CLIMATE CHANGE ADAPTATION AND SOSIAL RESILIENCE: CAPACITIES, INEQUALITIES, GOVERNANCE CHALLENGES AND TRANSFORMATIVE PATHWAYS

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(Received 22nd December 2024; revised 18th February 2025; accepted 27th February 2025)

Abstract. Climate change represents a multidimensional challenge that extends beyond environmental disruption to profoundly reshape social systems, economic structures, and governance arrangements. This study critically synthesises interdisciplinary literature to examine how climate impacts interact with societal vulnerabilities, adaptive capacities, and institutional frameworks to shape resilience outcomes across regions and sectors. Moving beyond technocratic and sector-specific approaches, the analysis emphasises that vulnerability is socially produced through unequal exposure, sensitivity, and most critically, adaptive capacity. Marginalised populations, including low-income households, women, Indigenous communities, smallholder farmers, older adults, and informal urban residents, experience disproportionate climate risks due to limited access to resources, political representation, and decision-making power. The study highlights how adaptation is inherently social, embedded within cultural norms, governance structures, and development trajectories rather than confined to discrete environmental interventions. While resilience-building strategies can reduce short-term risks, the findings demonstrate that incremental adaptation alone is insufficient under escalating climate pressures. Instead, transformative pathways, encompassing institutional reform, inclusive governance, integration of local and Indigenous knowledge, climate-smart infrastructure, and equitable finance mechanisms, are required to address structural drivers of vulnerability. Cross-sectoral impacts on ecosystems, health, infrastructure, and livelihoods reveal strong interdependencies that demand coordinated and justice-oriented responses. The study further identifies persistent barriers to effective adaptation, including governance fragmentation, knowledge gaps, financial constraints, and exclusionary planning processes. By situating climate adaptation within broader questions of equity, social capital, and political economy, this analysis underscores that resilience is not merely a technical outcome but a contested social process. Effective climate action therefore requires transformative, participatory, and inclusive strategies that align adaptation with sustainable development and social justice goals.
Keywords: *climate change, adaptation, social vulnerability, resilience, governance*

Introduction

Climate change has emerged as one of the most profound challenges of the twenty first century. The frequency and severity of climate-related hazards extreme temperatures, intense storms and flooding, droughts, and rising sea levels are projected to increase with global warming, raising new risks to life, livelihoods, and infrastructure across developing and developed regions alike (Andrijevic et al., 2020; Chung Tiam Fook, 2017; Burch et al., 2014). Adaptation is a process that addresses these emerging risks and increases the resilience of human and natural systems, and the need for adaptive responses has never been greater.

A holistic understanding of adaptation requires unpacking the complex interactions between climate impacts, society, and existing capacities, and analyzing the barriers and pathways that promote or hinder adaptive responses. The framework presented here aims to elucidate these complex interactions by synthesizing insights from the fields of climate science, economics, public health, engineering, social sciences, and development studies. The conceptual foundations of climate impacts and vulnerabilities, the social dimensions of adaptation, and the distinctions between adaptive capacities, resilience outcomes, and transformational pathways are outlined. Subsequent sections further assess the impacts of climate change across multiple sectors; identify barriers that limit adaptive capacity; and discuss pathways that enhance resilience to climate-related hazards.

Results and Discussion

Conceptual foundations

Climate change impacts societies across the globe, with rising temperatures, changing precipitation patterns, increasing weather volatility, and sea-level rise projected to become progressively more pronounced this century (Colloff et al., 2021). Vulnerabilities vary widely among and within geographic and socio-economic contexts, resulting from a combination of exposure, sensitivity, and adaptive capacity (Hölscher et al., 2019). Climate dimensions include both socio-economic and environmental factors that can influence vulnerability, yet a narrow focus on the climate system is frequently adopted. Impacts and vulnerabilities are typically assessed from a sectoral vantage, with attention to climate-sensitive ecosystems, economic productivity, human health and well-being, and critical infrastructure. While socio-economic conditions are essential to decipher vulnerability, the social features of adaptation themselves are often overlooked. Vulnerable groups may include people depending on marginalised livelihoods, women from low-income households, communities in peripheral rural regions, and those inhabiting precarious urban settlements.

Climate impacts and vulnerabilities

Vulnerability to climate change expands beyond exposure to environmental hazards or sensitivity to specific impacts. At its root, vulnerability encompasses the capacity to anticipate, prepare for, and cope with climate impacts (Maru et al., 2014). This section defines vulnerability in relation to climate change and social adaptation, focusing on exposure, sensitivity, and adaptive capacity. It also describes populations and regions considered particularly vulnerable.

The concept of vulnerability embraces exposure, sensitivity, and adaptive capacity. Exposure refers to the nature and degree to which a system is exposed to significant climatic variations. Sensitivity assesses how climate variations are actually manifested in a system. Adaptive capacity indicates the amount of independent adaptation that is deemed achievable in response to climate changes. Poor adaptive capacity lies at the root of vulnerability to climate change. The weakest link of the adaptation capacity chain thus defines the overall system vulnerability to climate change. Since an increase in exposure or sensitivity is likely to increase vulnerability, the focus on adaptive capacity is necessary for evaluating and assessing efforts to build resilience.

Several groups have been identified as particularly vulnerable to climate change. Specific at-risk populations include: low-income households with few resources to cope; the elderly, who often have limited mobility and are physically sensitive to unsafe climate conditions; children, whose mental development and health status can be curtailed by climate change; and women and smallholder farmers, who depend on subsistence agriculture and lack access to valuable machinery, fertilizers, and information. At the institutional level, municipalities responsible for providing climate-sensitive basic services exhibit increased vulnerability.

Social dimensions of adaptation

The definition of adaptation to climate change encompasses a wide variety of alterations in systems, practices, and individuals, highlighting its universally social nature (Suprayitno et al., 2024; Novalia and Malekpour, 2020; Ziervogel, 2019; Schlosberg et al., 2017). Societal norms and individual behaviors influence these processes. Forms and focus of adaptation differ considerably, depending on the local context and on the actors involved. Examining the social dimensions of adaptation means studying the norms that underpin and shape climate change response. Societal norms provide motivation for individuals to develop infrastructure, build capacity, strengthen institutions, change resource management, gather and disseminate data, adjust patterns of consumption and production, shift to alternate livelihoods, and undertake other measures vital for adaptation. Successful adjustments to disruptive conditions may simultaneously favour equitable, rapid, and sustainable development, stimulate increased social mobility and equity, and accelerating urbanisation. Governance that fosters equitable access to resources permits marginalized social groups to participate in adaptation with maximal equity, thereby enhancing the overall effective response to climate change. Barriers arise when dominant actors engage in climate adaptation measures that do not incorporate equitable resources and opportunities for lower-income and marginalised social actors, threatening participation in the adaptive process.

Cross-sectoral studies of adaptation undertaken across six highly vulnerable countries indicate that planners, officials, and civil society specify existing contexts, describe impacts of stresses on physical and social systems, recommend measures to strengthen capacity, record responses, and identify actors. Adaptation remains nested within broader development policy, practice, and programming, not solely linked to climate-specific or environmental interventions. Responses to multiple socio-ecological stresses demonstrate how current adaptation initiatives already prioritise diverse stresses and encompass targeted-specific action on such responses. Whereas adaptation is conventionally viewed as a discrete or targeted intervention under climate change, it is in practice unfolding through ongoing, persistent activities conditioned by different but often overlapping stressed-related stresses.

Capacity, resilience, and transformation

Capacities comprise a broad spectrum of a social system's attributes and characteristics that facilitate climate adaptation, ranging from human and social capital to governance, infrastructure, knowledge, technology, economies, and institutions. Resilience represents the capacity to cope with perturbations in ways that maintain

essential functions, systems, structures, and identity. Transformative pathways encompass wider systemic changes in the pursuit of adaptive capacity and resilience.

Building adaptive capacity enables communities and social systems to carry out climate-smart policies and practices, ensuring resilience that supports social and economic development and well-being. Resilience-building strategies can generate intermediate resilience outcomes, but can also initiate broader changes in system structure, stakeholder involvement, and governance arrangements, thereby transforming the climate governance paradigm. A resilient system is able, in an iterative cycle, to reconfigure, renew, replace, and adapt interventions continuously across social and biophysical domains. Emerging opportunities for transformative climate action arise from the cumulative processes of resilience building and are realised through shifts in governance, action agendas, and practice towards more integrated and effective climate strategies.

Assessing impacts across sectors

Climate change affects society and the environment in complex, interconnected ways. Assessment frameworks can help identify interactions among different climate impacts, enabling analysis of, for example, downstream consequences of drought on energy supply or investment in irrigation to support agricultural diversification under anticipated demand shifts. Such systems approaches introduce significant additional complexity, as every sector and region connects uniquely and sector-specific indicators may reflect local conditions even when linked. Therefore, many impact studies concentrate on individual sectors without detailed inter-relationships, allowing clearer characterization of climate impacts. Significant impacts on water resources and agriculture, river and coastal flooding, the natural environment, and the built environment have emerged across several regions.

Environment and ecosystems

Changes in climate can affect ecosystems through direct losses of species, alteration of ecosystem dynamics and interactions, stimulation of biological invasions, and modified soil development. Associated impacts may include: disruption of ecosystem essential services, acceleration of the biodiversity crisis, and crossing of ecological thresholds. Ecosystems are defined by their biotic community, underlying physical environment, and essential processes, which vary with respect to plant–animal interactions, disturbance regimes, and nutrient cycling. Ecosystems supply a variety of essential and regulating services, such as air and water purification and carbon fixation. Ecosystem services are affected by biophysical changes and variability owing to climate change and other socio-economic pressures and environmental stresses. Impacts across many ecosystems, including arctic, alpine, montane tundra, wetland, coastal and estuarine-salt marshes, savanna, forest, mountain, grassland-steppes, riverine systems, and many ecosystems in developed regions, have been reported in the literature. The extent and timing of climate change impacts on ecosystems vary across global regions. In addition, even in the absence of climate change, multiple ecosystem engineering activities within society induce stress to ecosystems.

Ecosystems, geographical locations, socio-political systems, sectoral dependence, and technological development contribute to variability in vulnerability and adaptive capacity at local levels. Other factors that shape the systems of interaction or coupled

systems between climate and coping responses include human mobility or community resilience. These factors extend from the external environment to household and micro-level units. Coping, adaptability, and adaptive capacity traditionally characterize responses at the local micro-level dimension. Resilience and adaptation express and signify regional governmental measures and strategies through policy responses at the macro-level through policy actions. When climate hazards reach micro-household level, the first response is coping. At the transitional period from coping to a sustainable climate resilient process, the first phase switches to adaptability. An adaptive capacity concept then appears through the definition of vulnerability. When strategy at the community level approaches social–ecological system sustainability, the regional response pursue a second adaptation strategy through resilience concept or experimental, step-wise planning and building through a transformative adaptation action perspective.

A climate change adaptation measure includes initial changes with respect to: (i) properties of the structure or system that determine the functioning of the system; (ii) the mode of the entire operation or use of the system; and (iii) criteria or objectives for performance assessment of the system. Adaptive measures observed in environmental changes may differ across regions, landscape or climatic zones, and influential exogenous driving forces. The previous adaptation findings are examined and the additional requirements indicated regarding adaptation requirements approach on ongoing degradation difficult to recover or needing a longer period than traditional long-term project period high-light the necessity of coining a new adaptation consideration and re-definitional guidance.

Economy and development

Throughout the globe, temperature rise and other climate variables are changing. These changes will produce direct physical impacts on human systems, through extreme events and chronic weather patterns. Both macroeconomic and microeconomic frameworks provide a framework to anticipate potential macroeconomic and microeconomic impacts, as well as to understand how other social factors—including income distribution, poverty, and gender may condition adaptation responses. The effects of climate change and natural hazards on national economies will depend, in part, on their evolving vulnerability to such events. Gross domestic product (GDP) will still rise, but climate will alter the path to GDP to varying degrees.

Climate Change and External Forces Will Shift the Structure of Economic Development and Influence National and Regional Trajectories. A climatic scenario of explicitly squeezed freshwater and significant temperature rise will stop industrialization as presently defined in many countries and produce abnormal transitions in sectoral zone economies across the globe. External physical forces will, under certain scenarios, greatly reinforce regional imbalances and decide development pathways on continental scales.

Health and well-being

Climate change is projected to have significant adverse effects on health and well-being in the coming decades. A variety of climate stressors, including heat, drought, flooding, and vector-borne diseases, are closely linked to morbidity and mortality. Environmental factors are joined by fragility of social capital, insecurity of livelihood

systems, and suboptimal climate adaptation as key determinants of vulnerability to health impacts. For some at-risk communities, climate change threatens to exacerbate existing health inequities. Mental health consequences may also arise from collective stressors like loss of traditional food systems, territorial degradation, cultural displacement, and the related deterioration of community cohesion.

Increasingly, human health is being recognized as a complex and multifaceted well-being concept that encompasses social, economic, cultural, environmental, and biological factors. Well-being is affected both positively and negatively by climate change. Positive health determinants include better construction standards, reduced crowding, improved provision of basic services in communities, adequate housing, occupational health measures, greater community cohesion, increased healthy snacks in schools, and wider access to health services. Negative determinants obviously include disasters, weather-related accidents, water-borne diseases, crop failures that lead to malnutrition, and respiratory ailments.

Infrastructure and urban systems

Climate change threatens infrastructure and urban systems across a range of climate threats, including extreme temperature, flooding, drought, and storms. Infrastructure such as energy systems, telecommunication networks, transport and housing networks, and critical facilities like hospitals, schools, and jails are particularly vulnerable to climate risks. These systems are interconnected and interdependent, meaning that risks to one component can have cascading impacts elsewhere. Urban areas where low-income populations rely on inexpensive, informal housing are especially at risk. Infrastructure in rural areas is also vulnerable, as many developing countries remain largely rural.

Adaptive capacities and barriers

The Adaptive capacity a key element of vulnerability in climate change assessments, is often defined as the ability of a system to adopt alternative strategies and to construct and deconstruct options at various levels. In certain socio-technical contexts, the boundaries of such a capacity may be tightly prescribed. Therefore, the dimension of radical change remains ambiguous in climate-change assessments, as reinforcing processes or transformative re-designs are equally possible if radical change is restricted on one dimension. Based on a transformational landscape approach, the influence of the concepts of mitigation, seamless travel, telework, dematerialisation, technical effciency, voice mail and high-temperature processing on increases or decreases of the carbon-induced climate-change pressure is examined. Such an analysis identifes the correspondences between major climate-change technologies and general systems theory relating to normative description of transition patterns and pacifying climate pressures.

Governance and institutions

Adaptation to climate change—defined as “the process of adjustment to current or expected climate change, and its effects”—encompasses multi-level governance and institutions that affect adaptation capacities, responses, and outcomes. National and local governments, regional organizations, bilateral and multilateral donors, civil society (including non-governmental organizations and community-based organizations),

indigenous and local communities, the private sector, and the academic community all play roles in governance. Nationally Determined Contributions, National Adaptation Plans, adaptation strategies, regional climate strategies, and local and municipal climate plans constitute specific institutional arrangements.

Knowledge, data, and tools

Climate change is changing the world; it is also changing the way various sectors and institutions must begin to approach the problem. The quantity and quality of climate data is increasing, the models to interpret the data are improving, new decision-support tools are emerging, and methods to evaluate adaptation investments are being established. Nevertheless, the use of climate information to support decision-making is still in an early stage, particularly in developing regions and small island states. Efforts are needed to improve community understanding of climate data, translate raw climate information into climate risk information relevant to community lives and livelihoods, and build community capacity to utilize climate risk information in decision-making. Climate impact assessment and adaptation planning is still limited to a few sectors and regions, such as a few economic models or a few case studies regarding water world-wide. Even in countries that have begun taking such actions, support for climate issues remains limited, encompassing only a few adaptation sectors still not covering rural and community levels. Many decision-support systems are developed for adaptation planning but remains at a theoretical level and are rarely applied.

Finance and investment

Climate 92378df4-93fe-4103-a568-dd309df54d54 is creating significant uncertainty regarding future climate conditions and the corresponding risks to infrastructure and other assets in the developing world. For public globally and private internationally investors, this uncertainty complicates infrastructure investment and climate adaptation decisions. Beyond insulating future damage at a project's outset, adaptation measures require investment prior to realizing any long-term climate-related benefits. As extreme weather scenarios become increasingly plausible, placing a premium on no-regrets actions that minimize future risk, many high-physical-risk investments, such as those in vulnerability-prone locations, remain attractive alternatives. Adaptation must therefore remain feasible in light of these impending economic, equity, and sustainability challenges. Climate-resilient infrastructure provides strong opportunities for adaptation financing. Cost–benefit analyses consistently demonstrate the value of avoiding climate-damaging exposure; moreover, in several cases, the present value of undertaking climate-resilient investment may exceed that of not investing at all. However, climate filtration must be included in project-, country-, or region-level forecasts. Privatizing adaptation is accompanied by transition risk and may exacerbate uneven development, ill-defined rights, and the agricultural lag. Greater access and lower prices alone are insufficient to stimulate finance for climate-vulnerable sectors, especially in countries with poor management, governance, logistical challenges, or gender bias. Public financing remains critical in vulnerable countries even to ensure that the transition to climate-resilient development does not replicate analog development failures.

Equity, justice, and social capital

Distributing climate change burdens raises questions of fairness; compensating loss and damage involves justice; urban sustainability links to environmental equity. Addressing climate health impacts and related inequality requires a just approach. Equity principles inform burdens from climate shocks and adaptation needs, emphasizing marginalization and intersectionality. Justice among rival theories underpins climate adaptation also relevant for public policy. At meta-ethical, distributive, and procedural levels, distinctions inform processes across scales. Equity must permeate substantive, procedural, and transformative frameworks; effective and just climate responses hinge on social capital, defining voices in the adaptation discourse. Participatory governance strengthening linkages fosters social capital. Inclusion in adaptation processes depends on social identities; certain groups possess more agency; social connections, networks, and collective action mediate adaptation access. Social ties mobilize resources, facilitate information dissemination, and co-create options. Collective responses targeting tangible and relational assets establish the foundation for resilient communities.

Adaptive capacity resides at individual and collective levels; attributes, capabilities, and opportunities characterize actors; social capital underscores capabilities and opportunities jointly facilitating climate change adaptation at various scales. Inclusive participation fosters ownership, critical reflection, shared values, trust, and local knowledge integrated with scientific understanding; social networks, norms, relationships, and capacity co-evolve within a systematic framework. Safety nets in shock-prone contexts safeguard livelihoods for economic and psychological resilience, promoting experimentation with climate-relevant adaptation options; actors undertake incremental investments or devote attention to alternative scenarios among system choices perceived as secure. Enabling structures nurture contextually relevant adaptation processes and foster opportunities shared widely throughout society.

Pathways to resilience

A compatible combination of mitigation and adaptation actions is essential for long-term resilience building. Ideal strategies allow for coordination between goals for reduced carbon emissions and the need for short-term adaptation to near-term climate risks. Climate-smart governance reforms are needed to promote accountability and participation; integrate planned adaptation into climate strategies; and enhance flexibility in policy and investment decision making to reflect new information or unanticipated shifts in climate risks. Climate-smart agriculture, water management and forestry practices explicitly address changing climate conditions while improving food security and ecosystem services. Local knowledge, tacit understanding of specifics of shifting climate risks and participation of multiple stakeholders in co-design are critical in planning location-specific, culturally appropriate, environmentally friendly and socially beneficial projects. Scalable technologies can improve water supplies, conserve energy and protect infrastructure, while modular infrastructure maximize climate safety. Monitoring, evaluation and learning need clearly specified criteria, benchmarks, timeframes and feedback loops to fully embed these procedures in decision making.

Mitigation–adaptation synergies

Development pathways can progress without reconsidering the fundamental principles of development and growth, but on the short term, an integrated consideration

of mitigation and adaptation can unleash numerous co-benefits across sectors and contribute to sustainable development. Several parameters can reduce the incremental impact of climate change, the internalization of feedbacks, improvements in modelling uncertainty, and the explicit integration of adaptation, but synergies between sectoral adaptation and mitigation actions are ignored. Such coordinated responses can significantly ease both the socio-economic and environmental dimensions of climate change. Greenhouse gas mitigation strategies can have immediate benefits, the avoided impact on temperature change is related to large-scale mitigation efforts, the residual impact will remain systemic, and an early reduction of emissions will help accelerate the uptake of renewable energies. Integrated climate policies promote broadly sustainable pathways and produce widely beneficial outcomes across multiple priorities, trade-offs between objectives do arise.

Climate-smart governance

Nations need to ensure that governance supports equitable adaptation and takes advantage of opportunities that climate change will bring. Strong climate-smart governance reduces vulnerability through measures that integrate climate change into planning, policy development, and risk management. It promotes climate-resilient growth through good economic stewardship and by creating and maintaining an enabling environment for a wide range of private sector responses. Governance affecting climate change influences the well-being of people more than any of the other drivers; therefore, adaptation that includes people reduces demand and competition for adaptation-related resources. Climate-smart governance directs the relevant social dimensions of adaptation in a region, at times linking the local with the national level. Ensuring equity in adaptation is an important component of climate-smart governance, and to this end it must balance different needs and retains a focus on marginalized populations. Climate-smart governance encompasses reforms that promote transparency and accountability and adaptively plan for future risks, thus reducing vulnerability and enhancing resilience.

Local knowledge and community-based adaptation

Local knowledge plays an important role in climate change adaptation, particularly in vulnerable regions like the Cook Islands. Certain dimensions of traditional environmental knowledge, as well as how adaptation programs could be designed to affect local knowledge, are explored. Gender dimensions of local knowledge are examined to determine how they may vary between women and men and how that understanding could be integrated into community-based adaptation strategies. The potential influence of local knowledge on adaptation outcomes is also considered and research gaps identified.

Indigenous peoples possess knowledge systems that remain particularly relevant in the face of climate change. In many vulnerable settings, indigenous knowledge represents a much larger pool of available adaptation options than do formal scientific tools. Knowledge about traditional ecosystem management, for example, has been recognized as a key element of adaptation to climate change. Even areas where climate change action is more advanced may benefit from examples from non-technical communities, as indicated by a recent crowd-sourcing campaign, which illustrates the challenges involved in documenting and redistributing such basic adaptations. This

focus gives priority to tacit knowledge, as formal techniques alone imply that community participation should occur when already-adopted actions are modified or questioned rather than at earlier stages.

Indigenous peoples possess sophisticated knowledge systems for understanding much of their local environment. The Millennium Ecosystem Assessment recognized the value of such worldviews for ecosystem management contributing to climate change adaptation. In numerous settings, indigenous communities and informal neighbourhoods are already implementing their own responses to climate change. The documentation and optional systematic diffusion of the wider body of such measures remains vital, however, requiring public support and authoritative instruments.

Technology, innovation, and infrastructure upgrades

Climate change presents multiple risks to transport networks, telecommunications, energy supply, and agriculture infrastructures, with the potential to disrupt supply chains, ecosystem services, and interdependent economic sectors. Extreme weather events threaten the deterioration of structural and electronic components, such as road surfaces, paving materials, and traffic-control systems, affecting mobility and serviceability. Subsurface water infiltration threatens roads and pavements through mechanisms such as pavement heaving and freezing, the rise of soil moisture content, saturation, and softening of the subgrade, along with toxicity and corrosion. Climate change also alters energy consumption, affecting the efficiency of refrigeration, heating, and ventilation systems, with supplementary air conditioning leading to additional cooling demand and further energy consumption. Numerous commercial road corridors and rail routes, accounting for a notable share of hunting and food manufacturing, operate in water-limited areas within semiarid regions, where growing-carrier tranquillity is threatened by climate change. Climate change influences agricultural production, with water-limited farming systems expected to experience some of the strongest changes in cropping and land-use systems, which may affect the economic viability and sustainability of such sectors. Robust design and technology obsolescence constitute major concerns for infrastructure developments throughout the life cycle, owing to climate change, material degradation, and functionality alterations.

Monitoring, evaluation, and learning

Effective monitoring, evaluation, and learning (MEL) are essential to understanding progress and informing adaptive strategies. The key monitoring question is "Are we doing what we intended to do?" MEL involves assessing project results against objectives, capturing lessons learned, and applying findings to improve future outcomes. Effective monitoring ensures timely data collection on key indicators for which the project can verify changes—which at a minimum address the project’s initial problem specifications; evaluation uses the data collected at predetermined intervals to analyze achievements, failures, and persistent constraints; and learning captures these understandings for continuous improvement and responsiveness, a process made more complex by broader societal, technical, and institutional change. To the extent possible, MEL approaches should integrate social, cultural, and gender perspectives to enhance understanding of vulnerabilities and resilience; combine qualitative and quantitative methods to provide simultaneous and sometimes cross-confirming insights into multiple dimensions; and apply analysis within and for small groups of stakeholders along with

communication to broadly dispersed audiences. Regular review and updates to the MEL framework should support rather than constrain ongoing processes, managing information flows appropriately for the overall scope and purpose of climate services; the need to accommodate capacity-building priorities; and the aspiration to achieve sustainable development goals and similar ambition. MEL enhances accountability and encourages systematic reflection on experience, ideally alongside broader arrangements for tracking, documenting, and learning from local knowledge, community-based climate action, technology innovation, and climate-smart governance.

Case studies and comparative insights

Emerging from an in-depth and multidisciplinary synthesis of vulnerability and adaptation literature, this synthesis offers a comprehensive look at climate change impacts and adaptive capacity on both a sectoral and demographic basis, considering both developing and developed country contexts and integrating extensive scientific details and data. Underpinning the work is a clear acknowledgement that building adaptive capacity, while a necessary condition for mitigating the adverse impacts of climate change, is insufficient on its own. An important theme is that approaching climate impacts, adaptation options, and adaptive capacity separately can lead to considerable inefficiencies, ineffectiveness, and inequity in adaptation initiatives. Additionally, consideration of equity and social justice in adaptation is imperative.

The case studies—coastal communities; urban centres and housing; rural livelihoods and agriculture; and Indigenous peoples and traditional territories—provide a concise comparative examination of different systems under climate change. Consideration of the linkages between climate change and adaptation interventions across various urban and rural settings facilitates the elaboration of socio-technical innovations capable of responding to external shocks, irrespective of the water-scarcity challenges faced by urban centres and rural communities, and the development of adaptation options rooted in local knowledge and capacities.

Coastal communities

Coastal communities are disproportionately vulnerable to climate change due to their geographic location and socio-economic conditions. As global average sea levels rise, many coastal areas are experiencing increased flooding, more frequent and severe coastal storms, and, in some cases, more severe coastal and river erosion. Climate-related sea-level rise, combined with seasonal drought, longer time frames for climate-driven events, and declining water tables, jeopardize the long-term survival of close to 50 million people in Africa, the majority of whom live along the rapidly expanding coastal cities of the continent. In Asia, urban populations living in the low-elevation coastal zone or under threat from sea-level rise, flooding, and cyclone risks are projected to increase from 350 million in 2000 to 600 million in 2020. Coastal city managers and planners now are faced with urgent, complex problems that require immediate action. Significant investment will be needed in the coastal infrastructure throughout the cities and towns of South Asia, and measures to protect the coast against climate events such as cyclones, tidal inundation, and coastal river flooding must be planned and instituted.

Urban centers and housing

Sustainable housing and urban services underpin climate-resilient cities in developing contexts. Urban centers in developing countries account for a considerable share of global warming emissions, yet they remain the least resilient to climate change. Housing resilience in cities can diminish exposure to heat stress, flooding, and storm surges. Urban design—density, connectivity, and access to green space—largely determines the capacity for transforming road networks, transport modes, and energy usage to mitigate climate change impacts. Housing resilience and urban design interact with urban land-tenant relationships and basic service access, all influenced by city size and national development level. Access to basic urban services—water supply, sanitation, solid waste collection, storm drainage, electricity, and public transportation—remains limited in parts of Africa and South Asia, exposing low-income urban dwellers to climate hazards. In such situations, state involvement to secure low-income housing and accelerate service provision can enhance climate resilience.

Four, complementary patterns of urban organization entail specific climate risks and mitigation–adaptation responses. Intermediate patterns—characterized by in-situ improvement of slum dwellings and public service extension—predominate in sub-Saharan Africa. In such cities, adaptive capacity hinges on pro-poor partnerships that involve low-income groups as stakeholders in the planning and improvement of urban services.

Rural livelihoods and agriculture

Climate change affects rural livelihoods and agriculture by increasing risks to the farming sector, disrupting agriculture-related value chains, and limiting resource availability. Moreover, trade-offs among livelihoods are exacerbated, shifting aspirations toward non-farm economic opportunities. Such changes shape adaptation decision-making and capacity.

The farming sector in semi-arid Africa and India is highly affected by climate change through extreme temperatures and changing precipitation patterns. Frequent droughts, floods, and events such as hailstorms further complicate agricultural production. Smallholder farmers adopt risk-related strategies to sustain their farming and livelihoods. Diversification of livelihoods, including seasonal migration, labor exchange beyond agriculture, and development of farm and non-farm enterprises, has been observed.

Rural households adopt adaptation strategies based not only on material resources or risk exposure, but also on the perception of risk affecting household dynamics and well-being. By understanding the relationship among climate risk, livelihood diversification, and aspiration, it is possible to inform policies. Such policies should promote risk mitigating as well as aspiration-enhancing adaptations within a specified time frame rather than farm system replacement. This informs the importance of government attention, technical support, and market access to facilitate the adoption of diversification strategies through human, social, financial, and physical capital.

Indigenous peoples and traditional territories

Indigenous communities represent approximately 370 million people who have a historical and enduring relationship with the land and act as stewards of over 80% of the world's biodiversity. Indigenous Traditional Ecological Knowledge (TEK) is a holistic approach that has been adapted over time to ensure continued environmental quality and

is inherently dynamic, evolving as ecosystems and cultures change. Within the African continent, indigenous ways of knowing and strategies related to climate change adaptation have been largely ignored in formal policy responses. Indigenous knowledge is often seen as the intellectual property of Indigenous peoples as opposed to a "common good" for scholars and scientists. Adaptation strategies have also been developed but such strategies do not yet address the long-standing colonial marginalization of Indigenous peoples' rights of self-determination and land tenure. Nations have committed to upholding Indigenous peoples' human rights through numerous declarations and frameworks such as the UN Declaration on the Rights of Indigenous Peoples and convention No.169 of the International Labour Organisation on Indigenous and Tribal Peoples. Conflicts in jurisdictions over land tenure occur when a commitment to uphold Indigenous peoples' human rights and climate change adaptation strategies are at odds. The loss of Indigenous people, cultures and livelihoods as well as the devasting impacts of climate change on the well-being of Indigenous peoples as a result of climate change necessitate a rethinking of rights and leadership as a priority.

Policy implications and pathways for action

The Action Agenda is the main outcome of a multi-year process to review, reinforce, and take forward the global agenda for climate change. Its well-structured approach outlines the core risks posed by climate change, identifies actions that can be taken to address these risks—cutting across national and regional boundaries and building on local knowledge—and distils the key ingredients of effective implementation. The central message is that channelling these ingredients in ways that respond to the needs of different groups, foster ownership and advance equity offers a way to create genuine momentum for climate action and pave the path to global change. These insights articulate some of the implications of these considerations and identify the actions needed across various categories: Actions at the national level to articulate priorities for adaptation and resilience; Actions to promote cooperation and action within regions, including investments in shared risk and opportunity; Actions to advance financing mechanisms that align local, national and international financial resources with climate-smart resilience-building needs; and Actions to mainstream climate change in education agendas, curricula and training opportunities.

National-level strategies

Adaptation governance at the national level typically seeks to increase coordination across sectors and scales, manage complex interactions and risks, and ensure inclusiveness and equity. Different countries have adopted various governance models and mixes of adaptation policies that reflect national circumstances, priorities, and established regimes for governance in related domains. Diverse national contexts are present within any region, which can manifest in physical, ecological, biological, socio-economic, political, governance, diversity, and technological spheres. Climate trends may present variable risks across these national contexts, even significantly different from one country to another. Similar exposure patterns can nevertheless be expected internationally, for example in laboratory-scale experiments when a structured, controlled environment is replicated. Resilience-building policies and measures therefore also occur at a regional or subcontinent level. Coordination within within

regional or subcontinental governments promotes coherence of national actions across phenomena other than climate change.

Regional cooperation and planning

Climate change exacerbates existing socio-economic, demographic, and environmental pressures, compelling the search for cooperative arrangements across geographical scales. For instance, coastal states face common risks from rising sea levels and extreme weather. Urban systems connected by infrastructure, supply chains, or services also share vulnerabilities. Interdependencies as well as disparities in exposure, sensitivity, adaptation capacity, or institutional responsiveness further motivate cooperation. These challenges and opportunities drive nations and communities to collaborate. Bilateral or multilateral agreements on transboundary issues are therefore essential.

Adaptation finance mechanisms

Climate adaptation costs are expected to far exceed amounts currently provided through traditional, public sources of finance. To supplement and catalyze this mobilization of new private sector capital, innovative financial instruments are needed that clearly articulate the business case for climate resilience and enable such investments to be rewarded and recuperated. Climate risk insurance is currently the most pervasive and significant form of adaptation finance, included in the climate strategies of 38 countries. The prioritization of effective climate risk insurance is considered an essential step toward the realization of national adaptation goals. However, the widespread mainstreaming of climate resilience in socio-economic planning, a necessary prerequisite for effective adaptation to climate remains severely limited in many developing countries because of entrenched governance, finance, policy, and capacity challenges.

Education, communication, and capacity building

The need to build capacity for adaptation to climate change is urgent for all societies vulnerable to its impacts. Education, awareness, and communication on climate and development are essential for vulnerable people and communities to understand and respond to their situation. People need to know how to manage their exposure to climate change or to build resilience to its impacts. Such knowledge must be widely disseminated, given the threats to lives and livelihoods, material assets, ecosystems, and future generations. There must be strong mechanisms for reversing current trajectories of socioeconomic, environmental, and health deterioration, as the risk of eventual adaptation collapse increases.

The capacity to adapt to climate change must be strengthened at all levels of society, from the household and community to national and global. Adults and youth require enhanced knowledge of climate-compatible and resilient alternatives and opportunities to pursue these courses of action. Capacities need to be built in vulnerable population groups that remain marginalised and have limited access to options for action. Such approaches require out-of-the-box thinking that challenges the dominant narratives of policy change and seeks avenues that are not yet well considered in national discussions. At the household and community level, the capacity to adapt to climate change can be enhanced through the strengthening of social capital.

Conclusion

At the beginning of a new decade, climate change remains one of the defining issues of our time. In the span of just a few years, societies have absorbed, contended with, and formed new insights about the climate challenge. Questions posed earlier remain outstanding, but alternative approaches and avenues of action have come into view. Moving toward a climate-safe, sustainable future requires profound transformation—an urgent collective response, involving many stakeholders working simultaneously across scales, sectors, and spatial and temporal scales. Unfolding simultaneously, climate change impacts alter the way societies operate and interact in myriad complex and interrelated ways. Climate change adaptation can support, and sometimes requires, a reevaluation of goals, values, systems of consideration, procedures, means of research, and ways of gathering knowledge about topics, events, processes, futures, and the interconnections between the environment and behaviour.

Acknowledgement

This research is self-funded.

Conflict of interest

The authors confirm that there is no conflict of interest involve with any parties in this research study.

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