ADAPTATION STRATEGIES AND PRACTICES TO ADVERSE EFFECTS FROM CLIMATE CHANGE: TAIWAN'S EXPERIENCE AND IMPLICATIONS

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ABSTRACT

The world population is expected to grow to near ten billions before the year 2050, with the most increased areas are predicted to be in the sub-Saharan, Africa and south Asian regions. It is estimated that the global food production must be multiplied to feed these populations and hence, agricultural productivity needs to be sustainably improved to meet the increased demand. However, challenges to agri-food supply chains are enormous. Food production is worsening through the depletion of natural resources, energy shortage, limited arable land, environmental degradation and other challenges of global concerns facing today, including climate change. Increasing fossil fuel energy use and emission of greenhouse gases (GHGs) are considered the major anthropogenic factors accelerating pace of warming climate. According to the latest scenarios of Intergovernmental Panel for Climate Change (IPCC), air temperature will rise about 2–5°C by the late 21st century, depending on the region and emissions condition. The diversified effects of changing climate are not only about temperature increase, but also the induction of phenomena such as irregular precipitation patterns, weather extremes, sea level rise and increasing carbon dioxide concentration. For example, the erratic and unpredictable nature of droughts and floods increased in Taiwan over the last decades. Changes in the magnitude of rainfall and its distribution will cause significant agricultural disasters as well as affect the availability of water for crops production. Many countries are now actively using a variety of applicable technologies and tools to engage in agricultural research and development in response to climate change. The outputs from R&D activities will support building of resilience systems to reduce constraints and risks imposed by abiotic and biotic stresses from abnormal weather and climate patterns. In Taiwan, a series of cross-domain integrated research projects

have been initiated and implemented since 2012, in order to develop the necessary technologies and practices for realization of policies to ensure the sustainable development of agriculture and food security under climate change. The grand challenge and concern of policy is that while most of the effects of climate change will happen in the future much of the mitigation and adaptation costs are already currently felt now. As such, multidisciplinary and multi-sectoral collaborations have been promoted to study in reducing GHG emissions from the agricultural sector and developing integrated climate-smart management of cropping systems domestically. Research on climate-smart farming is mainly working on adapting and constructing multiple resilience to cope with climate change and their impacts on agriculture and food production. The efforts and expectations are to help establish local agriculture as a dynamic and highly competitive industry, and to increase farmers' income and welfare and upgrade the farm sector's competitiveness, making agriculture as a model of Lifestyle of Health and Sustainability (LOHAS).

Keywords: Agricultural productivity, research and development activity, cross-domain integrated research project, policy, resilience.

INTRODUCTION

The world population is expected to grow to near ten billions before the year 2050, with the most increased areas predicted to be in the sub-Saharan, African and south Asian regions. It is estimated that the global food production must be multiplied to feed these populations (Foley *et al.* 2011). Therefore, the most pressing world issues relevant to food production should be carefully considered and resolved. With that, agricultural productivity is of top priority that should be sustainably improved to meet the increased food demand and so as to ensure sustainable agricultural development. Further, public health issues such as food security and food safety can only be solved under the premise of adequate food production.

However, near-term challenges to agri-food supply chains are enormous and complex (Fig. 1). Food production is worsening through the depletion of natural resources, energy shortage, limited arable land, environmental degradation and other challenges of global concerns facing today, including climate change. The phenomenon of global warming is now well-recognized and is considered as one of the primary causes of ongoing climate change. The effects of climate change have been already observed across the globe and are anticipated to be intensified in the future. According to the climate

change scenarios provided by the reports of Intergovernmental Panel for Climate Change (IPCC), a scientific and intergovernmental body under the auspices of the United Nations (UN), even if everything possible were done to reduce and stabilize emissions of greenhouse gases (GHGs), negative impacts of climate change are projected to become more intense and severe in the near future (IPCC 2014).

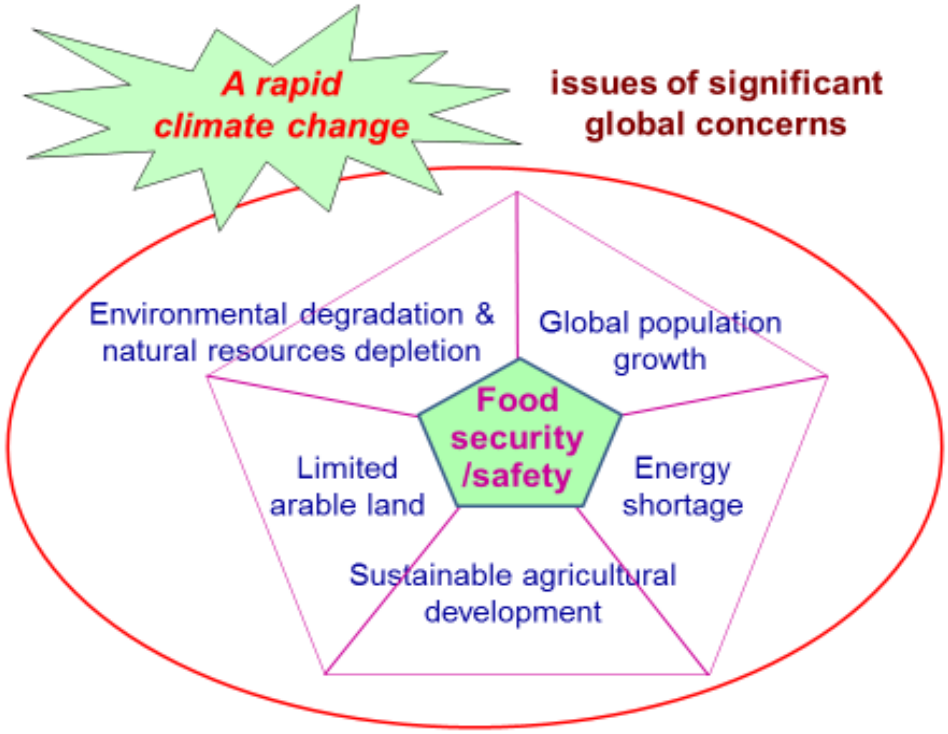

Fig. 1. Near-term challenges facing global agriculture.

In the face of such a complicated and difficult situation, global communities must seek solutions to challenges in a different way from the past. There should be a consistent endeavor to strengthen multidisciplinary and multi-sectoral collaboration and cooperation on issues related to climate change, with continued efforts to promote adaptive agricultural research and development and its sustainable management and to reduce GHG emissions (Yang and Yao 2018). Increasing fossil fuel energy use and emission of GHGs are now considered the major anthropogenic factors accelerating pace of warming climate.

CLIMATE CHANGE AND FOOD SECURITY

The majority of climate scientists agreed that a rapid climate change is real and can be felt. As declared by the Food and Agriculture Organization (FAO) of the UN, climate change will affect all four dimensions of food security: food availability, food accessibility, food utilization and food system stability (FAO 2008). As a result, it will impose profound impact on human health, livelihood, food production and marketing, etc. Risks to hunger and malnutrition will also be increased causing a serious threat to global food security. In terms of short-term impacts, it will result to more frequent extreme weather events, while long-term influences are mainly caused by the warming temperatures, irregular precipitation patterns, sea level rise and increased carbon dioxide (CO_2) emissions. Climate change and food security together have multiple interrelated risks and uncertainties to agriculture for societies and ecologies.

Uncertainty in climate forecasting and impacts

Unfortunately, on the basis of the latest scenarios of IPCC, air temperature will rise about 2–5°C by the late 21st century, depending on the region and emissions condition. Further, the diversified effects of changing climate are not only about temperature increase, but also through the induction of phenomena such as irregular precipitation patterns, weather extremes and sea level rise (Fig. 2). Comparing the temperature records in the period of 1880-2017, it is clear that the future temperature will develop in a hotter direction and the rate will increase (Table 1). Some facts are summarized and listed below:

- It is the 41th consecutive year that annual temperature above the 20th century average since 1977.
- All 17 years in the 21th century are among 18 warmest years on record (1998 is ninth).
- Seven warmest years have all occurred since 2010 and 4 warmest years have been last 4 years.
- Temperatures in 2015-2016 were majorly influenced by strong El Niño.
- Temperature increased 0.07℃ per decade since 1880 while 0.17℃ since 1970.
- The year 2017 was the third warmest year in the National Oceanic and Atmospheric Administration's 138-year series of weather record.

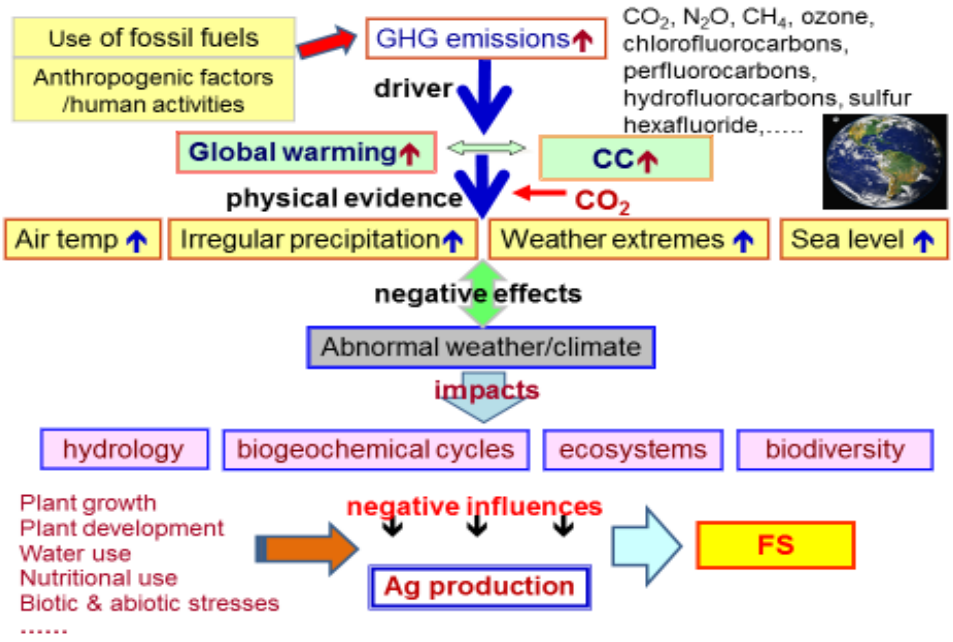

Fig. 2. The relationship between climate change (CC) and food security (FS).

Table 1. The global combined land and ocean annually-averaged temperature rank and anomaly (change from 20th century average) for each of the 10 warmest years on record (1880-2017)

Rank 1= warmest Period of record: 1880-2017	Year	Anomaly, ℃	Anomaly, ℉
1 (rank out of 138 years)	2016	0.94	1.69
2	2015	0.90	1.62
3	2017	0.84	1.33
4	2014	0.74	1.33
5	2010	0.70	1.26
6	2013	0.67	1.21
7	2005	0.66	1.19
8	2009	0.64	1.15
9	1998	0.63	1.13
10	2012	0.62	1.12

From NOAA State of the Climate, https://www.ncdc.noaa.gov/sotc/global/201613.

As to precipitation pattern changes, rainfall is increasing and the intensity is more concentrated, but the distribution is uneven (IPCC WGI AR5 Summary for Policy Makers and NOAA state of the Climate). In river

flow projection, it is projected a non-stationarity of river flows. The future is not like the past, less water in rivers in sub-tropical regions (Milly *et al.* 2008). The rise of sea level will also put food producing land at risk (Chang *et al.* 2012). Based on scenarios of RCP4.5, 6.0, and 8.5 of AR5, ocean acidification poses substantial risks to marine ecosystems, especially polar ecosystems and coral reefs. It will puts ocean based food at risk.

In recent years, weather extremes happen more frequently around the world. Some extreme weather events have been attributed to human-induced global warming and climate change. In Taiwan, for example, the erratic and unpredictable nature of the droughts and floods increased over the last decades and gave rise to huge agricultural and economic losses. Changes in the magnitude of rainfall and its distribution also caused significant agricultural hazards as well as affected the availability of water for crops production recently.

Multifaceted impacts and interventions

To those agriculture-based communities/societies that are already vulnerable to food insecurity, such as people living by the sea, low-lying areas, drylands, the Arctic and in mountains, it is likely to be the first affected. They may face immediate risk of increased crop failure, lack of appropriate crop and animal varieties, outbreaks of new species of pests, diseases and weeds, and yet, not ready for proper adaptive managements. This may also lead to shifting the levels of vulnerabilities of food systems in both developing and developed countries. In fact, agriculture, forestry and fisheries are all affected by climate change and contribute to food insecurity as a whole. It is necessary to strengthen the resilience capacity of all food production systems and the mitigation of the climate challenge (Yang and Yao 2018). Likewise, the implications for other components of the food supply chain deserve equal consideration and take a broader view to explore. What we like to emphasize is that impact of climate change on food security is not limited to a specific region, but global and comprehensive.

Evidence of climate change in Taiwan

As a member of global community and part of the ecological environment, Taiwan is also suffering from the impact of climate change and its influences on agricultural production. Temperature has increased by about 1.4°C over the past century. The number of total rainfall days has decreased yet it has more extreme rainfall events. Sea level has been rising 5.77 mm per year in the period of 1993-2003. In terms of seasonality, summer months become longer while shorter in winter and spring. Days of warm night have increased

but a decreasing trend in the occurrence of cold nights. There is no long-term trend in the number of typhoon, but decadal variation is significant, less frequent in 1950's and 1970-1990 (4.0 per year) and more frequent in 1960's and 2000-2010 (5.4 per year). The duration of typhoon is longer, with more heavy rainfall. The projected Impacts on agricultural productivity is substantial and variability in crop production is high.

Approaches of mitigation and adaptation

When it comes to tackling climate change to prevent the impacts on the different elements of the earth system, there are two main ways being applied: mitigation and adaptation (FAO 2008, IPCC 2014). Mitigation may refer to actions to reduce and curb GHG emissions, while adaptation refers to the process by which an organism or a system to reduce vulnerability to climate change. In other words, mitigation attends to the causes of climate change, yet adaptation addresses its impacts and adaptive methods.

Mitigating climate change

Major practices for mitigating climate change include reducing GHG emissions and sequestering or storing carbon in the short term and systematic curbing emissions of GHG from various aspects of agricultural production, practice energy efficiency and greater use of renewable energy over the long term. Although the entire food system is a source of GHG emissions, primary production is by far the most important component. Considering it should be the foremost solution, incentives are needed to encourage or persuade crop and livestock producers, agro-industries and ecosystem managers to adopt good practices for mitigating climate change.

Mitigation measures for agricultural sector

Mitigation measures for climate change are mainly to reduce GHG emissions, followed by carbon sequestration and storage. In an energy conservation and carbon reduction action plan, such as those considered by Taiwan' Council of Agriculture (Yang and Yao 2018), the following measures are suggested for planning:

- Establish GHG estimation, investigation and monitoring system;
- Improve rice farming techniques to reduce methane (CH_4) emissions;
- Ameliorate nitrogen fertilizer technology to reduce nitrous oxide (N_2O) emissions;
- Improve livestock management to reduce CH_4 emissions;

- Reduce the number of fishing vessels to reduce CO_2 emissions;
- Enhance soil carbon sequestration and storage;
- Increase energy crops cultivation and use of forest biomass to replace fossil fuels; and
- Strengthen tree planting and afforestation.

Managing climate risk through adaptation

Risk exists when there is uncertainty about the future outcomes of ongoing processes or about the occurrence of future events, especially under climate change scenario. Adaptation is about reducing and responding to the risks climate change poses to people's lives and livelihoods and ecosystems. Reducing uncertainty by improving the information base and devising innovative schemes for securing against climate change hazards will both be important for successful adaptation. Adaptive management can be a particularly valuable tool for devising strategies and measures that respond to the unique risks to which different ecosystems and livelihood groups are exposed. It is also the primary practice that can directly bring benefits to farmers.

Adaptation measures for agricultural production

In terms of adaptation measures, many actions have been developed to help reducing vulnerability and enhancing resilience to the consequences of climate change. Some feasible and effective measures that have been adopted in Taiwan are listed as follows:

- Flexible and diverse crops cultivation for climate disasters;
- Variety improvement to increase the resistance/tolerance to abiotic and biotic stresses;
- Research and development of adaptive practices on possible adverse effects;
- Preparation of preventive and precautionary mechanism to climate and production risks;
- Use of protected cultivation for vulnerable crops; and
- Efficient use of resources by applications of water-conserving, energy-saving and carbon-reduction technologies.

Strengthening resilience

To increase climate resilience of vulnerable farmers, it is always including their livelihoods and agro-ecosystems against the impacts of climate variability. Generally strengthening resilience involves adopting practices

that enable vulnerable smallholders to protect existing livelihood systems, diversify their sources of income, change their livelihood strategies or migrate, if this is the best option. Changing consumption patterns and food preparation practices, including food loss and waste reduction, are important to protect food security in many circumstances. Safeguarding food security in the face of climate change also implies avoiding the disruptions or declines in global and local food supplies that could result from changes in temperature and precipitation regimes and new patterns of pests, diseases and weeds.

Most of all, raised productivity from improved agricultural management is crucial to ensure food supply and food security both domestically and globally, and sustainable management practices to food production systems for adaptation and associated mitigation should be given high priority (Yang and Yao 2018). Conservation agriculture (CA), which widely adopted in the developing countries, is an alternative choice of food production system that can make a significant difference to efficiency of water use, soil quality, capacity to withstand extreme events, and carbon sequestration. Although with lower-yielding production, practices of CA to promote agrobiodiversity, soil health and effective use of natural resources are important for local adaptation and resilience that in turn can sustain long term crop productivity. In addition, the climate-smart agricultural operation mode, which has received widespread attention recently, also takes into account the considerations and functions of adaptation and mitigation.

2017 Taiwan's national action guidelines for mitigation and adaptation

Taiwan revised its implementation guidelines for mitigation and adaptation to cope with climate change in 2017. The summary is as the followings:

Agriculture mitigation

- Implement eco-friendly agricultural cultivation to stabilize agricultural production
- Promote low-carbon agriculture, improve agricultural resource recycling
- Strengthen forest resource management; raise the net quantity of national carbon sinks

Agriculture adaptation

- Safeguard resources for agricultural production

- Strengthen the monitoring and early warning system
- Reinforce government subsidies and insurance system
- Integrate technology to improve the capacity for climate resilience in agriculture, forestry, fishery and animal husbandry
- Ensure food security
- Build sustainable agriculture that is adaptive to climate risks

Additionally, policy challenges have also been taken into consideration. Since exact nature of effects and effectiveness of adaptation and mitigation are uncertain, issue on 'most effects in future but much of mitigation and adaptation, costs now' was vigorously discussed. It has been agreed that the grand challenge today is how much to invest now in mitigation and adaptation in interest to future parties at likely cost of current.

CLIMATE-SMART AGRICULTURE

According to FAO, climate-smart agriculture (CSA) is an approach that helps to guide actions needed to transform and reorient agricultural systems to effectively support development and ensure food security in a changing climate (FAO 2018, http://www.fao.org/climate-smart-agriculture/en/, visited on 09/15/2018). Its aims are to tackle three main objectives: (1) sustainably increasing agricultural productivity and incomes, (2) adapting and building resilience to climate change, and (3) reducing and/or removing GHG emissions, where possible. In other words, CSA is not only an approach for developing agricultural strategies to secure sustainable food security under climate change, but also a way providing the means to help stakeholders from local to national and international levels identify agricultural strategies suitable to their local conditions. Its context can be summarized in Fig. 3.

Practices for CSA

From the aforementioned description of CSA, this comprehensive approach aims to guide the agricultural production system to adapt to the climate change scenarios. Therefore, any practice or method that can maintain proper agricultural production under the changing climate can meet this definition. Here we recommend six measures with various practices that can be adapted to fit for specific conditions, as that are being applied in Taiwan.

1. Adjust breeding and planting practices

- Enhance the breeding work for biotic and abiotic stress resistance and/or tolerance to the new environment and variations in pest sources brought about by climate change

- Cultivate a diverse suite of crop species and varieties and adjust cultivation locations with corresponding planting and harvesting day
- Change of farming system, including rotation, mixed farming of trees and non-tree crops and others, to new farming conditions

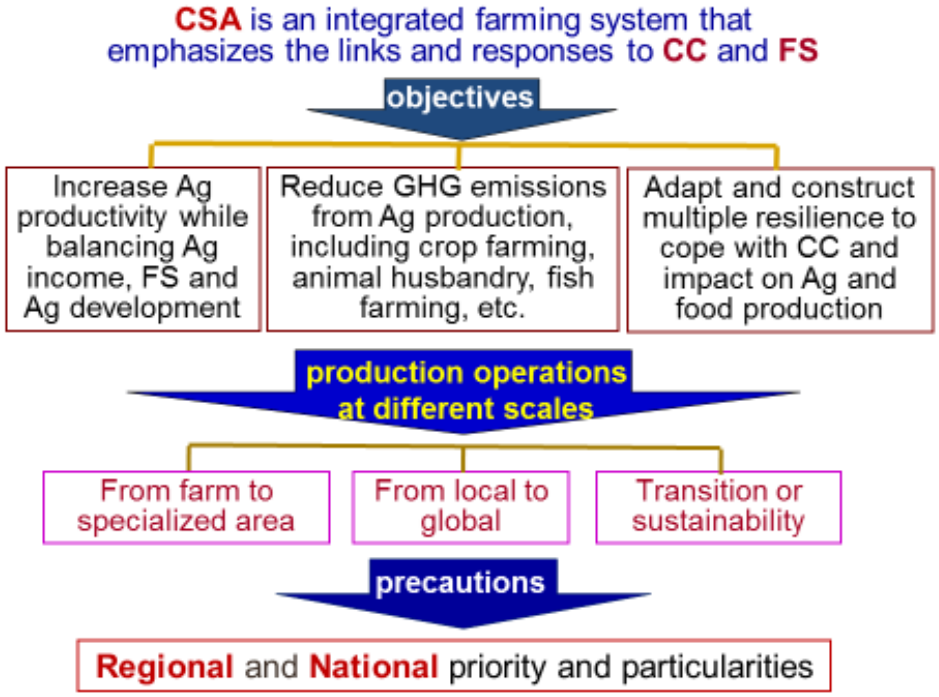

Fig. 3. The objectives and context of climate-smart agriculture (CSA). CC: climate change. FS: food security.

2. Improve cultivation techniques and risk management

- Improve water and fertilizer use efficiency and unit water and fertilizer productivity
- Reduce energy input and improve GHG emissions
- Strengthen forecasting and early warning capabilities to reduce production risks

3. Alternate management to changes of pests, diseases and weeds

- Explore the changes in diseases, insects and weeds caused by climate change and develop collective management methods to reduce their harmful effects
- Adapt to changes in local pests, diseases and weeds caused by climate change, changing cultivated crops and their cultivation methods

4. Improve water use and management

- Strengthen the development, utilization and management of water sources to reduce risks of flood and drought
- Select drought-tolerant varieties and adopt water-saving cultivation for areas with shortage of irrigation water sources

5. Improve farmers' ability to adjust to climate change

- Training of growers/farmers to adapt to climate change and the corresponding methods of adaptation to maintain agricultural production
- Rewarding non-essential energy consumptions that help reduce GHG emissions

6. Adjust agricultural food policy and its dissemination

- Improve food self-sufficiency rate to maintain food security
- Publicize the importance of local production and local consumption
- Support the government's various food and agriculture policy

Practically, CSA approach can be combined with a variety of practices, mixing with adaptive and mitigation means of solutions. In any case, it is important that such an approach maintains proper agricultural production under climate change and in aid of ensuring food security.

CONCLUDING REMARKS— THE WAY FORWARD

Agriculture is a bio-based industry which people rely on living and hence, has to meet the challenge of increasing food production on land already in use for the growing of global population, especially under the current climate change scenario. Climate change has multidimensional implications and will be a continuous process for a long period of time. Food production is at risk in many places, and production is shifting and will shift more. Extremes are of concern and responses to vulnerability and resilience should be identified, planned and implemented. Adopting CSA approach is one way of helping the agriculture sector to develop climate-resilience strategies to secure sustainable food production under climate change.

In the food and agriculture sector, adaptation and mitigation are often side by side of each other so that adopting an integrated strategic approach act for the 'smart way' solutions is strongly encouraged. Both public and private investments on activities aiming at reducing GHG emission and increasing resilience and adaptability to the negative impacts of climate change are necessary. Many mitigation actions, as well as adaptation

practices, have high payoffs within the food and agriculture sectors of low-income developing countries in the Asia-Pacific Region and is worth developing and promoting, especially those adaptive mechanisms that directly benefit farmers. It may also be possible to apply additional resources from regional and international aid agencies, which are becoming increasingly interested in investing applicable resources in adaptive responses to climate change influences.

One important activity of climate change work for a country or regional and international organization is to build a platform or network to promote local or multi-lateral dialogue. Key items, such as what the impacts of climate change are likely to be and what options exist for reducing vulnerability and enhancing resilience, are of important concerns. Moreover, international cooperation is a work that is worthy of long-term promotion and implementation by each country. It can help solve cross-regional issues through bilateral or multilateral experience exchange, collaborative research and joint projects. As such, it would provide local, regional or international communities with site-specific or suitable solutions.

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