effectiveness of the buffer in filtering out contaminants. Example metric: Average concentration of nitrogen in buffer zones around agricultural fields. Potential data source: USDA's Agricultural Research Service.
- Groundwater quality: This refers to the quality of the water that is stored underground, which can be impacted by pollution from a range of sources, including agricultural, industrial, and urban activities. Example metric: Average concentration of arsenic in groundwater in a given aquifer. Potential data source: U.S. Geological Survey's National Water-Quality Assessment Program.
- Number of hazardous waste violations within buffer zones: This refers to the number of instances where hazardous waste regulations have been violated within buffer zones, indicating potential threats to nearby ecosystems and public health. Example metric: Number of hazardous waste violations reported within buffer zones of industrial sites in a given year. Potential data source: EPA's Enforcement and Compliance History Online.

- Completion of emergency response plans and drills/exercises: This refers to the degree to which emergency response plans and training have been developed and implemented to address potential environmental hazards, such as natural disasters or chemical spills. Example metric: Percentage of facilities with up-to-date emergency response plans and completed drills in the past year. Potential data source: EPA's Risk Management Plan program.
- Number of community engagement events: This refers to the number of events, such as workshops, meetings, or public forums, which have been held to engage community members in environmental decision-making processes. Example metric: Number of community workshops held on green infrastructure planning and implementation. Potential data source: Local government or non-profit organizations involved in community engagement.
- Number of households or individuals relocated: This refers to the number of households or individuals who have been relocated due to environmental hazards, such as flooding, wildfire, or toxic pollution. Example metric: Number of households relocated due to sea level rise in a given coastal area. Potential data source: Local or state government relocation programs.
- Number of households or individuals resettled: This refers to the number of households or individuals who have been resettled to new locations that are more resilient or sustainable in the face of environmental hazards. Example metric: Number of households resettled to eco-friendly homes after a disaster. Potential data source: Non-profit organizations involved in disaster recovery.
- Number of community-led initiatives or programs implemented: This refers to the number of initiatives or programs that have been implemented by community organizations, such as non-profits or grassroots groups, to address environmental challenges and promote sustainability. Example metric: Number of community-led initiatives to increase urban tree canopy cover. Potential data source: Local or regional sustainability networks or alliances.

G. Scenario 4 metric descriptions:

- Percentage of high-risk land acquired for conservation in underserved communities: This refers to the proportion of ecologically important land that has been acquired for conservation purposes in communities that are underserved or marginalized, particularly those areas that are at risk of development or other forms of human disturbance. Example metric: Percentage of high-risk land acquired for conservation in low-income communities. Potential data source: The Conservation Fund's Green Infrastructure Toolkit.
- Green infrastructure coverage percentage in underserved communities: This refers to the proportion of green infrastructure, such as parks, green roofs, and rain gardens, in communities that are underserved or marginalized. Example metric: Percentage of green infrastructure coverage in communities of color. Potential data source: The Trust for Public Land's ParkScore.
- Number of buildings retrofitted to meet higher standards in underserved communities: This refers to the number of existing buildings in underserved communities that have undergone retrofitting or renovation to improve their energy efficiency and reduce their carbon footprint. Example metric: Number of residential buildings retrofitted to meet Energy Star standards in low-income neighborhoods. Potential data source: The Department of Energy's Building Performance Database.
- Disparities in access to green infrastructure projects across demographic groups: This refers to the differences in access to green infrastructure projects, such as parks or trails, across different demographic groups, such as race or income. Example metric: Ratio of park acreage per 1,000 residents in low-income neighborhoods compared to high-income neighborhoods. Potential data source: National Recreation and Park Association's Park Metrics.
- Number of green infrastructure projects installed in underserved communities that address specific ecosystem services: This refers to the number of green infrastructure projects that have been implemented in underserved communities to provide specific environmental benefits, such as stormwater management, air quality improvement, or wildlife habitat creation. Example metric: Number of green roofs installed for air quality improvement in communities of color. Potential data source: EPA's Green Infrastructure Mapping Database.

- Percentage of population living within a half-mile radius of a green infrastructure project in underserved communities: This refers to the proportion of people who live close to green infrastructure projects in underserved communities, which can provide a range of environmental, health, and social benefits. Example metric: Percentage of population living within a half-mile radius of a community garden in low-income neighborhoods. Potential data source: American Community Survey.
- Number of trees planted in green infrastructure projects in underserved communities: This refers to the number of trees that have been planted in green infrastructure projects in underserved communities, which can help reduce urban heat island effects, improve air quality, and provide wildlife habitat. Example metric: Number of trees planted in street tree projects in communities of color. Potential data source: Tree Equity Score.
- Wetland acreage restored in underserved communities: This refers to the number of wetlands that have been restored to their original state or improved to function more effectively as habitat and ecosystem services providers in underserved communities. Example metric: Acres of wetlands restored in low-income neighborhoods in a given year. Potential data source: National Fish and Wildlife Foundation's Restoration Explorer.
- Increased buffer zone width in socially vulnerable communities: This refers to the width of the buffer zone around sensitive areas, such as water bodies or wetlands, which is designed to protect them from pollution and other forms of disturbance in socially vulnerable communities. Example metric: Average width of buffer zones around streams in communities of color. Potential data source: EPA's Stream and River Monitoring and Assessment.
- Lowered pollutant levels accepted in areas with high social vulnerability: This refers to the levels of pollutants, such as nitrogen, phosphorus, or sediment, which are allowed in areas with high social vulnerability, such as low-income or minority communities, which can lead to disproportionate impacts on public health and the environment. Example metric: Maximum acceptable levels of lead in drinking water in underserved communities. Potential data source: EPA's Safe Drinking Water Information System.

- Increased groundwater quality testing in underserved communities: This refers to the increase in frequency and scope of testing for contaminants in groundwater sources in underserved communities, which can help identify and address environmental health risks. Example metric: Number of wells tested for arsenic in rural communities with limited access to safe drinking water. Potential data source: The Rural Community Assistance Partnership's National Rural Water Quality Program.
- Increased hazardous waste oversight in marginalized communities: This refers to the increase in regulatory oversight and enforcement of hazardous waste management in marginalized communities, where industrial pollution and waste disposal can pose significant risks to public health and the environment. Example metric: Number of hazardous waste sites inspected for compliance with environmental regulations in environmental justice communities. Potential data source: EPA's Enforcement and Compliance History Online.
- Community-involved emergency response planning in socially vulnerable communities: This refers to the development and implementation of emergency response plans that are co-designed and co-implemented with community members in socially vulnerable communities, which can help ensure that emergency responses are equitable and effective. Example metric: Number of community members involved in the development of an emergency response plan in a low-income neighborhood. Potential data source: Local government or community-based organizations.
- Percentage increase in green space access for vulnerable communities: This refers to the increase in the availability and accessibility of green spaces, such as parks or community gardens, for vulnerable communities, which can provide a range of social, economic, and environmental benefits. Example metric: Percentage increase in the number of parks or playgrounds per capita in low-income neighborhoods. Potential data source: The Trust for Public Land's ParkServe.
- Engagement events for marginalized groups: This refers to the number and type of events, such as workshops, meetings, or public forums, which are specifically targeted to engage marginalized groups in environmental decision-making processes. Example metric:

Number of environmental justice workshops held in communities of color. Potential data source: Local or state government or community-based organizations.

- Relocation of people by demographics: This refers to the number and demographic characteristics of people who have been relocated due to environmental hazards, such as flooding, wildfire, or toxic pollution. Example metric: Number of households relocated due to air pollution in a low-income neighborhood. Potential data source: Local or state government relocation programs.
- Resettlement by demographics: This refers to the number and demographic characteristics of people who have been resettled to new locations that are more resilient or sustainable in the face of environmental hazards. Example metric: Number of households resettled to eco-friendly homes in a community of color after a disaster. Potential data source: Non-profit organizations involved in disaster recovery.
- Programs developed for vulnerable communities: This refers to the number and type of programs that have been specifically designed to address environmental challenges and promote sustainability in vulnerable communities. Example metric: Number of urban agriculture programs implemented in low-income neighborhoods. Potential data source: Local or regional sustainability networks or alliances.
- Participation rates of vulnerable and marginalized communities in planning and decision-making: This refers to the degree to which vulnerable and marginalized communities are included and engaged in environmental planning and decision-making processes. Example metric: Percentage of environmental planning meetings attended by community members in a community of color. Potential data source: Local or state government or community-based organizations.

H. Scenario 5 metric descriptions:

- Number of critical infrastructure elements upgraded to meet higher standards: This refers to the number of critical infrastructure elements, such as bridges, roads, and power grids, which have been upgraded to meet higher standards for resilience and sustainability. Example metric: Number of bridges retrofitted to withstand higher flood levels. Potential data source: Department of Transportation's National Bridge Inventory.

- Number of properties in low-lying areas protected from flooding and other hazards: This refers to the number of properties that have been protected from flooding and other hazards through infrastructure improvements such as levees, seawalls, and green infrastructure. Example metric: Number of properties in flood-prone areas protected by flood walls or barriers. Potential data source: FEMA's National Flood Insurance Program.
- Amount of land protected by infrastructure improvements: This refers to the amount of land that has been protected from environmental hazards such as floods, wildfires, or landslides through infrastructure improvements. Example metric: Acres of land protected by wildfire fuel breaks or fire-resistant vegetation. Potential data source: USDA Forest Service's Wildland Fire Decision Support System.
- Percentage of green elements in grey infrastructure projects: This refers to the proportion of green infrastructure elements, such as rain gardens or green roofs, included in traditional grey infrastructure projects, such as roads or buildings. Example metric: Percentage of green infrastructure elements incorporated into stormwater management systems. Potential data source: EPA's Green Infrastructure Wizard.
- Amount of impervious surface retrofitted with green infrastructure: This refers to the number of impervious surfaces, such as parking lots or rooftops, which have been retrofitted with green infrastructure, such as rain gardens or green roofs, to manage stormwater runoff and provide other environmental benefits. Example metric: Square footage of impervious surface retrofitted with green roofs. Potential data source: Green Roofs for Healthy Cities' Green Roof Database.
- Reduction in air pollution levels: This refers to the reduction in levels of air pollutants such as particulate matter, nitrogen oxides, and sulfur dioxide, which can have negative impacts on public health and the environment. Example metric: Percentage reduction in particulate matter concentrations in a given city. Potential data source: EPA's Air Quality System.
- Reduction in number of properties impacted by flooding: This refers to the reduction in the number of properties that are impacted by flooding, which can cause property damage and loss of life. Example metric: Percentage reduction in number of properties that experience

flooding in a given area. Potential data source: National Oceanic and Atmospheric Administration's Coastal Flood Exposure Mapper.

- Reduction in extreme heat days: This refers to the reduction in the number of days with extreme heat, which can have negative impacts on public health, particularly for vulnerable populations such as the elderly or those with underlying health conditions. Example metric: Percentage reduction in the number of days with temperatures over 90°F in a given area. Potential data source: NASA's Earth Observatory.
- Improvement in water quality: This refers to the improvement in water quality in rivers, lakes, and other bodies of water, which can have positive impacts on public health, recreation, and the environment. Example metric: Reduction in fecal coliform concentrations in a given river. Potential data source: EPA's National Water Quality Inventory.
- Reduction in number of public health complaints: This refers to the reduction in the number of public health complaints related to environmental hazards, such as air pollution or hazardous waste, which can indicate improvements in environmental health. Example metric: Percentage reduction in number of asthma-related emergency room visits in a given area. Potential data source: Centers for Disease Control and Prevention's National Environmental Public Health Tracking Network.
- Number of community engagement events: This refers to the number of events or activities that have been organized to engage community members in environmental planning and decision-making processes. Example metric: Number of public meetings held to solicit community input on a proposed infrastructure project. Potential data source: Local or state government or community-based organizations.
- Number of community-led initiatives or programs implemented: This refers to the number of community-led initiatives or programs that have been implemented to address environmental challenges and promote sustainability. Example metric: Number of community gardens or urban farms established in a low-income neighborhood. Potential data source: Local or regional sustainability networks or alliances.

- Percentage of vulnerable populations involved in planning and decision-making: This refers to the degree to which vulnerable populations, such as low-income or minority communities, are involved in environmental planning and decision-making processes. Example metric: Percentage of community members from low-income neighborhoods serving on a local environmental commission or board. Potential data source: Local or state government or community-based organizations.

I. Scenario 6 metric descriptions:

- Number of critical infrastructure elements upgraded to meet higher standards in vulnerable areas: This refers to the number of critical infrastructure elements, such as bridges, roads, and power grids, which have been upgraded to meet higher standards for resilience and sustainability in vulnerable areas. Example metric: Number of bridges retrofitted to withstand higher flood levels in low-income neighborhoods. Potential data source: Department of Transportation's National Bridge Inventory.
- Number of vulnerable properties protected from flooding and other hazards: This refers to the number of properties that have been protected from flooding and other hazards through infrastructure improvements such as levees, seawalls, and green infrastructure in vulnerable areas. Example metric: Number of low-income households in flood-prone areas protected by flood walls or barriers. Potential data source: FEMA's National Flood Insurance Program.
- Percentage of vulnerable population living within the service area of infrastructure improvements: This refers to the proportion of vulnerable population living within the service area of infrastructure improvements such as upgraded critical infrastructure, flood protection infrastructure, or other hazard mitigation projects. Example metric: Percentage of low-income residents living within the service area of a new stormwater management system. Potential data source: Census data and project mapping.
- Percentage of green elements in grey infrastructure projects in vulnerable areas: This refers to the proportion of green infrastructure elements, such as rain gardens or green roofs, included in traditional grey infrastructure projects, such as roads or buildings, in vulnerable areas. Example metric: Percentage of green infrastructure elements incorporated into

transportation infrastructure projects in low-income neighborhoods. Potential data source: EPA's Green Infrastructure Wizard.

- Amount of impervious surface retrofitted with green infrastructure in vulnerable areas: This refers to the number of impervious surfaces, such as parking lots or rooftops, which have been retrofitted with green infrastructure, such as rain gardens or green roofs, to manage stormwater runoff and provide other environmental benefits in vulnerable areas. Example metric: Square footage of impervious surface retrofitted with green infrastructure in communities of color. Potential data source: Green Roofs for Healthy Cities' Green Roof Database.
- Percentage of vulnerable population living within the service area of green infrastructure projects: This refers to the proportion of vulnerable population living within the service area of green infrastructure projects such as parks, green roofs, or community gardens in vulnerable areas. Example metric: Percentage of low-income residents living within a half-mile radius of a new community garden. Potential data source: Census data and project mapping.
- Reduction in air pollution levels in vulnerable areas: This refers to the reduction in levels of air pollutants such as particulate matter, nitrogen oxides, and sulfur dioxide, which can have negative impacts on public health and the environment in vulnerable areas. Example metric: Percentage reduction in particulate matter concentrations in low-income neighborhoods. Potential data source: EPA's Air Quality System.
- Reduction in number of properties impacted by flooding in vulnerable areas: This refers to the reduction in the number of properties that are impacted by flooding, which can cause property damage and loss of life in vulnerable areas. Example metric: Percentage reduction in number of properties that experience flooding in environmental justice communities. Potential data source: National Oceanic and Atmospheric Administration's Coastal Flood Exposure Mapper.
- Reduction in extreme heat days in vulnerable areas: This refers to the reduction in the number of days with extreme heat, which can have negative impacts on public health, particularly for vulnerable populations such as the elderly or those with underlying health conditions in vulnerable areas. Example metric: Percentage reduction in the number of

days with temperatures over 90°F in environmental justice communities. Potential data source: NASA's Earth Observatory.

- Improvement in water quality in vulnerable areas: This refers to the improvement in water quality in rivers, lakes, and other bodies of water, which can have positive impacts on public health, recreation, and the environment in vulnerable areas. Example metric: Reduction in fecal coliform concentrations in low-income neighborhoods. Potential data source: EPA's National Water Quality Inventory.
- Percentage of vulnerable population living within the service area of infrastructure improvements that reduce health risks: This refers to the proportion of vulnerable population living within the service area of infrastructure improvements that reduce health risks such as air pollution, flooding, and extreme heat in vulnerable areas. Example metric: Percentage of low-income residents living within the service area of a new stormwater management system that also reduces urban heat island effects. Potential data source: Census data and project mapping.
- Number of community engagement events in vulnerable areas: This refers to the number of events or activities that have been organized to engage community members in environmental planning and decision-making processes in vulnerable areas. Example metric: Number of public meetings held in environmental justice communities to solicit community input on a proposed infrastructure project. Potential data source: Local or state government or community-based organizations.
- Number of community-led initiatives or programs implemented in vulnerable areas: This refers to the number of community-led initiatives or programs that have been implemented to address environmental challenges and promote sustainability in vulnerable areas. Example metric: Number of community-led tree planting initiatives in low-income neighborhoods. Potential data source: Local or regional sustainability networks or alliances.
- Percentage of vulnerable populations involved in planning and decision-making in vulnerable areas: This refers to the degree to which vulnerable populations, such as low-income or minority communities, are involved in environmental planning and decision-making processes in vulnerable areas. Example metric: Percentage of community members

from environmental justice communities serving on a local environmental commission or board. Potential data source: Local or state government or community-based organizations.

- Disparities in access to community engagement events and decision-making opportunities across demographic groups: This refers to the disparities in access to community engagement events and decision-making opportunities that exist across demographic groups in vulnerable areas. Example metric: Percentage difference in attendance rates between white and non-white community members at public meetings in environmental justice communities. Potential data source: Local or state government or community-based organizations.