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RESEARCH ARTICLE

Climate adaptation research priorities and funding: a review of US federal departments' climate action plans

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ABSTRACT

National-level governments are directing and funding climate adaptation research, which is essential to informing effective and equitable adaptation practices. We sought to understand how United States (US) federal agencies prioritize, direct, and fund research related to climate adaptation and climate resilience through analyzing climate action plans created in 2021 by 13 agencies who are members of the US Global Change Research Program. We examine: (1) agencies' stated climate adaptation research priorities; (2) how agencies address collaboration, outreach, accessibility, and usability of research outcomes; and (3) agencies' adaptation research funding opportunities. We argue that certain research needs, justice and equity considerations, and interdisciplinary research should be emphasized to a greater degree. While adaptation research capacity and funding opportunities are expanding, they remain inadequate for the scale of research needed.

Key policy insights

- US federal agencies vary in their integration of research as a core component of their climate adaptation plans, but most prioritize research that is relevant and accessible to stakeholders and decision-makers.
- While all agencies addressed environmental justice, some could more substantially incorporate justice considerations into their climate adaptation research.
- Adaptation research and strategies should ensure that collaborations are inclusive and sustainable and would benefit from meaningful and respectful collaboration with tribes and Indigenous Peoples, as well as marginalized and under-represented groups.
- Multidisciplinary research is key to climate adaptation and should be enhanced through increasing funding support for crosscutting programmes.

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1. Introduction

The United States (US) and broader global community are increasingly facing challenges from climate change that will acutely impact communities and ecosystems in the coming decades (USGCRP, 2018). President Biden recognized the immediacy of this challenge and issued an Executive Order (E.O. 14008), *Tackling the Climate Crisis at Home and Abroad*, shortly after taking office in 2021. The E.O. directed federal agencies to create plans describing the actions they planned to take to increase the resilience and adaptive capacity of their operations and facilities, including addressing the agency's climate vulnerabilities and how the agency can use its purchasing power to create more resilient supply chains and increase facilities' energy and water efficiency

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(Biden, 2021). The plans include ongoing actions, new initiatives starting in 2021 and 2022, and specific milestones to be achieved within the next five years. In these plans, adaptation can be seen as adjusting to 'actual or expected climate and its effects in order to moderate harm or take advantage of beneficial opportunities,' and resilience is the capacity to recover quickly from disruptions in ways that maintain essential and desirable social and ecological functions and characteristics (IPCC, 2022, p. 7).

Related federal actions also shape the current adaptation research landscape in the US. Executive Order 14008 also established the Justice40 Initiative, which directs the exploration of how 40% of certain federal investments can benefit disadvantaged communities. Other recent developments include President Biden's PREPARE plan for promoting climate adaptation in economically developing countries and increased funding for some research programmes in the 2022 Inflation Reduction Act. Notably, the U.S. is the only G20 country without a comprehensive national adaptation plan; a bipartisan bill to create one was introduced in the Senate in 2022, but it has not been passed into law (Parsons & Adams, 2022; Parsons & Keenan, 2021; "Senators", 2022).

We seek to understand how research into adaptation and resilience is conceptualized, prioritized, and directed by federal agencies in plans for 13 agencies that are part of the US Global Change Research Program (USGCRP) (Table 1). The USGCRP was created by Congress to coordinate federal research activities related to the global environment (USGCRP, 2022). We also include the US Geological Survey's (USGS) Landscape Science Strategy (released in 2021 independent of the E.O.) because of USGS's role as the scientific research branch of the Department of Interior (DOI) and as the lead agency of the regional Climate Adaptation Science Centers (CASCs) (Jenni et al., 2021). We include analysis of the Department of Homeland Security's (DHS) plan because it joined USGCRP in February 2023, although it was not a member at the time its plan was published in September 2021. Our objectives are to answer the following: (1) What are the major climate adaptation research priorities as identified by the US federal government? (2) How do the agencies address research collaboration, outreach, accessibility, and usability in these action plans? (3) What are the existing funding opportunities from these agencies? We note how plans address research collaboration, outreach, accessibility, and usability because these themes emerged in many of the USGCRP member agency climate action plans. This reflects consensus in the most recent IPCC assessment that inclusive governance, partnerships with traditionally marginalized peoples, and processes that link multiple forms of knowledge lead to 'more effective and enduring adaptation outcomes' that are more locally appropriate and sustainable (IPCC, 2022, p. 31).

2. Methods

We focused on USGCRP member agencies' climate adaptation plans because they are the federal entities who drive research and investment to better understand global environmental change. We conducted a systematic review of these 13 plans by reading each in depth and highlighting content on adaptation research, which included topics that agencies identified as needing additional research and descriptions of how this research should be approached and executed. We took detailed notes on these research mentions, and synthesized data into themes that emerged across several agencies' plans, including: (1) topics needing additional research, (2) how research can address equity and environmental justice, (3) the need for more social science and interdisciplinary research, and (4) how to make research relevant and accessible. Because they were less relevant to our objectives, we did not focus on adaptation needs of the department as a government institution, such as initiatives regarding employee education, infrastructure changes, or monitoring agency adaptation. Research in this sense involves systematic investigation that provides generalizable knowledge related to understanding and adapting to the impacts of climate change (i.e. excluding programme assessment or monitoring for implementation, effectiveness, or surveillance outside of a research context [Wurtzebach et al., 2019]) and can involve multiple partners (i.e. federal agencies themselves, academic institutions, private actors, etc.). We limited our analysis to the original adaptation plans, but agencies are now releasing annual updates on progress towards goals.

We also searched for and reviewed recent grant opportunities in 2021 and 2022 among the USGCRP agencies that may provide funding for research focused on climate adaptation in the physical and social

sciences. Our search included weekly notifications of new sponsored funding opportunities from the SPIN database using the key word search 'climate adapt*' from early 2021-December 2022, as well as adding opportunities as they emerged (i.e. recent funding made available in the 2022 Inflation Reduction Act). We also include a list of National Science Foundation (NSF) grants that may fund projects related to adaptation, as the NSF is a member of the USGCRP but did not develop a climate adaptation plan. Many opportunities in Table 2 do not solely focus on climate adaptation research, but we include funding sources that are likely to support projects related to climate adaptation. Thus, the list is not comprehensive of all federal funding for adaptation research (which is difficult to determine), but it does represent major funding opportunities that have emerged to support climate adaptation research at the federal level.

3. Results

Departments' climate adaptation plans emphasized research differently: some prioritized research (e.g. USDA), others focused on internal assessments and incorporating adaptation into agency operations through cooperating with local partners (e.g. EPA), and yet others did not incorporate research into their plans (e.g.. USAID). Climate adaptation plans often include research and monitoring because there is a need to better understand how adaptation should occur; this information-seeking is also reflected in state and local-level adaptation plans (Koski & Keating, 2018; Woodruff & Stults, 2016). In federal agency plans, two overarching research priorities emerged: (1) improving understanding of climate change impacts on the department's focus area; (2) developing modelling projections of climate in interaction with other variables to inform decision-making. Some, but not all, departments emphasized the need to better understand equity and justice related to climate change; others mentioned the need for interdisciplinary research and broader incorporation of incorporating social science (Table 1). Certain agencies have dedicated research branches and thus a greater focus on research.

A frequent theme across departments was ensuring research results are relevant and accessible to stakeholders and decision-makers (Table 1). This requires effective collaboration and outreach so that research endeavours will lead to the actual 'adoption and application of climate-smart adaptation strategies' (USDA, 2021, p. 15). Several departments argued that research questions should be based on stakeholders' needs and advocated for collaboration with stakeholders, communities, and other agencies. Some (i.e. DOT, USAID) also noted the particular need to meaningfully involve those who are most vulnerable to climate change or who have historically been marginalized in decision-making.

Some departments (e.g. the USDA, DOC, and HSS, which are especially active in research grant-making) emphasized that they are increasing funding opportunities specifically for climate adaptation research (Table 2). Several departments (e.g. USDA, DOC, HHS, EPA, DHS) note they are reevaluating their grant-making priorities, criteria, and evaluation processes so that climate resilience is considered in all funding opportunities. USDA has established new funding opportunities for 'climate extension and education' and increased funding for USDA Climate Hubs (Table 2). The DOC will expand NOAA's Climate Adaptation Partnerships (formerly RISA) programme and the Sea Grant College Program and is requesting increasing funding to improve NOAA's own research and data services.

4. Discussion

We argue that adaptation research should be core to climate action planning for all member agencies of the USGCRP, contributing to President Biden's emphasis on the need for a 'whole-of-government approach' to address the climate crisis (The White House, 2021). At the same time, we recognize that agencies have different missions: while many agencies have entire branches focused on research, others (i.e. DOT, Department of State, USAID, DHS) do not have this research capacity. Working with agencies' stakeholders and partners to determine research needs, directly applying updated research in agency activities, making research results accessible, and funding research gaps can advance place-based, effective, and equitable climate adaptation actions. We argue below that a few critical themes should be more fully addressed by agencies in their research agenda-setting: meaningfully integrating justice and equity considerations; respectfully collaborating with

Table 1. How USGCRP federal agencies' climate action plans address research.

Department description	Research priorities	How are equity and environmental justice addressed?	How are interdisciplinary and/or social science research addressed?	How will research be made relevant and accessible?
US Department of Agriculture (USDA, 2021) Area of focus: agriculture, food, natural resources (forests and rangelands), and rural development Agencies include: Agricultural Research Service (ARS), Forest Service (USFS), Natural Resources Conservation Service (NRCS), National Institute of Food and Agriculture (NIFA), and Research, Education, and Economics (REE)	• Climate impacts on agricultural productivity, pollinators, and vector-borne livestock diseases • Adaptation strategies and practices: examining existing, developing new, and understanding barriers • Soil and forest health, improved fertilizer technologies, climate-resilient plant genetics, and pest and disease outbreaks	• Meaningfully engage with vulnerable communities to understand impacts, identify adaptation barriers and opportunities, and collaboratively develop solutions • Evaluate adaptation/resilience programmes for disproportionately high impacts and maladaptation • Provide assistance and resources to historically underserved producers and vulnerable communities	Need to incorporate social and behavioural sciences and utilize a multidisciplinary approach	• Work through Climate Hubs, extension units, land-grant institutions, technical service providers, and grant programmes • Engage with partners, especially underserved communities and tribes • Co-produce science • Incorporate Indigenous Traditional Ecological Knowledge (ITEK) into climate-smart practices • Create accessible research opportunities through community colleges and minority-serving institutions • Present data in accessible and usable formats • Increase investment and technical capacity • Evaluate feedback from user communities
Environmental Protection Agency (EPA, 2021) Area of focus: protecting human health and the environment	• Scientific evidence to support EPA decision-making • Will identify priority research needs of its partners and regional branches	• Environmental justice emphasized throughout the plan, including collaborating, consulting, and developing research priorities around the needs of underserved communities and considering impacts of EPA actions	Need social science investigations	• Consult and partner with all levels of government, tribes, organizations, businesses, and stakeholders to develop and deliver relevant research • Provide 'training, tools, technical support, data, and information' for adaptation (EPA 2021, p. 11) • Communicate research results • Create a central repository for information and tools
Department of Interior (DOI, 2021; Jenni et al., 2021) Area of focus: natural resources and cultural heritage Agencies include: USGS, Bureau of Indian Affairs, National Park Service, Bureau of Land Management, and US Fish and Wildlife Service	• Climate impacts on cultural resources, communities served by the DOI, and plant and animal species • Evaluate renewable energy development on public lands and waters	• Research vulnerable communities and environmental justice • Develop environmental justice screening tools • Ensure adaptation actions do not have disproportionate impacts	USGS: need inter- or transdisciplinary research, including the integration of social and economic science	• Create science with stakeholders and institutionalize this process • Develop research products that are accessible, usable, and relevant to landowners and managers • CASC network produces actionable climate adaptation

	• USGS: enhanced data synthesis and forecasting			science through outreach and grant programmes that respond to science needs
Department of Energy (DOE, 2021) Area of focus: energy development and regulation Agencies include: network of National Laboratories, Office of Science	• Climate science for hazard analysis and projected impacts • Development of climate technologies (i.e. power grid resilience, water reuse, vehicle electrification)	• Support adaptation and resilience in energy and environmental justice communities near DOE sites	Not emphasized	• DOE energy research, technology development, and demonstration should be made available to others • Collaborate with community leaders to provide desired technical assistance and training
Department of Defense (DOD, 2021) Area of focus: national security and the armed forces Agencies include: Defense Advanced Research Projects Agency (DARPA)	• Threat analysis, modelling and simulation, wargaming, experimentation, and artificial intelligence to predict environmental conditions and create decision support tools	• Consider environmental justice (disproportionate impacts on low income and/or minority populations) of training, testing, and acquisitions	Not emphasized	• Work with communities adjacent to installations to increase resilience
Department of Homeland Security (DHS, 2021) Area of focus: public security Agencies include: U.S. Customs and Border Patrol; U.S. Immigration and Customs Enforcement (ICE); Federal Emergency Management Agency (FEMA); Science and Technology Directorate	• Impacts of climate change on the DHS mission: migration, preventing disease and infection spread, resilient facilities, infrastructure, services, and supply chains, tools and technology to help communities with adaptation and resilience, and impacts in the Arctic region	• Actions described in the plan should distribute benefits equitably and ensure adverse impacts do not have disproportionate impacts • Expand outreach to EJ communities and their access to financial assistance programmes • Engage stakeholders in DHS decision-making, especially low-income and minority communities • Consider EJ in NEPA	Not emphasized	• Not emphasized
Department of Commerce (DOC, 2021) Area of focus: economic growth Agencies include: National Institute of Standards and Technology (NIST) and National Oceanic and Atmospheric Administration (NOAA)	• Analyses and projections of climate change impacts on the U.S. economy (i.e. impacts of natural disasters) • Building codes and zoning standards to develop climate-ready infrastructure • Assessment of community-scale resilience, including social and economic system resilience and	• Research the distributional exposure to climate impacts	Need for interdisciplinary research and social science to reach vulnerable and underserved communities	• Engage with stakeholders through working with Sea Grant universities and with NOAA's National Integrated Drought Information System (NIDIS) • NOAA's Climate Adaptation Partnerships (formerly Regional Integrated Sciences and Assessments, RISA) programme provides targeted research to aid in regional climate adaptation

(*Continued*)

Table 1. Continued.

Department description	Research priorities	How are equity and environmental justice addressed?	How are interdisciplinary and/or social science research addressed?	How will research be made relevant and accessible?
	interactions (NIST Community Resilience Program, 2021)			through long-term local relationships
Department of Health and Human Services (HHS, 2021) Area of focus: human health and well-being Agencies include: Center for Disease Control (CDC) and National Institutes of Health (NIH)	• Impacts of climate change and adaptation strategies on health and disease • Integrating public health data with climate projections and other data across agencies • Building a public health workforce that can respond to climate impacts • Rapid research response to natural disasters	• Need to increase research in environmental justice and health equity	HHS is leading transdisciplinary initiatives	• Communicate climate and health information through products such as dashboards
National Aeronautics and Space Administration (NASA, 2021) Area of focus: civilian space programme and research in earth systems, climate, aeronautics, and space	• Updated climate modelling and regional climate projections • Providing data for agencies to conduct weather forecasting, improve early warning systems, and analyze vulnerabilities of supply chains and critical launch infrastructure • Aeronautic technologies and processes that aid in climate adaptation and mitigation	• NEPA requires consideration of environmental justice associated with proposed projects	Not emphasized	• Open data and science lead to better and faster climate adaptation
Department of Transportation (DOT, 2021) Area of focus: ensure the US has a safe, efficient, and modern transportation system	• Resilience of transportation infrastructure (cost-benefit analysis) • New transportation technologies • Downscaled climate projections	• Meaningfully involve the most vulnerable in creating adaptation and resilience plans	Not emphasized	• Share information broadly about new technologies and climate-resilient transportation infrastructure
Smithsonian Institution (Smithsonian Institution, 2021) Area of focus: museums and research and education centres for enhancing access to knowledge	• Climate impacts on species, biodiversity, ecosystems, and people (i.e. climate-human interactions) • How organisms and ecosystems are responding to climate change	• Public climate change outreach and research should include equity and environmental justice issues	Not emphasized	• Improve public programmes on climate change and incorporate environmental justice and equity • Increase public access to the Smithsonian's climate change research collections and long-term datasets

	• Improving climate change datasets platforms			
Department of State* (US Department of State, 2021) Area of focus: foreign policy and international relations	• Granular data on climate impacts and natural hazards for vulnerability assessments and scenario planning for overseas sites and facilities, supply chains, relevant local infrastructure, and local staff health risk	• Work with host countries to avoid maladaptation and inequitable distribution of environmental benefits and harms in increasing resilience of facilities	Not emphasized	• Engage host countries with improving local infrastructure for climate resilience through sharing data and best practices and creating joint projects
US Agency for International Development* (USAID, 2021) Area of focus: civilian foreign aid and international development assistance	• Utilize data produced by other agencies for climate projections	• Collaborate with those experiencing negative climate change impacts but historically hold little power, promoting justice and equity	Not emphasized	• Research not emphasized

*President Biden's President's Emergency Plan for Adaptation and Resilience (PREPARE) was launched in November 2021 at the Conference of the Parties in Glasgow (COP26) to initiatea 'whole-of-government effort to help more than half a billion people in developing countries adapt to and manage the impacts of climate change' (PREPARE, 2022). This plan calls for more international research on accurate and usable climate information and warning systems, as well as climate-smart development planning with regards to infrastructure, water, health, and food security. It calls for collaboration with local academic institutions and community groups and using social, behaviour, and economic sciences to better understand adaptation possibilities, topics which were not explicitly articulated USAID's climate action plan.

Notes: Federal agency areas of focus and how they address research priorities, equity and environmental justice, and interdisciplinary, relevant, and accessible research in their climate action plans. Sub-agencies listed within department descriptions are not comprehensive but represent a subset most likely to be involved in adaptation research.

Indigenous Peoples; understanding outcomes of adaptation actions; increasing multidisciplinary research; and ensuring that collaborations are inclusive and sustainable. These themes can be addressed by all agencies with the recognition that some may have more research capacity than others.

Efforts to enhance climate adaptation and resilience must include justice and equity considerations and partnerships with traditionally marginalized peoples in order to be locally-informed, effective, and sustainable (IPCC, 2022; Maldonado et al., 2016; Rising Voices Center for Indigenous and Earth Sciences, 2022; Tripati et al., 2023). Nearly all agencies mentioned environmental or climate justice in their action plans. Some agencies emphasized the need to better understand justice and equity in both climate impacts and adaptation and resilience actions and to consult or collaborate with marginalized communities in research and broader agency efforts (i.e. USDA, EPA, DOI). Other departments, while mentioning justice, did not elaborate on how their action plans or research would consider justice and equity (i.e. State Department and NASA). The implementation of the Justice40 initiative requires integration of environmental justice into agencies' day-to-day operations and research directions. Despite the environmental justice movement's dependence on research, the capacity of environmental justice organizations to collect, analyze, and disseminate data is limited because the significant technical and financial investment needed often exceeds environmental justice groups' capacities (Martín, 2021). With these new directives focused on justice, federal agencies' research efforts and funding opportunities have the potential to help fill this gap in much-needed environmental justice data collection if attention is paid to making sure funding opportunities are widely accessible to organizations and interest groups. For example, within the Department of Interior, The Bureau of Indian Affairs' Tribal Climate Resilience Program provides support for federally recognized tribes to plan and implement climate adaptation and resilience, including providing 'technical and financial assistance, access to science, and educational opportunities' (DOI, 2021), p. 6; Table 2). The EPA recently created the Environmental Justice Thriving Communities Grantmaking programme (Table 2) in response to E.O. 14008, which funds organizations or partnerships to provide support to environmental justice communities, design application grant processes, and award grants with the intent of reducing barriers to accessing federal funding by environmental justice communities (EPA, 2023).

Agencies increasingly benefit by recognizing how research and the implementation of adaptation and resilience strategies improve from meaningful and respectful collaboration with tribes and Indigenous Peoples. There are ongoing calls to engage Indigenous and local knowledge systems for climate adaptation in ways that prioritize community needs and knowledge strengths (IPCC, 2022; Maldonado et al., 2014; STACCWG, 2021). Some of the agencies' climate action plans (e.g. USDA, EPA, DOI) addressed engagement and consultation with tribes and Indigenous Peoples to understand climate impacts and collaborate on solutions, support opportunities for Indigenous knowledge to guide adaptation, evaluate implementation to avoid maladaptation or disproportional impacts, and to make assistance and research opportunities accessible. Other agencies largely did not outline how they would engage with tribes (i.e. DOD, NASA, State, Smithsonian). Others referenced tribes but did not emphasize their unique roles as autonomous governments or holders and generators of Indigenous knowledge (i.e. DOE, DOT, and DHS). Tribes and Indigenous Peoples are key partners for adaptation solutions in pathways that should uphold their sovereignty.

More agency research attention could be paid to the outcomes of adaptation-driven actions. Some agencies (e.g. USDA, DOI, NASA, State, and USAID) explicitly mention that their climate actions should avoid maladaptive practices, particularly when addressing changes to facilities. We argue that agencies need to better prioritize research into their selected adaptive actions to determine if and why they meet resilience and adaptation goals over time, since both climate impacts and social systems are dynamic (Parsons & Keenan, 2021).

There is a need for multidisciplinary research that considers the complex, multidirectional interactions of climate change impacts on natural and human systems (NAS, 2019; NASEM, 2019; NASEM, 2021; National Research Council, 2013). A subset of agencies (e.g. USDA, EPA, DOI, DOC) call for multidisciplinary research in some arenas, asserting that social science is necessary to meet adaptation goals because they are contingent upon understanding and contextualizing social and cultural frameworks in which stakeholders operate (Table 1). Social science enables better understanding of outcomes and tradeoffs of different actions and can help make informed adaptation decisions through investigating motivations, barriers, opportunities, and the roles of social organizations (Davis & Wollenstein, 2021). Social science can also bring insights to better understand

Table 2. Major US federal research funding opportunities related to climate adaptation.

Agency	Grant opportunity	Total amount to award
DOC- NOAA	[1] Climate Program Office grants	$11,100,000
DOC- NOAA	[2] Environmental Literacy Program: Increasing community resilience to extreme weather & climate change	$4,100,000
DOC- NOAA	[3,+] Research and Forecasting in Weather and Climate	$50,000,000 in grants; $150,000,000 TBD
DOE- Office of Science	[4] Biological and Environmental Research: Atmospheric System Research	$15,000,000
DOE- Office of Science	[5] Earth System Model Development and Analysis	$10,000,000
DOE- Office of Science	[6] Urban Integrated Field Laboratories	$85,000,000 total for 2022 and future years
DOE	[7] Continuation of Solicitation for the Office of Science Financial Assistance Program	$400,000,000
HHS- CDC	[8] Building Resilience Against Climate Effects (BRACE): Implementing and Evaluating Adaptation Strategies that Protect and Promote Human Health	$20,000,000
DOI- BIA	[9] Tribal Climate Resilience Program includes funding for training and workshops; adaptation planning; ocean and coastal management; capacity building; relocation, managed retreat, and protection-in-place planning; internships; and youth engagement, some aspects of which involve research	$13,848,373 (2021)
DOI- BLM	[10] Joint Fire Science Program (DOI and partnering agencies): Task 1) Longevity of fuel treatment effectiveness under climate change;Task 2) Fuel treatment effectiveness across landscapes; Task 3) Pre-fire management actions for reducing post-fire hazards, and Task 4) Social and political factors that influence fire suppression and rehabilitation costs	$1,500,000–$6,000,000
DOI- ONHR	[11,+] Native Hawaiian Climate Resilience (from Office of Native Hawaiian Relations)	$25,000,000
DOI- USGS	[12] Climate Adaptation Science Centers (CASC) regional funding opportunities	$22,200,000
DOD- DARPA	[13] AI-assisted Climate Tipping-point Modeling	Unknown
EPA	[14,+] Environmental and Climate Justice Block Grants (from the Inflation Reduction Act of August 2022) Includes the Environmental Justice Thriving Communities Grantmaking Program, the Environmental Justice Collaborative Problem-Solving Cooperative Agreement Program, and the Environmental Justice Government-to-Government Program	$3,000,000,000
EPA	[15] The Environmental Justice Thriving Communities Technical Assistance Centers Program (5 year programme)	$100,000,000
EPA	[16] Cumulative Health Impacts at the Intersection of Climate Change, Environmental Justice, and Vulnerable Populations/Life Stages: Community-Based Research for Solutions	$8,100,000
EPA	[17] Environmental Education Grants Program	$2,500,000-$3,000,000
EPA	[18,+] Clean Air Act Grants	$25,000,000
EPA	[19] Environmental Justice Small Grants Program	$1,600,000
NASA	[20] Research Opportunities in Space and Earth Sciences (ROSES), (including land-cover/land-use change, carbon monitoring, carbon cycle science, hydrology, weather and atmospheric dynamics, modelling, analysis, and prediction)	$600,000,000
USDA- NIFA	[21] Foundational and Applied Science Program	$300,000,000
USDA- NIFA	[22] Sustainable Agricultural Systems (SAS)	$80,000,000
USDA- NIFA	[23] Farm of the Future	$3,936,000
USDA- NIFA	[24] Integrated Research, Education, and Extension Competitive Grants Program – Organic Transitions	$7,500,000
USDA- NIFA	[25, +] From Learning to Leading: Cultivating the Next Generation of Diverse Food and Agricultural Professionals	$250,000,000
USDA- NRCS	[26] Conservation Outreach: Racial Equity and Justice Conservation Cooperative Agreements	$50,000,000
USDA- Rural Housing Service	[27] The American Rescue Plan Act Emergency Rural Health Care Grant Program	$500,000,000
USDA, DOD, Dept. of Education, DHS, DOC- NIST	[28] National Artificial Intelligence (AI) Research Institutes Accelerating Research, Transforming Society, and Growing the American Workforce	$140,000,000

(*Continued*)

Table 2. Continued.

Agency	Grant opportunity	Total amount to award
NSF	[29] CAS, Critical Aspects of Sustainability: Sustainable Solutions to Climate Change; DISES, Dynamics of Integrated Socio-Environmental Systems; FM, Future Manufacturing; GCR, Growing Convergence Research; HEGS, Human-Environment and Geographical Sciences; MSB, Macrosystems Biology; ORCC, Organismal Response to Climate Change; PIRE, Partnerships for International Research and Education; SAI, Strengthening American Infrastructure.	Variable Amounts

[1]https://cpo.noaa.gov/Funding-Opportunities
[2]https://www.noaa.gov/office-education/elp
[3]https://www.noaa.gov/news-release/statement-from-noaa-administrator-on-signing-of-historic-inflation-reduction-act
[4]https://www.energy.gov/science/ber/biological-and-environmental-research
[5]https://www.energy.gov/science/articles/department-energy-provide-10-million-climate-and-earth-system-modeling-research
[6]https://www.energy.gov/science/articles/urban-integrated-field-laboratories-will-equitably-address-critical-scientific
[7]https://www.grants.gov/web/grants/search-grants.html?keywords=continuation%20doe
[8]https://www.cdc.gov/climateandhealth/BRACE.htm
[9]https://www.bia.gov/service/tcr-annual-awards-program
[10]https://www.firescience.gov/JFSP_funding_announcements.cfm?pass_fiscal_year = 2023
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[12]https://www.usgs.gov/programs/climate-adaptation-science-centers/news/funding-opportunity-applications-are-now-being
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[14]https://www.epa.gov/inflation-reduction-act/advancing-environmental-justice
[15]https://www.epa.gov/environmentaljustice/environmental-justice-thriving-communities-technical-assistance-centers
[16]https://www.epa.gov/research-grants/cumulative-health-impacts-intersection-climate-change-environmental-justice-and
[17]https://www.epa.gov/education/grants
[18]https://www.epa.gov/grants/clean-air-act-grants-under-inflation-reduction-act
[19]https://www.epa.gov/environmentaljustice/environmental-justice-small-grants-program
[20]https://science.nasa.gov/researchers/solicitations/roses-2022/research-opportunities-space-and-earth-sciences-roses-2022-be-released-february-14-2022
[21]https://www.nifa.usda.gov/grants/funding-opportunities/agriculture-food-research-initiative-foundational-applied-science
[22]https://www.nifa.usda.gov/grants/funding-opportunities/agriculture-food-research-initiative-sustainable-agricultural-systems
[23]https://www.nifa.usda.gov/grants/programs/farm-future
[24]https://www.nifa.usda.gov/grants/funding-opportunities/integrated-research-education-extension-competitive-grants-program-0
[25]https://www.nifa.usda.gov/grants/funding-opportunities/learning-leading-cultivating-next-generation-diverse-food-agriculture
[26]https://www.nrcs.usda.gov/news/usda-to-invest-50-million-in-new-cooperative-agreements-for-racial-justice-and-equity
[27]https://www.rd.usda.gov/erhc
[28]https://www.nsf.gov/pubs/2022/nsf22502/nsf22502.htm
[29]https://beta.nsf.gov/funding

Notes: Major research funding opportunities related to climate adaptation offered by US federal agencies in 2021 and 2022. These are opportunities that are either explicitly focused on (rows highlighted in blue) or are likely to fund adaptation research. This list is not the result of a systematic review but includes many of the major current federal adaptation research funding opportunities ([+]denotes funding provided through the Inflation Reduction Act of 2022). These opportunities include some that are currently open, will be opened again, or closed.

the policy hurdles and public support challenges of different adaptation policy solutions. For example, planting trees has been embraced as a natural climate solution to mitigate, and, in many cases, adapt to climate change (Fargione et al., 2018). However, in overstocked western US forests that are adapted to frequent fires that have been suppressed for decades, planting additional trees is maladaptive and can increase fire hazard (Coppoletta et al., 2015; Thompson et al., 2007). Moreover, social science can reveal insights on stakeholder reluctance or willingness to participate in collective actions, such as temporary water sharing arrangements during periods of drought (Dilling et al., 2019; Marston & Cai, 2016). An example of federal research addressing these interdisciplinary gaps is the DOC NIST Community Resilience Program, which facilitates research on dependencies among social, economic, and infrastructure systems to better understand community resilience. The programme includes creating tools and metrics related to community resilience (beyond individual asset resilience) for the public to utilize in planning (i.e. tools to prioritize investing to enhance resilience) and engaging community feedback on these tools across the US (NIST Community Resilience Program, 2021).

Most agencies do not explicitly acknowledge the need to work across disciplines, and, in particular, the humanities are largely unaddressed in these action plans. For example, environmental history, through its examination of human-nature relationships over time, is particularly suited to understanding sociocultural contexts. Historically-informed climate adaptation practices lengthen the temporal scope, focus on specific communities or path dependencies, and interrogate the structures of science used to make adaptation decisions (Adamson et al., 2018; Hughes, 2016). The humanities also privilege multiple perspectives and foster understanding in ways that develop not just understanding, but also empathy. Empathy connects humans to their environment and to each other in ways that accommodate diverse thinking and inspire sustainability (Brown et al., 2019).

Social science and humanities can fundamentally reshape the entire research process, including research questions and design, collaboration with stakeholders and rights-holders, methodological approach, analyses, and outreach techniques. Social science research processes take time and training and should be utilized throughout research steps, beyond simply communicating results or cursorily engaging stakeholders and rights-holders (Davis & Wollenstein, 2021). Fully integrating a range of social science and humanities researchers into adaptation fields will mean exploring the possibilities of a wide variety of solutions beyond traditional frameworks and approaches (Castree et al., 2014). Historically, climate change research in the natural and technical sciences has received 770% more funding than climate social science research (1990–2018; Overland & Sovacool, 2020), a disparity that can be addressed with new or expanded research funding opportunities (Table 2). For example, while not focused explicitly on adaptation, the NSF's Dynamics of Integrated Socio-Environmental Systems (DISES) programme funds research to advance understanding of the interactions among environmental and human components of an integrated system, where both social and biophysical approaches are central to the entire research process.

We argue that long-term, meaningful and sustained engagement with stakeholders and rights-holders in completing research is necessary to achieve climate adaptation and resilience goals (NASEM 2021). All of the action plans call for some form of collaboration: some agencies emphasized co-production of research with stakeholders, yet others' action plans engaged with stakeholders primarily through providing data, training, or unspecified collaboration. Collaboration and outreach both need to be thoughtfully considered and implemented to achieve outcomes, overcome power asymmetries, avoid superficial partner engagement, and support self-determined needs of Indigenous Peoples and marginalized and underrepresented communities (CTKW, 2014; Gardner-Vandy et al., 2021; Latulippe & Klenk, 2020).

5. Conclusions

Achieving the research priorities set out in these federal agency climate action plans requires ongoing stakeholder and rights-holder engagement, interdisciplinarity, and investment in understanding climate change impacts, adaptation options, and implementation on the scales that are 'commensurate with the daunting challenges posed by the impacts of climate change' (NASEM, 2021, p. 10). Given the needs we identify above, we suggest that funding opportunities need to operate as crosscutting programmes to support transdisciplinary research, compensate for the time and effort needed to facilitate meaningful interdisciplinary and stakeholder

or rights-holder collaborations, support longitudinal research, and increasingly be dedicated specifically to climate adaptation research (NASEM, 2019). Future work on federal agency response to climate adaptation research could engage with sub-national (local and state) adaptation plans, understand how inter-agency collaboration on climate adaptation is evolving, and analyze the implementation of these plans' goals and their impact on resilience (Koski & Keating, 2018; Rai, 2020; Woodruff & Stults, 2016). We see these agency action plans as an important step in the climate response of the US federal government and offer these recommendations for expanded adaptation research in light of the urgency of effective climate adaptation.

Several key takeaways can be applied to other national contexts. The research approaches suggested here (integration of justice and equity, meaningful collaboration with Indigenous Peoples and affected actors, and understanding adaptation options and outcomes through a multidisciplinary lens) should be considered in all adaptation plans, particularly in countries heavily involved in funding research. The US and other wealthy nations should also play a role in funding adaptation research in other nations with limited access to in-country research funds; the US Department of State and USAID could expand their adaptation research priorities to more explicitly involve other nations. Future research could apply these research questions (what national adaptation research priorities are identified, how collaboration, outreach, accessibility, and usability are addressed, and existing funding opportunities) to other nations' adaptation approaches. The US also provides an example of tackling nation-wide adaptation that does not rely on cohesive, national adaptation planning, but rather is driven by sub-national and national agency-driven initiative.

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