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Research Paper

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RESEARCH NEEDS AND RESEARCH ISSUES TO MITIGATE THE MULTIDIMENSIONAL IMPACT OF CLIMATE CHANGE

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ABSTRACT

Research is needed to improve understanding of human environment systems towards climate forcing, feedbacks, responses, and thresholds in the earth system and climate-related human behaviors and institutions. Research is required to support effective responses to climate change vulnerability and adaptation analyses of coupled human-environment systems. This paper examines the research needs and identifies the research areas in the context of climate change. It outlines the research issues to mitigate the impact of climate change on environment, agriculture, biodiversity, human health, energy, forest, wet lands, range lands, oceans, water, waste management and capacity building. This paper makes a special note on research issues on capacity building, climate change policy, climate change mitigation and climate change adaptation. This paper concludes with some interesting findings.

KEYWORDS: *climate change, environment, agriculture, biodiversity, human health, energy, forest,*

INTRODUCTION

Research investments across a broad range of disciplines are critically important to building understanding of, and in some cases reducing uncertainties related to, the physical and human-induced processes that govern the evolution of the climate system. This assessment demonstrates the continued need for high quality data and observations, analysis of Earth system processes and changes, and modeling that increases understanding and projections of climate change across scales. Social science research is also essential to improved understanding and modeling of the drivers of climate change, such as energy use and land-use change, as well as understanding impacts. Assessing a changing climate requires understanding the role of feedbacks, thresholds, extreme events, and abrupt changes and exploring a range of scenarios that drive changes in the climate system.

According to Handmer et al. (2012) and Fussel (2010), it is important for decision-makers to understand the value of ecosystem services, such as the protection mangrove forests and coral reefs provide from storm surges and the prevention of runoff and soil erosion by forests. Estimating the value of these services should play a part in prioritizing adaptive measures for regions and systems. Research is needed on how to extend integrated valuation approaches across groups, sectors and regions, with inputs from sector and regional experts, to ensure that no important factors are externalized across sectors, space or time.

RESEARCH NEED FOR MONITORING CLIMATE CHANGE

To monitor how climate is changing and to uncover the reasons for those changes: In this context, the following research needs are required. Precipitation: Continue supporting work on atmospheric rivers and

field studies on the role of aerosols and other factors in the regional climate to better characterize local-scale precipitation variability including extremes.

***Land uplift*:**

Measure the relative vertical movement of lands affected by sea-level rise through collaboration with government agencies. To determine where climate changes are most detectable and to assess potential monitoring

Strategies and capabilities:

Sensor networks: Support the monitoring of appropriate measures, including climatic and hydrological conditions. This work requires dense networks of sensors in areas with strong gradients of coastal, urban, and mountainous areas to improve high spatial resolution downscaling techniques.

Technologies for monitoring:

Evaluate the capability of current monitoring networks to track climate change metrics important to the State. Determine how new observation technologies including satellite data can be incorporated.

CLIMATE PROJECTIONS

To explore what the latest generation of global models project regarding climate change and to improve downscaling methods including those necessary to model extreme events. A climate scenario is very essential to develop the next generation of climate scenarios that produce relevant regional information that can support engineering design and long-term planning.

Statistical downscaling methods are needed to project the climate change scenario. Continue developing, testing, and improving statistical downscaling models, including the creation of new statistical downscaling techniques that are driven by large-scale climatic features that are supposed to be modeled relatively well by the global climate models. Investigate performance of statistical downscaling techniques in simulating extreme events. This area of work also includes the development of improved bias-correction techniques.

Dynamic models: Continue improving dynamic climate models to add, for example, the simulation of changes in vegetation patterns that in turn affect regional climate. Use dynamic models to explore crucial resource and vulnerability issues. Coordinate this work with government agencies.

Model comparisons: Use dynamic climate models to identify the physical parameters driving differences among various climate projections. Create climate projections for certain periods and check their results with the results of the statistical models inter-comparison of regional climate models. Ideally, statistical and dynamic models should produce, in a broad sense, similar results after bias-correction of the dynamic models. Differences in results should be investigated and used to assist with further improvements for both statistical and dynamic models.

Extreme events: Investigate performance of global and regional climate models, in comparison to historical observations, in producing the patterns and conditions responsible for extreme events relating to heat waves, floods, drought, coastal storms, and fire-prone conditions.

Forecasts: Explore the use of day-ahead and seasonal probabilistic forecasts to prepare for extreme events and decadal probabilistic projections for long-term planning.

RESEARCH NEEDS TO MITIGATE THE GREEN HOUSE GAS EMISSION

Biogenic sources: Improve accounting for biogenic methane and nitrous oxide emissions from poorly characterized area sources, such as nitrogen fertilizer and manure, which can also improve quantification of air quality effects. Land use change impacts on carbon stocks and albedo: Quantify emissions associated with agricultural and urban expansion, as well as climate-forcing impacts associated with changes in albedo.

Emissions from the natural gas and oil systems: Improve the accounting of emissions at the source level, in terms of the numbers, amounts, and locations of fugitive methane leaks.

Emissions from the combustion of fossil fuels: Continue to improve alignment of data related to the amount of fossil fuels combusted with the measurement of ambient CO2 concentrations at different temporal and geographical scales.

Natural sources and sinks: Quantify carbon and nitrogen cycling emissions and storage in both agricultural- and non-agricultural soils and sediments of different management practices in wetlands, riparian areas, and reservoirs. Improve understanding of baseline conditions, processes and projected trends in forestlands with respect to biomass, carbon stocks, forest health, disturbances, species migration, and genetics in relation to climate. Develop improved accounting methods for carbon stocks in lands to determine if, as suggested by preliminary research, a less dense forest stores more carbon than the currently overgrown forest. If this is correct, the concern that

forest thinning might decrease carbon stored in forests may be incorrect. Compile baseline data on urban forests to adequately characterize urban tree canopy coverage and structure as an important tool for helping to mitigate the urban heat island effect.

Water system sources: Improve collection of data documenting water use and associated GHG emissions. In addition, improve collection of data documenting energy used in new desalination technologies, groundwater pumping, recycled water use, and water treatment processes to improve understanding of how energy is used by water utilities and urban water consumers. In some cases, research is needed to develop the tools that can assist with data collection. Short-lived climate pollutants: Improve understanding of sources and scale of emissions of short-lived climate pollutants – including methane, black carbon, and hydrofluorocarbons – and further quantify the GHG and air quality co-benefits associated with reducing methane, particulate matter, and black carbon. Validation of emission inventories: Continue to reduce the uncertainties associated with emissions inventories, which will help refine attribution of emissions to sources.

RESEARCH NEEDS TO MITIGATE THE IMPACT OF CLIMATE CHANGE ON AGRICULTURE

Agriculture is a critical economic sector that provides a safe, reliable, diverse, and nutritious source of food for millions of people. Agriculture also provides many other societal benefits, including employment opportunities, wine and fiber production, potential carbon storage in soils, and other ecosystem services from both crop and animal sub-sectors.

FARMLAND CONSERVATION RESEARCH NEEDS

Characterize the impacts of continued urbanization of farmland on GHG emissions under different development scenarios and land use policies.

NITROGEN AND MANURE MANAGEMENT RESEARCH NEEDS

Increase the understanding of the interplay of nitrogen forms, soil conditions, and management practices that affect nitrous oxide emissions specific to conventional and organic agricultural systems, including the use of fertigation the application of fertilizer through irrigation, cover crops, and slow release nitrogen fertilizers. Consider and explore the relationship between nitrogen management and carbon sequestration. Support field studies of the kinetics of nitrogen mineralization under various conditions to determine the application rates that would prevent the adverse impacts and maximize the environmental benefits of applying manure or compost to agricultural soils. Generate information on nitrogen supply-demand relationships from these studies to provide a scientific basis for adjusting the application rate and timing of manure or compost in the field to reduce GHG emissions.

CROP AND LIVESTOCK MANAGEMENT RESEARCH NEEDS

Develop information to maximize the GHG mitigation potential through optimal selection and management of crop rotation based on individual site characteristics and cropping systems. Conduct research at test plots to determine the effectiveness of potential adaptation measures such as structural, mechanical, or biological methods to reduce crop heat stress and the switch to alternative crops or varieties that may be better suited to future conditions. Develop crop-breeding options to increase heat and cold tolerance and to identify low-chill varieties of temperate fruit and nut crops. Develop varieties that are more resilient to pests that may arrive in region under a warmer climate. Implement animal breeding research programs to increase resistance to anticipated heat extremes and diseases associated with a warmer climate.

RESEARCH NEEDS DUE TO WATER MANAGEMENT

Investigate innovative methods to supply water more reliably to the agricultural sector and to use water more efficiently. For example, flood management projects could be designed to allow floodwaters to recharge groundwater, which would be available during drought periods to farmers and other users. Increasing soil carbon on croplands and rangelands, through the application of compost and other strategies, would increase soil water holding capacity and reduce the amount of water needed for irrigation. Investigate other soil management techniques, such as cover cropping, minimum tillage, and soil amendments, as well as dry farming and on-farm ponds, for their potential to store water, reduce overall water use, and reduce energy related GHGs.

To address the economic and environmental impacts and co-benefits of potential emission reduction strategies:

Carbon sequestration: Quantify the benefits of techniques for storing carbon in soils in terms of compost application to rangelands, use of winter cover crops, and application of biochar through management practices.

Economics: Examine the economic impacts of GHG mitigation efforts. Quantify the economic and environmental effects of adaptation co-benefits associated with agricultural GHG mitigation practices. Investigate the costs, benefits, and risks associated with relocation of crops and animals to suitable climates.

To study the vulnerability of agricultural communities and resources to climate change impacts, and costs and benefits associated with reducing agricultural sector emissions:

Conservation tillage: Assess the potential of conservation tillage, including when used in conjunction with other soil management practices, for soil carbon sequestration and its effects on crop yields and pest management.

RESEARCH NEEDS TO MITIGATE THE IMPACT OF CLIMATE CHANGE ON BIODIVERSITY AND HABITAT

To address the vulnerability biological resources to climate change impacts and the effectiveness of strategies and technological innovations to safeguard the state from these impacts:

Habitat and species-related baseline conditions: Develop information against which to compare future changes in biodiversity, including high-resolution vegetation maps; species range maps, and statewide habitat maps. Complete vegetation mapping following the National Vegetation Mapping Standard. Identify current land use and land use policies, permitting, and planning statuses to understand how these features affect and should be included in habitat restoration and land acquisition decisions.

Climate impacts and risks to biodiversity: Determine impacts of climate change on the spread of invasive species, pests, pathogens, and diseases that affect the health of terrestrial and marine ecosystem and pose stresses to native fish, wildlife, and plants. Improve understanding of how shifts in the timing of life cycle events of breeding, food availability, and migration as a result of a changing climate will impact species. Identify critical habitat, refugia, and wildlife corridors that can allow for species movement across the landscape as climatic changes occur and suitable habitat locations potentially shift. Improve understanding of ecosystem services and the impacts of climate change and of mitigation and adaptation strategies. Assess species' tolerance and ability to adapt to short- and long-term climate disturbances. Investigate the impact of more frequent and intense wildfires on sensitive species and ecosystem conversion. Identify the impacts of extreme events of heat waves, flood, and drought on ecosystem function, resilience, and services. Vulnerability assessment: Conduct comprehensive statewide climate vulnerability assessment at the habitat scale for terrestrial and marine environments. Assess vulnerability from risks to rare plant species, birds, reptiles and amphibians, mammals, invertebrates, and aquatic species of concern.

Adaptation Strategies and Actions: Utilize climate impact and vulnerability information to develop new, or update existing, adaptation strategies and actions where appropriate. Develop decision-support tools to target the location and timing of restoration activities that reduce climate risk. Conduct finer-scale corridor analyses to inform land acquisition and investment decisions. Evaluate the costs, benefits, and effectiveness of adaptation options for biodiversity.

CLIMATE CHANGE EMERGENCY MANAGEMENT RESEARCH NEEDS

To assess the vulnerability of the people, resources, and infrastructure to climate change impacts and to identify effective strategies:

Vulnerability assessment: Expand and refine information about climate vulnerabilities of populations, infrastructure, property, food and agriculture, and biodiversity. Expand monitoring of extreme weather events such as flood, drought, heat, fire, and related losses to inform emergency management. Coordinate among sectors on research and monitoring funding, information sharing, and well-integrated actions to build safe and healthy communities.

Adaptation strategies: Examine possible strategies to reduce vulnerabilities. Assess the adequacy of surge and response capacity, the ability of the emergency system to handle a number of cases that rapidly exceeds the system's routine capacity, in light of climate projections for more frequent and more severe weather events such as flooding, fire, drought, extreme heat, and storms especially when coupled with sea-level rise. Assess the adequacy of current emergency surge and response capacities.

RESEARCH NEEDS TO MITIGATE THE IMPACT OF CLIMATE CHANGE ON ENERGY SERVICE

To support strategies and technological innovations necessary to significantly reduce GHG emissions and climate risk and their economic, public health, and environmental impacts or cobenefits, to identify synergies and trade-offs between mitigation and adaptation strategies, and to assess the vulnerability of the energy sector to climate change:

Energy efficiency and demand response: Develop next-generation energy efficiency technologies and strategies to cost-effectively achieve targets and goals which addresses retrofitting existing buildings. Investigate options to improve energy efficiency in buildings and other systems to reduce the energy sector's vulnerability to climate change while reducing GHG emissions. Develop and demonstrate advanced capabilities of demand response to increase grid flexibility.

Renewable energy, distributed generation, and energy storage: Develop and demonstrate utility-scale and distributed renewable generation as well as combined heat and power technologies. This includes organic resources such as biosolids from wastewater treatment facilities, biogas from landfills, and biomass from forests and agricultural lands. Develop and demonstrate technologies and strategies to improve the performance, economics, and environmental sustainability of baseload and dispatchable renewables. Develop and pilot potentially breakthrough energy storage technologies that enable a variety of beneficial grid functions.

Clean fossil fueled sources and infrastructure improvements for grid resilience and stability: Investigate ways to reduce the environmental footprint of existing energy technologies with respect to reduce fugitive methane emissions from the oil and natural gas systems. Investigate techniques to improve the efficiency of natural gas burning energy technologies while substantially reducing the emission of air pollutants. Develop technologies to improve the performance of the existing energy infrastructure facing climate change impacts towards innovative cooling technologies for thermal power plants. Develop and demonstrate new technologies and strategies that enable the transmission and distribution system to handle increased penetrations of renewables and distributed generation. Develop technologies and tools to maintain grid resilience and stability under a changing climate, particularly with regard to extreme events. Carry out scientific and engineering analyses to test and operationalize our conceptual knowledge regarding how to protect the existing and future energy infrastructure from climate impacts in both the electricity system and the supply network for natural gas. Analyze soft adaptation approaches, sometimes called "green infrastructure," by the way of using wetlands instead of or to complement the flood protection afforded by levees on an equal footing with engineering solutions, considering ecological and societal co-benefits. Better estimate the impacts of climate change on the existing energy infrastructure.

Energy scenarios and supply and demand forecasting: Continue to develop energy scenarios associated with deep GHG reductions with enough temporal and geographical resolution to inform long-term energy planning as well as identify potential unintended consequences such as substantial cumulative ecological and air quality impacts. Assess the vulnerability of the energy system to climate change in these scenarios to allow one to design an energy system that is more resilient to climate change. Develop and test innovative supply and demand forecasting methods, including probabilistic seasonal and decadal forecasts that incorporate projections of climate change to reduce vulnerability. Consumer choice and civic engagement: Investigate consumer choice and civic engagement as a critical complement to research and development for technological innovations.

RESEARCH NEEDS TO MITIGATE THE IMPACT OF CLIMATE CHANGE ON INDUSTRIAL ACTIVITIES

The industrial sector is generally understood to include manufacturing and production processes. It could be noted that industrial sources of GHGs associated with energy generation, use, and transmission; fuel use; and oil and natural gas extraction, production, distribution.

Energy efficiency and fuel-switching options: Improve energy efficiency, and explore fuel-switching options in the industrial sector. Model the effect on GHG emissions of fuel switching in the industrial sector, including electrification and renewable biomass, with feedback into energy scenario modeling. Monitor and assess economic costs and opportunities associated with efforts to improve efficiency and reduce emissions in the industrial sector. Carbon capture, utilization, and sequestration: Develop and demonstrate the capabilities of new and emerging CO2 utilization options that could provide economic benefits through new products, such as plastics, chemicals, and building materials. Vulnerability and safeguarding strategies for the industrial sector: Conduct scoping studies designed to identify research needs.

RESEARCH NEEDS TO MITIGATE THE IMPACT OF CLIMATE CHANGE ON FORESTRY

Forests act both as sources of GHG emissions and as sinks that remove CO2 from the atmosphere. They

provide an opportunity through management practices to offset emissions from other sectors. Wildfire, mortality of vegetation, drought, and other forms of disturbance cause a natural release of carbon to the atmosphere. Given enough time, healthy forests are resilient and will recover and regain carbon lost through such disturbances. However, climate change is expected to increase risks from these disturbances, possibly converting forested lands to carbon sources. Forests cannot be managed for carbon over the long term without maintaining their health and resilience, which in turn sustains their biodiversity. Therefore mitigation of climate change and preparing for climate risks to forests are inextricably interconnected. Research is needed to better understand how forest carbon pools are affected by land management and natural disturbance regimes in a changing climate.

Vulnerability assessment and adaptation in the forestry sector: Improve understanding of how a changing climate will influence disturbances to forest carbon such as fire, insects, disease, and invasive pests. Investigate impacts of ozone and air pollution on forests and their carbon storage capacity. Utilize paleoecology to better model and understand climate and vegetation dynamics. Reduce uncertainties in forest climate modeling and increase understanding of threats to forest carbon. Assess the influence of climate change on forest health and productivity and therefore on carbon storage. Identify potential climate-induced shifts in the ranges of forest plant species and identify potential areas of refuge for protecting forest health, habitat, biodiversity, and carbon storage.

Tools and approaches in the forestry sector: Develop analytical tools to integrate the data results from Forest Inventory and Analysis and other forest analytical tools into planning and policy decisions involving carbon storage. Improve tools and capabilities for monitoring and modeling climate-related changes in ecosystems processes that affect carbon fluxes. Identify best management practices to minimize losses to forest capacity to sequester carbon. Protect genetic variety of tree species through seed banks and nursery programs to maintain forest resilience.

Costs and benefits: Conduct multi-disciplinary and integrated analyses to understand the costs, benefits, feasibility, and acceptability of alternative strategies for forest carbon and other ecosystem services.

RESEARCH NEEDS TO MITIGATE THE IMPACT OF CLIMATE CHANGE ON WETLANDS

To explore wetland strategies to reduce GHG emissions and climate risk and how to monitor their effectiveness and co-benefits:

Wetland Carbon Protocol: Develop the scientific foundation to understand the potential for reducing emissions through wetland projects. This could allow wetland restoration projects to better monetize emission reduction benefits.

Wetlands as protective assets for flood protection: Develop a quantitative understanding on the role of wetlands as protective assets for rural areas and other infrastructures from coastal and inland flooding. Wetlands can dissipate wave energy and buffer the impacts of rising sea level and wave energy. The conservation and restoration of wetlands provides a promising strategy for both climate change mitigation and adaption.

RESEARCH NEEDS TO MITIGATE THE IMPACT OF CLIMATE CHANGE ON RANGELAND

Past research suggests that rangelands may have significantly greater carbon sequestration capacity than is currently being achieved. For example, native perennial plants in rangelands can sequester substantial amounts of carbon and are more drought tolerant than the invasive annual plants that have displaced them across much of the state. This is attributed to the deeper roots of perennial vs. annual species, but other mechanisms may also be at play and require further investigation.

Rangelands as carbon sinks: Quantify carbon sequestration of native perennial plants in natural and working lands. Expand recent field studies that suggest that the application of compost on rangelands used to raise cattle can sequester carbon in the soil without increasing methane and nitrous oxide emissions. Conduct grazing systems research trials to identify and evaluate strategies for increasing rangeland soil carbon through prescriptive grazing. Investigate how soil chemical and physical properties affect nutrient cycling, water availability, and forage quality. Explore the impact of managed grazing practices on GHG flux and carbon sequestration in rangelands. Investigate potential environmental and adaptive co-benefits, as well as impacts of rangeland carbon sequestration practices.

Co-benefits of rangeland carbon sequestration: Evaluate the potential for rangeland mitigation strategies to provide co-benefits, especially those that support adaptation.

Impacts of rangeland conversion: Fill data and research gaps on the implications of rangeland conversions. Identify priority areas and land use strategies for minimizing the adverse impacts of rangeland conversion.

RESEARCH NEEDS TO MITIGATE THE IMPACT OF CLIMATE CHANGE OCEAN AND COASTAL ECOSYSTEM AND RESOURCES

Monitoring and modeling ocean acidification and hypoxia and their impacts: Develop a regional approach for monitoring spatial and temporal variation of ocean acidification and hypoxia. Improve our ability to model pH, oxygen, and nutrients in the near-shore environment to determine contributions of local nutrient inputs to acidification and hypoxia, and identify geographic locations most susceptible to acidification and hypoxia. Determine key marine species that should be targeted for impact analyses, and perform modeling studies to assess food web responses under future climate scenarios and evaluate appropriate management strategies. Coastal ecosystem and fisheries management: Evaluate approaches to developing climate-ready fisheries and management actions within marine protected areas to improve resiliency to climate.

Monitoring impacts on the shoreline: Collect data to track shoreline changes and impacts from storms on beach and cliff erosion to improve methods for predicting shoreline evolution. Measure land elevation changes such as subsidence and tectonic activity in relation to sea-level rise.

Forecasting and climate impact scenario information: Develop updated methods for predicting flood frequency under changing climate, and improve forecasting of extreme events such as extreme precipitation associated with atmospheric rivers.

Role of marine protected areas in resilience: Investigate how, and the extent to which, marine protected areas contribute to the resilience of coastal and marine ecosystems, coastal communities and the broader economy.

Tools and approaches to prepare for climate risk to ocean and coast: Compile improved social and economic data, including the quantification of ecosystem services, to enable the evaluation of different approaches to prepare for climate risk with respect to seawalls, managed retreat, living shorelines and artificial reefs. Evaluate innovative adaptation approaches such as green infrastructure in the form of tidal wetlands, eelgrass, and native oysters to help reduce vulnerability to climate-related hazards. Capitalize on the opportunity of a statewide network of marine protected areas as a living laboratory, where considerable research and monitoring is already under way, for understanding the effects of climate change on ocean resources. Conduct multi-disciplinary and integrated analyses to understand the costs, benefits, feasibility, and acceptability of alternative strategies.

RESEARCH NEEDS TO MITIGATE THE IMPACT OF CLIMATE CHANGE ON PUBLIC HEALTH

To better understand the vulnerability of people to climate change impacts and the distribution of vulnerability among groups: Extreme temperature-related morbidity and mortality: Characterize health impacts of temperature extreme heat and cold, including downscaled projected impacts for local health planners, and specific vulnerability drivers such as urban heat island, built environment impacts and population vulnerabilities.

Air pollution, allergens, and wildfire exposures: Characterize population sensitivity for health risks from intensified airborne exposures - respiratory inflammation, aggravation of conditions such as asthma and emphysema, decreased lung function and damage to lungs, and cardiovascular disease.

Infectious diseases: Investigate how threats from life-threatening vector-borne diseases as well as potential water- and food-borne diseases may increase with changes in climate.

Occupational risks: Assess priority health impacts of climate change in occupational settings.

Vulnerability assessment and risk characterization: Characterize risk, especially to subpopulations already experiencing lower baseline health status, and ensure equity issues are addressed as effects of climate change and even mitigation actions themselves may threaten to intensify risks or hardships for these groups. Systemic social health, including mental health: Identify and forecast climate change impacts on populations through interdisciplinary engagement of physical scientists with social scientists, economists, agricultural and nutrition researchers, and other domain experts.

Surveillance and monitoring systems development: Develop and enhance tools to monitor

environmental and health indicators for diseases, vulnerabilities, protective and adaptive capabilities for conditions affected by climate change. For example, coordinate with central and regional rapid surveillance efforts; enhance the infrastructure for syndromic surveillance of climate-related morbidity.

To better understand which strategies would be the most effective to safeguard public health: Evaluation of interventions and risk communication: Assess whether current public health guidance is being utilized and its effectiveness through interdisciplinary research. Improve understanding of public knowledge, attitudes, and behaviors on climate risks and mitigation and adaptation/preparedness actions within a health frame. Support science to develop built environment and green infrastructure options: Expand knowledge of physical, mental, and societal impacts of urban forest ecosystems in the context of urban design. Develop strategies and technologies aimed at protecting vulnerable populations against heat without increasing air pollution and GHG burdens.

RESEARCH NEEDS TO MITIGATE THE IMPACT OF CLIMATE CHANGE ON TRANSPORTATION

To evaluate the effectiveness of strategies and technological innovations to significantly reduce GHG emissions in the transportation sector and their economic, public health, and environmental impacts or co-benefits:

Sustainable communities: Continue evaluating and testing of innovative approaches to reduce GHG emissions both direct and indirect through sustainable community strategies. Investigate how climate and land use policies will affect the climate resilience of the transportation system and the residential sector. Provide decision makers with a clear understanding of the public health, economic, and equity co-benefits of implementing smart growth considering potential climate and ways to avoid adverse impacts.

Life cycle studies of pavement material in transportation networks: Integrate the results of Life Cycle Analysis of GHG emissions with the estimation of life cycle costs. Continue work to reduce the embodied GHG emissions in pavement, as well as develop innovative new pavement materials with lower rolling resistance that have the potential to improve fuel efficiency for the millions of vehicles. Examine how materials used in the construction of the transportation network perform under climate change such as extreme temperatures and standing and moving water during flood events.

Sustainable freight: Develop advanced fuels, vehicles, intelligent transportation systems technologies, operations, and systems that reduce oxides of nitrogen and fine particulate matter such as black carbon in the freight area.

Advanced technology vehicles and consumer behavior: Continue to support research and development on technologies towards developing fuel cells, batteries, charging options, and vehicle-grid integration that will enable the deployment of zero or near-zero tailpipe GHG emission vehicles. Invest in market research on consumer and freight transportation sector acceptance and usage of zero or near-zero tailpipe GHG vehicles to inform policies and to increase adoption of these vehicles.

Alternative fuels: Support the development of new technologies that improve efficiency and reduce GHG emissions from biorefineries, and develop new methods to increase the production of alternative fuels through renewable hydrogen, renewable drop-in fuels. Examine the land-use impacts of biofuels crop production on the carbon sequestration potential of soils, air quality, and other ecosystem services from different biofuel crop types that are appropriate. Investigate the impact of climate change on projected biomass production to accurately project future alternative fuel supply.

Vulnerability of the transportation system and fuel infrastructure: Assess vulnerability of the state's transportation system to sea-level rise, extreme weather-related events, and other climate impacts. Examine the vulnerability and adaptation options of the fueling infrastructure that may be affected by sea-level rise.

WASTE MANAGEMENT RESEARCH NEEDS IN THE CONTEXT OF CLIMATE CHANGE

To identify the most effective strategies and technological innovations to significantly reduce GHG emissions in the waste management sector and to monitor their effectiveness:

Public education: Investigate methods to improve the efficacy of education and outreach efforts regarding source reduction, which is at the top of the waste management hierarchy and is the preferred approach to reduce GHG emissions from the waste sector.

Technology and practices: Investigate technologies and practices for handling solid and green waste and its byproducts that have the highest potential to reduce GHG emissions, as well as address other

issues such as water conservation, compost production, and renewable energy/fuel production. Improve measurement methods of GHG emissions at solid and green waste facilities to support assessment of different technologies and practices with regard to GHG emissions reductions.

Reducing waste generation: Develop new products and markets with the highest potential for reducing waste in the first place and its associated GHG emissions. To assess the vulnerability of waste management infrastructure in a region to climate change impacts: Vulnerabilities and adaptation options: Examine vulnerabilities of adaptation options for the waste management sector to climate change.

RESEARCH NEEDS TO MITIGATE THE IMPACT OF CLIMATE CHANGE ON WATER

To investigate the most effective strategies and technological innovations to significantly reduce GHG emissions in the water sector and their economic and environmental impacts or co-benefits:

Reducing embedded GHG emissions: Improve and develop less costly technologies and procedures for conserving water and energy. Provide insight and guidance for state and regional water management planning, and address water and energy conflicts and climate change mitigation needs through regional data collection on water and energy intensity. Conduct studies about the GHG benefits of increased use of non-traditional local water supplies to reduce the embedded GHG emissions associated with imported water.

To determine the vulnerability of water resources to climate change impacts and to measure and assess the effectiveness of potential strategies and technological innovations to safeguard the state from these impacts:

Understanding how climate change is affecting key water indicators: Measure how a changing climate is affecting water supply, because this information will enable planners to anticipate needs and to target future policies. Some of the monitoring needs are as follows; 1) changes in snow-covered and rain dominated portions of key watersheds, 2) the relationship between snow pack, rainfall, and groundwater recharge and quality, and 3) the effects of land-cover and ecosystem responses to climate change on precipitation-runoff relationships.

Understanding key vulnerabilities in the state's water system: Improve understanding by planners and resources managers of climate-mediated risks to the water, including wastewater and recycled water, infrastructure in the form of sea-level rise and flooding as well as impacts to water quality in rivers, lakes, and groundwater aquifers due to changes in precipitation, timing of flow, and temperature. Better characterize the risk to water supply and demand conflicts in-stream flows, agriculture, urban consumption, industry, and hydropower with climate change.

Developing a toolbox of adaptation strategies: Develop decision-support tools for adaptation in the water sector such as to determine where to prioritize regulations and technical and financial assistance to protect surface water quality, groundwater storage, assign water rights equitably, minimize urban flooding, and reduce the potential for public safety threats from water and wastewater facilities impacted by extreme events. Identify a toolbox of adaptation measures that water, wastewater, and recycled water facilities can implement to prepare for future sea-level rise and extreme storms. Investigate the pros and cons of desalination as an adaptation strategy, including its feasibility and acceptability, impacts on aquatic species, water quality, ecosystems, energy use, and potential GHG emissions from pumping seawater to the surface.

RESEARCH ISSUES ON CAPACITY BUILDING TOWARDS DEVELOPING CLIMATE CHANGE MITIGATION MECHANISM

1. What are the current institutional requirements for capacity building on a country-by-country and region by region in a council basis that will allow for effective administration of adaptation and mitigation funds?
2. What are the funding requirements for capacity building? Can capacity building be effective on climate change mitigation without clear knowledge of the amount and nature of eventual funding to be administered?
3. What are the country-specific and regional specific technical and training requirements for developing countries to conduct national inventories, communication programs, and successful measurement, reporting and verification regimes? What are the methodologies for identifying these requirements?
4. What good examples from the development community do we have of successful capacity building for climate change mitigation governance? What aspects of those situations

apply to climate change mitigation and adaptation funding? How can these efforts be coordinated with the climate community?

5. What methods for innovation and low-carbon technology research and development capacity building work on climate change mitigation and developing coping mechanism in developing countries, especially least developed countries?

RESEARCH ISSUES ON CLIMATE MITIGATION FINANCING

1. What funds are currently available and how might the Copenhagen Green Climate Fund be plausibly structured and organized?
2. What governance schemes for other funds have been successful and what is the relationship of the fund, the governance structure, and the time window?
3. In designing financing instruments, are there trades-offs between flexibility of the fund and adequate oversight? If so, what examples of successful flexible funds exist and why have they worked? Are such examples applicable to climate change?
4. What is the relationship between the number of institutions involved in financing and the adequacy of the provision of funds? Do more institutions dilute funding?
5. What is the relationship of climate funds to current Official Development Assistance? What lessons from current Official Development Assistance can inform conditionality provisions and governance for climate change mitigation and adaptation financing?
6. How does the source of funding influence the structuring and governance of the funds in climate change mitigation?
7. How adequate are estimates of financing needs and how does this adequacy vary between climate change adaptation funding needs, MRV funding needs, and mitigation funding needs?
8. What does it cost, by country, region to undertake an annual GHG inventory?
9. Are there good models from disaster relief and risk pooling experiences that might be useful in the structuring of climate change adaptation funding instruments?

RESEARCH ISSUES ON CLIMATE CHANGE POLICY

1. How are domestic climate politics affecting national policies and international negotiation positions?
2. How are domestic climate politics explained, and why do they vary across regions and countries?
3. What are the political impacts of negotiation blocks within international climate change policy, and how have these roles changed over time?
4. What role does political capital and leadership play in climate change policy setting and decision-making?
5. What are the political considerations regarding sources of funding for climate change mitigation and adaptation?
6. What role does civil society play in shaping international climate change negotiations?
7. What are the politics of managing and setting expectations and goals for Conferences of the Parties?
8. How important are political considerations of legitimacy and transparency in climate change negotiations? Does an effective climate change policy require broad-based, bottom-up political support?

RESEARCH ISSUES ON CLIMATE CHANGE ADAPTATION

1. What is the current state of the resilience of infrastructure to climate change in developed and developing countries?
2. What is the current state of country-specific National Adaptation Plans in the United Nations Framework Convention on Climate Change process?
3. What are the examples of successful adaptation plans and why have they been successful? What information or data are required to improve these plans? Is enforcement necessary or desirable? Do we have sufficient case studies?
4. How should decisions about the allocation of adaptation funds be organized?
5. Is there a need for "MRV" for adaptation? How much oversight is needed and at what levels?
6. What is the role of adaptation in developing country-specific low-carbon storylines?

CONCLUSION

It could be seen clearly from the above discussion that this paper has made elaborate discussion on research need for monitoring climate change, climate projections, research needs to mitigate the green house gas emission, research needs to mitigate the impact of climate change on agriculture, farmland conservation research needs, nitrogen and manure management research needs , crop and livestock management research needs , research needs in water management, research needs to mitigate the impact of climate change on biodiversity and habitat , climate change emergency management research needs, research needs to mitigate the impact of climate change on energy service, research needs to mitigate the impact of climate change on industrial activities, research needs to mitigate the impact of climate change on forestry, research needs to mitigate the impact of climate change on wetlands, and rangeland and research needs to mitigate the impact of climate change ocean and coastal ecosystem and resources. This paper further has highlighted the research needs to mitigate the impact of climate change on public health and transportation, waste management research needs in the context of climate change, research needs to mitigate the impact of climate change on water, research issues on capacity building towards developing climate change mitigation mechanism, research issues on climate mitigation financing, research issues on climate change policy and research issues on climate change adaptation. Hence the process of research on climate change is a broad area coverage and subject coverage. In this context, it is relevant to undertake interdisciplinary, multidisciplinary and transdisciplinary research towards studying the multidimensional impact of climate change on agriculture, forest, human beings, environment, oceans, biodiversity and public health.

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