Appendix B. Climate Change and Social Vulnerability

1. Introduction

The impacts and economic effects of climate change will have disproportionate effects across the U.S., with some experiencing more harm than others. In particular, some populations based on age, income, race/ethnicity, gender, education, disability, health status, and other factors are considered to be socially vulnerable.[1,2,3] Socially vulnerable populations are oftentimes more susceptible to exposure to climate-related hazards, such as air pollution, in which some racial minorities face higher risks of mortality and asthma from the same exposure. These individuals and communities will face higher risks than others due to having less capacity to anticipate, respond to, recover from, and adapt to climate- and weather-related events.[4,5] In this case, social vulnerability refers to the inherent characteristics of a population or system that makes them more susceptible to and less able to withstand adverse impacts. In other words, "social vulnerability is partially the product of social inequalities—those social factors that influence or shape the susceptibility of various groups to harm and that also govern their ability to

[1] Cardona OD, van Aalst MK, Birkmann J, Fordham M, McGregor G, Perez R, Pulwarty RS, Schipper ELF, and Sinh BT. 2012. Determinants of risk: exposure and vulnerability. In: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.)]. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge, UK, and New York, NY, USA, pp. 65-108.

[2] Cutter SL, and Finch C. 2008. Temporal and spatial changes in social vulnerability to natural hazards. *PNAS*, doi: 10.11073/pnas.0710375105

[3] Cutter SL, Boruff BL, and Shirley WL. 2003. Social vulnerability to environmental hazards. *Social Science Quarterly*, doi: 10.1111/150-6237.8402002

[4] Ebi KL, Balbus JM, Luber G, Bole A, Crimmins A, Glass G, Saha S, Shimamoto MM, Trtanj J, and White-Newsome JL. 2018. *Human Health. In Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II* [Reidmiller DR, Avery CW, Easterling DR, Kunkel KE, Lewis KLM, Maycock TK, and Stewart BC, (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 572–603. doi: 10.7930/NCA4.2018.CH14

[5] Jantarasami LC, Novak R, Delgado R, Marino E, McNeeley S, Narducci C, Raymond-Yakoubian J, Singletary L, and Powys Whyte K. 2018. *Tribes and Indigenous Peoples. In Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II* [Reidmiller DR, Avery CW, Easterling DR, Kunkel KE, Lewis KLM, Maycock TK, and Stewart BC, (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 572–603. doi: 10.7930/NCA4.2018.CH15

respond."[6] As climate change is projected to intensify in the future, the magnitude of impacts not only depends on the degree of vulnerability and exposure to these events but also the actions communities take to adapt to the changing conditions.[7] How well people and their communities are able to adapt depends on a variety of social and economic factors, including social cohesion and resources.[8] This technical appendix explores how climate change and social vulnerability are conceptualized and how disproportionate impacts can be assessed using a place-based approach. It also explores examples in the assessment literature of where climate change and social vulnerability are intersecting. Finally, it ends by outlining key aspects of how this report examines climate change and social vulnerability.

2. A Conceptual Framework for Analyzing Climate Change and Social Vulnerability

Climate change and resulting extreme events are causing varying degrees of impact on people's lives. The extent of impact is contingent on exposure and vulnerability. In general, exposure refers to the people, assets, or systems located where a climate or weather event may occur, and vulnerability refers to whether the exposed will be adversely impacted. In other words, people cannot be vulnerable if they are not exposed, but they can be exposed and not vulnerable. Vulnerability is a key component in climate change research that is often conceptualized and categorized in different ways depending on the scientific fields that use it. This presents challenges for interdisciplinary research that centers on vulnerability and adaptation to climate change due to widespread disagreement about how to define vulnerability and its associated concepts of exposure, risk, and sensitivity. The Intergovernmental Panel on Climate Change (IPCC) broadly classifies vulnerability and exposure as dynamic and dependent on environmental, social, economic, institutional, demographic, cultural, governance, and environmental factors.[9] Therefore, impacts are derived from a multifaceted set of interacting conditions and drivers in which populations are not just passively affected but "active managers of vulnerability."[10] To effectively reduce climate-related impacts, it is necessary to understand and address social vulnerability, which will require an integrated approach that considers both its causes and ways to enhance people's coping and adaptive capacities.

[6] Cutter SL, Boruff BL, and Shirley WL. 2003. Social vulnerability to environmental hazards. *Social Science Quarterly*, p. 243. doi: 10.1111/150-6237.8402002

[7] Cardona OD, van Aalst MK, Birkmann J, Fordham M, McGregor G, Perez R, Pulwarty RS, Schipper ELF, and Sinh BT. 2012. Determinants of risk: exposure and vulnerability. In: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation [Field CB, Barros V, Stocker TF, Qin D, Dokken DJ, Ebi KL, Mastrandrea MD, Mach KJ, Plattner GK, Allen SK, Tignor M, and Midgley PM, (eds.)]. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge, UK, and New York, NY, USA, pp. 65-108.

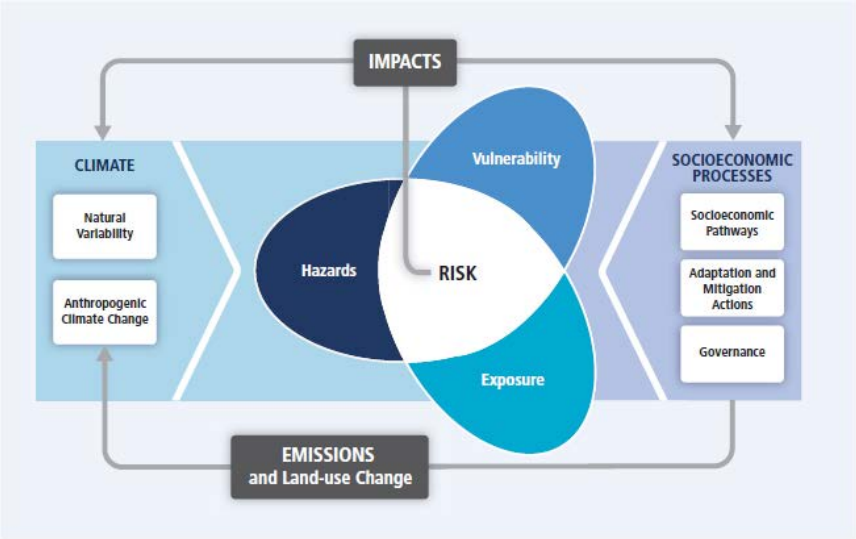
[8] Lempert R, Arnold J, Pulwarty R, Gordon K, Greig K, Hawkins C, Hoffman D, Sands D, and Werrell C. 2018 Reducing Risks Through Adaptation Actions. In Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II [Reidmiller DR, Avery CW, Easterling DR, Kunkel KE, Lewis KLM, Maycock TK, and Stewart BC, (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 1309–1345. doi: 10.7930/NCA4.2018.CH28

[9] Cardona OD, van Aalst MK, Birkmann J, Fordham M, McGregor G, Perez R, Pulwarty RS, Schipper ELF, and Sinh BT. 2012. Determinants of risk: exposure and vulnerability. In: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation [Field CB, Barros V, Stocker TF, Qin D, Dokken DJ, Ebi KL, Mastrandrea MD, Mach KJ, Plattner GK, Allen SK, Tignor M, and Midgley PM, (eds.)]. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge, UK, and New York, NY, USA, pp. 65-108.

[10] Cardona et al. 2012. p. 71

Vulnerability is multidimensional, varying across temporal and spatial scales, which oftentimes makes organizing frameworks subjective and contentious.[11] Nevertheless, frameworks are a useful conceptual tool to both organize and define key concepts of a particular body of work. This report adopts the diagram developed by the WGII AR5 (Figure 1) to explain the relationship between hazards, vulnerability, and exposure, to the risks of climate change impacts. Notably, the risk of climate-related impacts depends upon the interactions between climate-related hazard events and the vulnerability and exposure of the human-environment all of which are affected by the climate system and underlying socioeconomic processes. [12]

Figure 1. Conceptual Diagram from the WGII AR5 Illustrating how the Risk of Climate-Related Impacts Depends Upon the Interactions between Climate-Related Hazards and the Vulnerability and Exposure of the Human-Environment System. Drivers of Hazards, Exposure, and Vulnerability Include the Climate System (left) and Socioeconomic Processes (right).



Due to its multidimensional nature, climate change and social vulnerability is inherently "place-based" interacting with exposure and climate-related hazards to create risk.[13] In other words, the hazards and vulnerabilities a remote coastal community faces may differ from those an inland urban area or agriculturally intensive region may experience, and thus, the associated risks may also differ. For example, a coastal community may face inundation from sea level rise, wash-out of roads from storm surge, and damage to structures from extreme weather. If such a community is reliant on a tourism economy or has a large retiree population, then the risk for adverse impacts is greater than it might be for a coastal community with a younger population or diversified economy, due to the underlying

[11] Cardona et al. 2012.

[12] Campos M, Warren R, Birkmann J, Luber G, O'Neill B, and Takahashi K. 2014. Emergent risks and key vulnerabilities. In: *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects*. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field CB, Barros BR, Dokken DJ, Mach KJ, Mastrandrea MD, Bilir TE, Chatterjee M, Ebi KL, Estrada YO, Genova RC, Girma B, Kissel ES, Levy AN, MacCracken S, Mastrandrea SR, and White LL, (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1039-1099.

[13] Cutter SL, Boruff BL, and Shirley WL. 2003. Social vulnerability to environmental hazards. *Social Science Quarterly*, doi: 10.1111/150-6237.8402002

socioeconomic and demographic characteristics of the population. By contrast, hazards facing an inland urban area may include changes in air quality or increases in extreme heat events.

The challenge, when examining vulnerability to climate change, is that environmental conditions are changing, thereby introducing new risk conditions that communities must face (e.g., increase in frequency and duration of high heat days in northern U.S. cities). Furthermore, the cumulative or compound effects of recurring or overlapping extreme events increases the risks to people, systems (e.g., infrastructure), and economic sectors[14] by altering their resources and capacity to prepare for, cope with, and adapt to these events.[15] It is the "impacts affecting interconnected systems [that] can cascade across sectors and regions, creating complex risks and management challenges."[16] As part of risk management, governments and communities typically take two approaches to reduce risk and costs associated with impacts from climate change. Specifically, implementing climate mitigation strategies to reduce the hazard and adaptation strategies to reduce exposure. Even though risk is hazard-specific, underlying features (e.g., poverty, age, race/ethnicity, lack of social networks, housing tenure, etc.) are predisposing individuals or groups to be adversely affected irrespective of the type of climate or weather event. Understanding these features presents an opportunity for a third approach to risk management. This involves proactively considering responses that better address underlying drivers of social vulnerability and increasing the adaptive capacity and resilience of human-environment systems. In other words, social vulnerability is not immutable, and in the climate hazard context, can be directly addressed through efforts to enhance adaptive capacity.

3. Climate Change and Social Vulnerability in Existing Assessments

Potential impacts and risks to vulnerable populations are increasingly described in climate science assessments.[17,18,19] As climate change continues to transform the environment, humans will face progressively greater challenges to their health and well-being with low-income people, children, older

[14] Maxwell K, Julius S, Grambsch A, Kosmal A, Larson L, and Sonti N. 2018. Built Environment, Urban Systems, and Cities. In *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment*, Volume II [Reidmiller DR, Avery CW, Easterling DR, Kunkel KE, Lewis KLM, Maycock TK, and Stewart BC, (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 438–478. doi: 10.7930/NCA4.2018.CH11

[15] Cardona OD, van Aalst MK, Birkmann J, Fordham M, McGregor G, Perez R, Pulwarty RS, Schipper ELF, and Sinh BT. 2012. Determinants of risk: exposure and vulnerability. In: *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation* [Field CB, Barros V, Stocker TF, Qin D, Dokken DJ, Ebi KL, Mastrandrea MD, Mach KJ, Plattner GK, Allen SK, Tignor M, and Midgley PM, (eds.)]. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge, UK, and New York, NY, USA, pp. 65-108.

[16] Jay A, Reidmiller DR, Avery CW, Barrie D, DeAngelo BJ, Dave A, Dzaugis M, Kolian M, Lewis KLM, Reeves K, and Winner D. 2018 Overview. In: *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II* [Reidmiller DR, Avery CW, Easterling DR, Kunkel KE, Lewis KLM, Maycock TK, and Stewart BC, (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 33–71. doi: 10.7930/NCA4.2018.CH1

[17] Ebi KL, Balbus JM, Luber G, Bole A, Crimmins A, Glass G, Saha S, Shimamoto MM, Trtanj J, and White-Newsome JL. 2018. Human Health. In: *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment*, Volume II [Reidmiller DR, Avery CW, Easterling DR, Kunkel KE, Lewis KLM, Maycock TK, and Stewart BC, (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 572–603. doi: 10.7930/NCA4.2018.CH14

[18] Jantarasami LC, Novak R, Delgado R, Marino E, McNeeley S, Narducci C, Raymond-Yakoubian J, Singletary L, and Powys Whyte K. 2018. Tribes and Indigenous Peoples. In *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment*, Volume II [Reidmiller DR, Avery CW, Easterling DR, Kunkel KE, Lewis KLM, Maycock TK, and Stewart BC, (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 572–603. doi: 10.7930/NCA4.2018.CH15

[19] Lempert R, Arnold J, Pulwarty R, Gordon K, Greig K, Hawkins Hoffman C, Sands D, and Werrell C. 2018. Reducing Risks Through Adaptation Actions. In *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment*, Volume II [Reidmiller DR, Avery CW, Easterling DR, Kunkel KE, Lewis KLM, Maycock TK, and Stewart BC, (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 1309–1345. doi: 10.7930/NCA4.2018.CH28

adults, and some communities of color experiencing greater health risks.[20] For example, hotter temperatures are not only expected to result in a greater number of heat-related deaths, but also affect electricity demands and power system costs, which could lead to more brownouts (intentional reduction of capacity) and blackouts (complete interruption of capacity).[21] People who live in inadequately air-conditioned housing are especially at risk from heat stress.[22] Rising temperatures reveals a disproportionate effect on individuals with lower incomes whose budgets are strained by rising energy costs, who are more likely to live in inadequate housing, and who are elderly and not only more sensitive to heat but oftentimes on reduced incomes.

In addition to direct impacts from hazard events, there are also cascading impacts that will have disproportionate effects. For example, food security in urban areas is vulnerable to disruptions from climate- and weather-related events due to the interconnected nature of its sectors (e.g., food supply shortages from decreased agricultural production, changes in food distribution due to transportation challenges, increasing food prices from decreased supply, etc.).[23] The disruptions to urban areas' food security is expected to disproportionately impact and exacerbate the situations of those who already suffer from food insecurity[24] increasing their risk. These people facing greater risk are socially vulnerable and may include, but are not limited to, children, older adults, low-income communities, and the unemployed.

The underlying social, economic, and geographic factors shaping exposure to climate-related impacts and adaptive capacities are also well illustrated by the dynamic coastal sector. Climate change impacts like sea level rise and heavy precipitation are amplifying the effects of coastal erosion, storms, and high tide flooding threatening coastal economies (e.g., property values, recreation, etc.), infrastructure, and people's safety and well-being.[25] Pre-existing social inequities in coastal areas are being further exacerbated by climate- and extreme weather-related impacts sparking important policy questions including who is most vulnerable to impacts, who should pay for losses, and how should coastal communities adapt to the changing conditions.[26] For example, property owners' access to resources (e.g., capital or insurance) heavily influences their ability to address (e.g., protect, modify, or retreat) climate- and extreme weather-related impacts.[27] Notably, coastal property protection decisions (e.g.,

[20] Ebi KL, Balbus JM, Luber G, Bole A, Crimmins A, Glass G, Saha S, Shimamoto MM, Trtanj J, and White-Newsome JL. 2018. Human Health. In *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment*, Volume II [Reidmiller DR, Avery CW, Easterling DR, Kunkel KE, Lewis KLM, Maycock TK, and Stewart BC, (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 572–603. doi: 10.7930/NCA4.2018.CH14

[21] Zamuda C, Bilello DE, Conzelmann G, Mecray E, Satsangi A, Tidwell V, and Walker BJ. 2018. Energy Supply, Delivery, and Demand. In *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment*, Volume II [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 174–201. doi: 10.7930/NCA4.2018.CH4

[22] Maxwell K, Julius S, Grambsch A, Kosmal K, Larson L, and Sonti N. 2018. Built Environment, Urban Systems, and Cities. *In Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment*, Volume II [Reidmiller DR, Avery CW, Easterling DR, Kunkel KE, Lewis KLM, Maycock TK, and Stewart BC, (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 438–478. doi: 10.7930/NCA4.2018.CH11

[23] ibid

[24] Maxwell K, Julius S, Grambsch A, Kosmal A, Larson L, and Sonti N. 2018. Built Environment, Urban Systems, and Cities. In *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment*, Volume II [Reidmiller DR, Avery CW, Easterling DR, Kunkel KE, Lewis KLM, Maycock TK, and Stewart BC, (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 438–478. doi: 10.7930/NCA4.2018.CH11

[25] Fleming E, Payne J, Sweet W, Craghan M, Haines J, Hart JF, Stiller H, and Sutton-Grier A. 2018. Coastal Effects. In *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, **Volume II*** [Reidmiller DR, Avery CW, Easterling DR, Kunkel KE, Lewis KLM, Maycock TK, and Stewart BC, (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 322–352. doi: 10.7930/NCA4.2018.CH8

[26] ibid

[27] ibid

shoreline armoring, beach nourishment) can employ a cost-benefit logic that usually favors areas with higher home values and incomes, whereas retreat often occurs disproportionately in areas with lower home values and incomes (e.g., minority communities), which can continue to promote historic patterns of social inequity.[28,29] As a result, individuals and marginalized communities who do not have access to these resources are increasingly vulnerable and less able to prepare for, respond to, and recover from impacts and likely do not have opportunities to participate in planning processes and voice their opinions.

These heat, health, urban, and coastal examples reflect a growing shift in research priorities from focusing solely on understanding a climate or extreme weather event to examining the ways in which people and systems are experiencing impacts and the systemic social and economic inequalities that exacerbate their exposure and vulnerability. Understanding the differential impacts on populations, communities, and systems is critical for developing tailored response and adaptation actions that includes a wide range of stakeholders. While there is an increasing emphasis on incorporating potential impacts to vulnerable populations into climate assessments (e.g., NCA4),[30] there is still a paucity in the literature on studies that quantify and monetize these risks. A recent National Academy of Sciences report confirmed this research gap and encourages the federal climate science community to better understand impacts to vulnerable populations, as well as emphasize risk management that prioritizes protecting the most vulnerable and addressing underlying drivers of vulnerability (i.e., inequity and exclusion).[31]

4. Examining Climate Change and Social Vulnerability in this Report

This Technical Report investigates observed and projected risks of climate change to socially vulnerable populations in the U.S. including analysis of whether and to what extent these risks are experienced disproportionately compared to the broader population. While this report is unable to quantify cascading or indirect effects and their disproportionate impacts, the individual literature reviews in the sector appendices do acknowledge them.

As established in prior research, this report projects changes in some of the most economically significant sectoral impacts of climate (e.g., air quality, temperature mortality, labor, roads, coastal infrastructure, and buildings in riverine floodplains), and projects spatial comparisons of monetized sectoral impacts to socially vulnerable populations. This report also examines how the increasing severity of climate change can affect the disproportionality of the incidence of impacts on socially vulnerable populations.

[28] Siders AR. 2018. Social justice implications of U.S. managed retreat buyout programs. *Climatic Change* 152, pages 239-257. https://link.springer.com/article/10.1007/s10584-018-2272-5

[29] Siders AR, and Keenan JM. 2020. Variables shaping coastal adaptation decisions to armor, nourish, and retreat in North Carolina. *Ocean & Coastal Management* 183. https://doi.org/10.1016/j.ocecoaman.2019.105023

[30] Jay A, Reidmiller DR, Avery CW, Barrie D, DeAngelo BJ, Dave A, Dzaugis M, Kolian M, Lewis KLM, Reeves K, and Winner D. 2018. Overview. In *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment,* Volume II [Reidmiller DR, Avery CW, Easterling DR, Kunkel KE, Lewis KLM, Maycock TK, and Stewart BC, (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 33–71. doi: 10.7930/NCA4.2018.CH1

[31] National Academies of Sciences, Engineering, and Medicine. 2021. *Global Change Research Needs and Opportunities for 2022-2031.* Washington, DC: The National Academies Press. https://doi.org/10.17226/26055.