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SHORT ARTICLE

Resilience Building and Collaborative Governance for Climate Change Adaptation in Response to a New State of More Frequent and Intense Extreme Weather Events

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Abstract
The weather conditions of the summer of 2022 were very unusual, particularly in Eastern Asia, Europe, and North America. The devasting impact of climate change has come to our attention, with much hotter and drier conditions, and with more frequent and intense flooding events. Some extreme events have reached a dangerous level, increasingly threatening human lives. The interconnected risks caused by these extreme disaster events are triggering a chain effect, forcing us to respond to these crises through changes in our living environment, which affect the atmosphere, the biosphere, the economy including the availability of energy, our cities, and our global society. Moreover, we have to confront the abnormal consequences of untypical, rapid changes of extreme events and fast switches between extreme states, such as from severe drought to devastating flooding. Recognizing this new situation, it is crucial to improve the adaptation capacity of our societies in order to reduce the risks associated with climate change, and to develop smarter strategies for climate governance. High-quality development must be science-based, balanced, safe, sustainable, and climate-resilient, supported by the collaborative governance of climate mitigation and adaptation. This article provides some recommendations and suggestions for resilience building and collaborative governance with respect to climate adaptation in response to a new planetary state that is characterized by more frequent and severe extreme weather events.

Keywords Climate change adaptation · Collaborative governance · Extreme weather events · Resilience building

1 Introduction

The frequency, scope, and intensity of extreme weather events in recent years and their catastrophic consequences have shocked human society and made great impressions on everyone. In the summer of 2022, the northern hemisphere—especially Western Central Europe, North America, and South-East Asia—was hit by extreme heatwaves, droughts, and/or floods, with records reaching new highs in many places (Fig. 1). These events brought great challenges to the economy and people's livelihoods,

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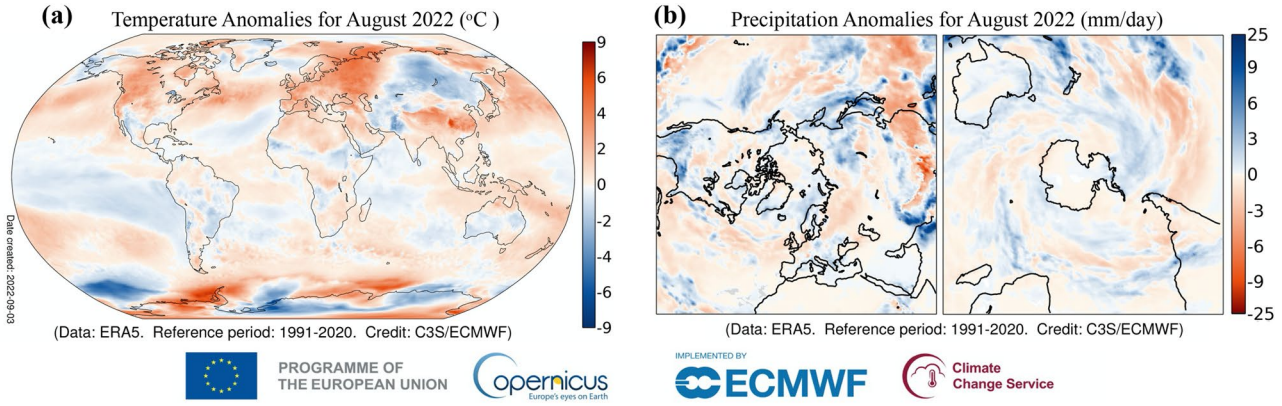

Fig. 1 **a** Temperature and **b** Precipitation anomalies for August 2022 with respect to the reference period of 1991–2020. *Sources* Copernicus Climate Change Service/ECMWF at https://climate.copernicus.eu/surface-air-temperature-august-2022, and https://climate.copernicus.eu/precipitation-relative-humidity-and-soil-moisture-august-2022.

including water and energy shortages, extra health burdens, extensive fires, severe crop losses, and high food prices.

The hottest summer on record for Europe paired with unusually dry conditions reduced some of Europe's main rivers to extremely low water levels, for example, threatening vital economic thoroughfares and exacerbating the continent's energy shortages. The heat also led to record-breaking fire activities in many European countries. More than 2500 fires were recorded, and more than 772,000 ha were burned in European countries in 2022, compared to an average of 900 fires and 318,000 ha burned between 2016 and 2021 (EFFIS 2022).

Most parts of China experienced the longest and most intense heatwave on record (CMA 2022) that lasted for 72 days—10 days longer (16% more) than the previous record of 62 days in 2013. More than 1 billion people suffered temperatures higher than 35 °C, and at least 360 million people faced exceptional temperatures higher than 40 °C, making medical attention to heat strokes a new normal in these regions. The accompanying long-lasting drought led to the drying up of rivers, lakes, and reservoirs, affecting the water and electrical power supplies.

While heatwaves gripped parts of Europe and Asia, some other places experienced extreme rainfall and flooding. In the southwest of the United States, for example, California's hot and dry Death Valley experienced a "once-in-a-thousand-year" extreme rainfall, with nearly a year's total worth of rain in 3 hours (37.1 mm). In Pakistan, one-third of the country was completely submerged by a devastating historic flood, causing more than 1100 deaths and billions of dollars in losses.

Although devastating, the extreme weather events that occurred in the summer of 2022 were not altogether unexpected. Observations have shown that extreme events including heatwaves, heavy precipitation, droughts, and tropical cyclones have been increasing in recent years and their attribution to human activities has strengthened since last assessment in 2014 (IPCC 2021). Scientists have warned that exceeding 1.5 °C global warming could trigger multiple climate tipping points, with irreversible and catastrophic consequences (Armstrong Mckay et al. 2022). Although climate tipping points for the Earth system have not been activated yet at the current global warming level of 1.1 °C, some extreme events intensified by climate change have reached the tipping point of human survival.

Heatwaves are a good example of how extreme weather events threaten human health. The maximum temperature a human can withstand is generally within the range of 40–42 °C. In the summer of 2022, the highest temperature in many areas exceeded this limit (Fig. 2a). But human temperature tolerance depends not only on the temperature but also on the humidity—represented by the wet-bulb temperature in meteorology—as well as on concomitant atmospheric pollutants, such as ozone. Studies have shown that even healthy people with strong climate adaptability cannot withstand a wet-bulb temperature higher than 32 °C. Once the wet-bulb temperature reaches 35 °C, we are no longer able to cool ourselves through sweating, leading to heat stroke, which means shocks to multiple organs and even permanent damage (Raymond et al. 2020). Extreme heatwaves over central Europe and especially the Paris region in the summer of 2003 demonstrated that the main health impacts and mortality cases were due to a combination of high temperature, humidity, and episodes of very high levels of ozone (Kovats et al. 2004; Schär et al. 2004). Continued exposure above this threshold can quickly lead to death by overheating. Some areas have already experienced wet-bulb temperatures close to humans' survival threshold (Fig. 2b). As global warming continues, strengthened evaporation is anticipated to

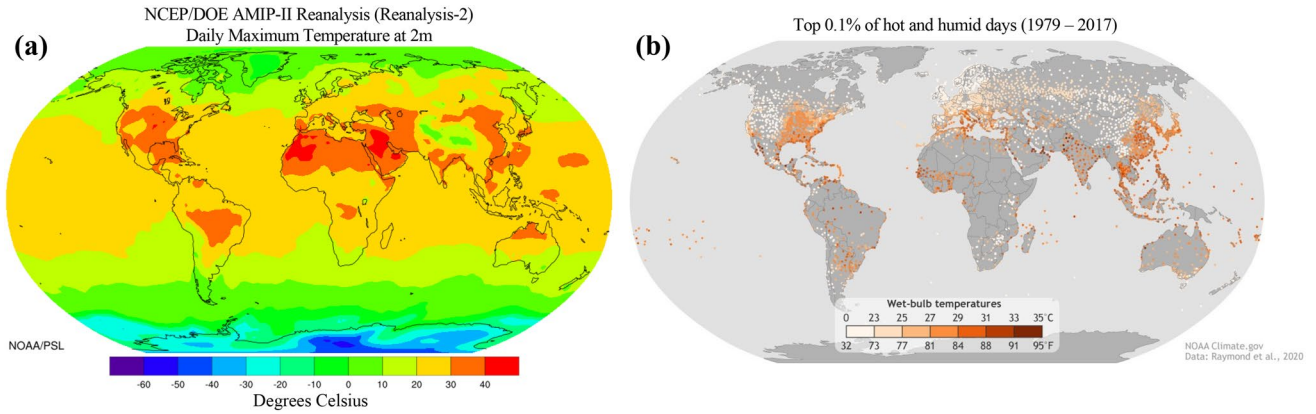

Fig. 2 **a** Daily maximum temperature at 2 m on 1 August 2022. Image provided by the NOAA/OAR/ESRL PSL, Boulder, Colorado, USA, from their Web site at https://psl.noaa.gov/mddb2/makePlot.html?variableID=138636&fileID=836783, with default setting except that "Date" was changed to "2022 Aug 1," "Contour Lines" changed to "No," "Plot Units" changed to "Celsius," and "Projection" changed to "Robinson." **b** Top 0.1% of wet-bulb temperatures at different locations between 1979 and 2017. *Source* NOAA website at https://research.noaa.gov/article/ArtMID/587/ArticleID/2621/Dangerous-humid-heat-extremes-occurring-decades-before-expected, with original data from Raymond et al. (2020).

increase the proportion of water in the atmosphere, and high-temperature days will become more intolerable (Raymond et al. 2020).

As global warming has progressed, hotter and drier conditions and more extreme flooding events have become the new state and the new normal. On the one hand, we need to adapt to this new state and deal with the negative consequences on energy, ecosystems, economies, societies, and public health. On the other hand, we need to be prepared for the untypical and rapid reversal of extreme events, such as the shift from extreme drought to extreme flooding, and from heatwaves to cold spells. As highlighted in the recently published report *United in Science* (WMO 2022a), adaptation is crucial to lowering the risks of climate impacts. Therefore, it is important, urgent, and crucial to act now to improve our adaptation capacity to reduce the risks of climate change, especially of extreme events.

2 Understanding the Emergence of New Risks Through Lessons Learned in the Process of Achieving Carbon Neutrality

In response to climate change, the whole world is working towards carbon neutrality to limit global warming. Cutting down the carbon emissions in the energy sector is essential, which requires remarkable transition from fossil fuel energies to clean and renewable energies. Recently, the energy crisis accompanying extreme weather events has brought our attentions to the emergence of new risks during the energy transition process.

2.1 Lessons Learned from the 2021 Texas Power Crisis Due to Extreme Cold Weather

The electricity resources of the state of Texas, United States, are dominated by natural gas (52%), followed by coal (20%), wind (17%), nuclear (9%), and other sources (2%) (Statista 2022a). In February 2021, the impact of extreme cold weather on the energy supply of the state caused significant blackouts and left more than 10 million people without electricity. All types of electricity generation technologies were impaired by the heavy winter storm, especially the natural gas and wind energy supplies due to damaged pipes that limited the natural gas supply and frozen wind turbines that shut down the wind energy supply. Other power plants also failed to operate at their best generation output levels. Moreover, the dramatically increased demand for heating during this extreme cold weather period caused a further collapse of the power supply (Busby et al. 2021).

Under extreme conditions, the reduced reliability of the power generating infrastructure has become an emerging risk that threatens the stability of the energy supply. The winterization of the reliability standards for the infrastructure should be developed and implemented to ensure that generators are prepared for extreme events in the future. Moreover, in the process of achieving carbon neutrality, clean and renewable energy sources, especially solar and wind energy will make great progress in large-scale and commercial uses. But their energy networks and supplies are more sensitive to weather conditions. Therefore, a portfolio of multiple energy sources and special fusion techniques are required to overcome the fragmentation and instability of renewable energy sources, and to establish resilience capabilities such as improving energy source reliability and

safety to ensure energy supply in extreme situations. In addition, the development of powerful freezing-resistant turbines for wind energy, and the preparation of redundant reserves of fossil fuel energy should be fully considered.

2.2 Lessons Learned from the Response to the 2021 California Power Shortages Due to a Record Heatwave

The electricity resources of the state of California, United States, are dominated by natural gas (47.3%), followed by solar (15.7%), hydropower (11%), nuclear (8.4%), wind (7%), and other sources (10%) (Statista 2022b). In July 2021, a record-breaking heatwave swept the state and lasted for days with a maximum extreme temperature of 50.5 °C, causing record-breaking power shortages, and some households experienced rolling blackouts. In contrast to the power shortages at peak times, there was a relatively abundant amount of grid electricity during effective solar radiation periods owing to the significant development of solar power. In response to the high fluctuations in power demand during the day, customers were urged to curtail electricity use as much as possible between 3 and 10 p.m. and shift energy use such as charging electric vehicles and using large appliances to the morning or early afternoon hours (CAISO 2021).

Power shortages during heatwaves have become a new normal in recent years. Similar power shortages and outages also occurred in August 2022 in Sichuan Province, China. The California case demonstrates the enormous potential for power saving at the customer end to reduce electricity demand at peak times. The shift to the use of electricity outside of peak times could effectively decrease the daily fluctuation of power consumption and reduce the risks of power shortages during weather extremes.

2.3 Lessons Learned from the 2022 Europe Energy Crisis

The energy available in the European Union (EU) highly depends on the import of fossil fuels. In 2020, only 42% of the total energy consumed by the EU countries was produced in the EU (Eurostat 2022). Of those energies, renewable energies accounted for the highest share of 40.8%, followed by nuclear (30.5%), solid fossil fuels (14.6%), natural gas (7.2%), and others. However, when gross consumed energies are counted, oil and petroleum products were the main source (34.5%), followed by natural gas (23.7%), renewable energies (17.4%), nuclear (12.7%), solid fossil fuels (10.2%), and others. In order to achieve carbon neutrality by 2050, Europe is strictly limiting the consumption of fossil fuels, and countries such as France and Germany are accelerating the process of phasing out coal. At the same time, the share of renewable energies has been continuously increasing in the past several years. Despite the current energy crisis, those policies have not been changed.

In 2022, affected by the Russia-Ukraine crisis, the natural gas, oil, and coal supplies from Russia to Europe significantly decreased. Although European countries experienced the hottest and driest summer on record in 2022, which had a positive impact on the production of solar energy, it led to a significantly lower share of wind and hydropower in the energy supply. In response to this unexpected energy crisis, many European countries have turned back to fossil fuels like coal for power generation in the short run. However, in the long run, this crisis may push them harder to enhance their capacity in renewable energy.

The 2022 Europe energy crisis has warned us that on the way to carbon neutrality, it is important to keep a balance between phasing in clean and renewable energy and phasing out fossil fuels, and to be well prepared for emergencies that call for a rapid change in the energy structure with redundant reserves. There is a need for long-term and proactive arrangements in many aspects of risk responses, particularly in terms of extreme weather events, infrastructure resilience, and preparedness for people's needs, in order to minimize losses from various risks.

3 Building Resilience Through Collaborative Governance for Climate Change Adaptation

When advancing the process of achieving carbon neutrality in response to climate change, the impacts of more frequent and intense extreme weather events have forced us to think soberly about developing smarter climate governance strategies for sustainable development. While climate mitigation actions contribute to the slowdown of climate warming, climate adaptation is of great importance and is a more direct approach to reducing disaster risk and protecting people (Robbert and Lesnikowski 2018). The key to climate change adaptation (CCA) is the reduction of climate risks. This needs to include reducing the impacts of rapidly changing or slow-onset extreme events, to lower the vulnerabilities of infrastructures that already exist or are under construction, and to limit the combination effects on the population and society due to extra health burdens originating from other sources (for example, air pollution). The goal of CCA is to achieve climate-resilient development in the near future.

Although more than 170 countries have already taken adaptation into account in their climate policies and planning, which has generated benefits in areas such as health, food security, and biodiversity conservation, there are still large gaps between actions already taken and the needs of society in response to the climate change impacts (IPCC 2022). Moreover, progress towards adaptation is unevenly

distributed across regions, and most implemented adaptation measures have been small-scale, fragmented, incremental, or sector-specific. Despite the general advocation of CCA in the 2015 Paris Agreement and the earlier United Nations Framework Convention on Climate Change (UNFCCC), there is a lack of a comprehensive and systematic guiding framework for countries' CCA actions, as well as a unified and coordinated operational framework for collaborative deployment within the UN system. Here, we present several suggestions and recommendations for resilience building through collaborative governance for CCA (Fig. 3).

The United Nations (UN) should take the lead in promoting CCA at the global level. Although the importance of CCA was highlighted in the Paris Agreement (Articles 7, 8), limited measurable progress has been made to promote CCA at the global level. Quite a few UN agendas and programs, such as the UN Framework Convention on Climate Change (UNFCCC), the Sendai Framework for Disaster Risk Reduction 2015–2030, the Sustainable Development Goals (SDGs), the Urban Agenda, and the Addis Ababa Action Agenda, are relevant to CCA in one way or another. These endeavors should be integrated into comprehensive and coordinated guidance for countries to optimize the allocation of limited resources for greater achievement. Therefore, it is essential and urgent to develop a new overarching CCA framework to integrate all these pieces together and to reduce fragmentation across those CCA efforts, to achieve intended benefits at scale more effectively and efficiently. It is important to have one UN organization (it could be an existing one) take the leading role in coordinating all the strategies and workplans.

Besides the overall framework to guide CCA, the UN should also take the lead in developing specific supporting action plans for different regions, fields, and industries and establish several corresponding programs to provide guidance, best practices, and strategies to member countries. In this regard, we call for a high-level committee to lead this work, in response to the Paris Agreement and the gaps identified by the latest Intergovernmental Panel on Climate Change report (IPCC 2022). Existing agencies or programs could continue their key roles to support CCA actions, contributing through planning, measurements, mobilization, joint initiatives, and other activities. The World Meteorological Organization (WMO), for example, is leading a UN initiative to ensure that every person on Earth is protected by early warning systems to increase nations' resilience to extreme weather (WMO 2022b). The United Nations Development Programme (UNDP) could support this by establishing a monitoring system with wider coverage to track all investments that have significant objectives for CCA, ensuring that these are provided in a balanced and equal manner to the identified prioritized areas with appropriate adaptation technical support. In addition, best practices including pilots, demonstrations, and campaigns should be initiated to support CCA actions at the local, country, and regional levels. International research communities, such as the International Science Council (ISC), Integrated Research on Disaster Risk (IRDR), the World Climate Research Programme (WCRP), the Global Framework on Climate Services (GFCS), the Global Atmosphere Watch (GAW) Programme, the Monitoring, Analysis and Prediction of Air Quality (MAP-AQ), and so on, could play important roles in sharing advisories on science-based solutions and delivering the best practices to their members and networks.

Similar to that at the UN level, it is also important to have an overall CCA strategic framework at the national level and

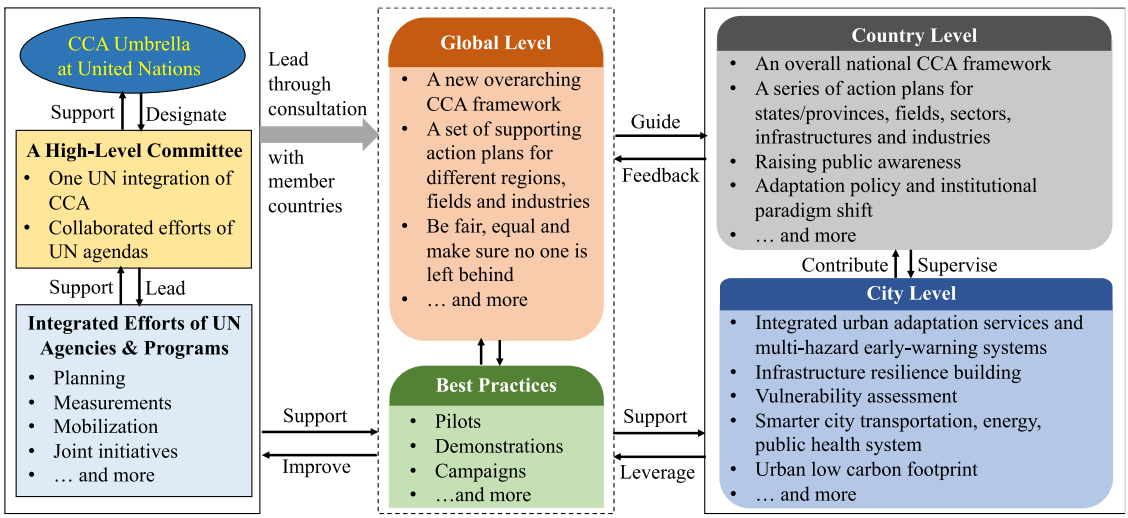

Fig. 3 Recommendations for climate resilient development (CRD) through collaborative governance for climate change adaptation (CCA), with the support of multi-stakeholder partnerships

a series of specific action plans for different states/provinces, fields, sectors, industries, and for the whole society. From the countries' perspective, it is important to bear in mind that the devastating impact of climate change is not affected by national borders and no country can escape from climate change impacts. High-quality development should not only pursue economic development, but also be science-based, balanced, safe, collaborative, resilient, and sustainable. Climate Resilient Development (CRD) is crucial and urgent for all countries. It cannot be obtained by a single policy, but requires collective choices made by society as a whole on a day-to-day basis. Finding solutions through the joint efforts of all parties, including governments, the private sectors, and citizens, can help to promote climate resilience development with the combination of top-down and bottom-up endeavors. Considering their resources and broad public coverage, the potential of private sectors could and should be exploited to support CCA actions. For example, let "race to resilience" be part of the CCA framework to promote the participation of multi-stakeholders in resilience building. While many countries already have CCA actions in place, there are large gaps between regions and countries. It is important to have coordinated actions at the national level to achieve "save all." There is also a large disparity in capacity building in response to climate change risks between countries. Developing countries are much less prepared compared to developed countries. Many developing countries are still in the stage of passive disaster response instead of disaster prevention and are struggling for compensation on loss and damage. The principle of common but differentiated responsibility and respective capabilities also works for CCA, as highlighted in the Paris Agreement. International cooperation is of great importance for implementing CCA. Developed countries need to provide financial resources and technical support to assist developing countries to reduce the damage and impacts of climate change (United Nations 2015). Unfortunately, limited progress has been made in delivering the committed annual USD 100 billion from developed countries to developing countries, which significantly constrains the CCA actions in developing countries. Nevertheless, the breakthrough agreement on creating a specific fund for "loss and damage" for vulnerable countries hit hard by climate disasters marked an important progress towards a fair world to make sure that no one is left behind (UNFCCC 2022). We hope to see more progress on climate financing to support CCA in the developing countries.

In addition, the participation and involvement of cities plays a determining role in maximizing the benefits of CCA. Cities, especially those heavily populated, are highly vulnerable to the impacts of climate change. Implementing CCA measures to increase the resilience of cities to climate change could not only save millions of lives but also significantly reduce economic losses. The integrated urban adaptation services—known as the Integrated Urban Services (IUS) (Baklanov et al. 2018; WMO 2019)—and the Multi-Hazard Early Warning System (MHEWS) (Tang et al. 2021) have been approached to assist cities with planning and facing weather/climate/environment extremes, based on best practices of many megacities and scientific achievements. The IUS and MHEWS are a must-have to support safe, healthy, sustainable, and resilient cities (SDG 11). Further endeavors should be undertaken to continuously strengthen the understanding of the occurrence characteristics and development mechanisms of extreme events, their turning points, and chain effects for better, quicker, and more accurate forecasting and early warning and more effective responses (Clancy et al. 2022; Zhang et al. 2022). Furthermore, it is also important to reevaluate the applicability of current infrastructure construction standards, as they are based on past experience and data, with limited compatibility with each other. With more frequent and intense extreme events in the context of climate change, the requirements may have dramatically changed. A comprehensive and systematic assessment of climate change vulnerability should be conducted to identify the weak parts. Measures such as updating construction standards and enhancing infrastructure resilience design that takes into account the requirement of redundancy are recommended for the preparedness for the new state of more frequent and intense extreme weather events. Moreover, the coordination of climate mitigation and adaptation actions should be improved. The goal of carbon neutrality calls for the construction of a smarter energy system with a multi-energy complementary supply, which is anticipated to stimulate innovation measures to improve stability, safety, and efficiency of energy utilization, phases out the usage of fossil fuels, and increases the share of renewable energy. However, the impact of climate change on the energy system and the vulnerability of renewable energy to weather/climate extremes should be fully taken into account and be well prepared for (Yalew et al. 2020). The construction of new energy systems should take this into account and the systems be well-equipped with redundancy.

Last but not least, the key of CCA, in terms of extreme events prevention and preparedness, is taking the impact of changing climate into account when conducting risk assessment, together with the consideration of possible compounding events that may interact significantly to occur together or in a chain (Zscheischler et al. 2018). The IPCC report indicated that the characteristics of future extreme events including frequency, intensity, and distribution of occurrence sites are likely to vary significantly compared to those happened in the past (IPCC 2021). Therefore, climate change adaptation research and governance, in addition to continuing to rely on historical disaster risk data (for example, frequency, loss, and damage) and local environmental information (for example, topography, economy, ecosystems, infrastructure,

and demography), must also take into account the new characteristics of extreme events under global climate warming. These need to be supported by extensive measurement and observational data, big data analysis techniques, and climate change modeling and its applications. Moreover, the common standards and methodologies for monitoring and assessment to facilitate adaptation, such as coherent and authoritative data standards, open data policy, and collective tool-kits, should be established urgently to support the objective inter/intra-regional comparisons and evaluations and to provide effective guidance to countries with limited capacity.

4 Conclusion

The more frequent and intense extreme weather events in the context of climate change are calling for rapid and effective actions. Promoting resilience building and collaborative governance for CCA to achieve climate-resilient development is crucial and urgent for all. The UN should take the lead in promoting CCA at the global level, through a high-level committee and integrated efforts of UN agencies and programs. The development of a new overarching global CCA framework and a set of supporting action plans should be prioritized and supported by the UN. Nations shall bring together all parties, including governments, the private sectors, and citizens, to contribute to CCA with both top-down and bottom-up endeavors. Enhanced collaboration between countries is crucial to make sure no one is left behind. Cities are the key for implementing CCA measures and maximizing CCA benefits. The integrated urban adaptation services and multi-hazard early warning systems are the must-have for cities, and continuous support should be driven to increase our understanding of the characteristics of extreme events. Other measures including vulnerability assessment, infrastructure resilience enhancement, and smarter city system design are highly commended. With the support of multi-stakeholder partnerships, the CCA actions are believed to reduce the risks associated with more frequent and intense extreme weather events.

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