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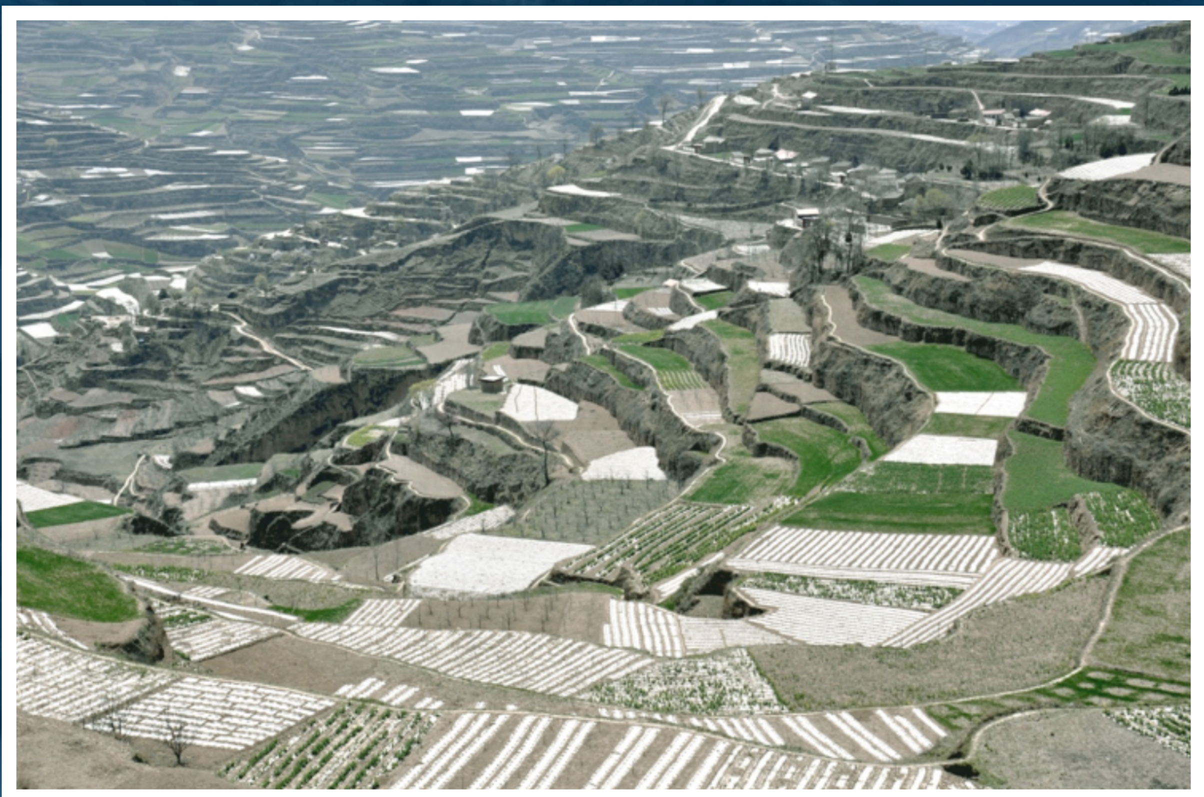
People's Republic of China

Economics of Adaptation to Climate Change in Water and Agriculture Sectors

Executive Summary



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Executive Summary

Scientific evidence increasingly indicates that the earth's climate is undergoing significant change characterized by global warming. *A recent analysis by the World Meteorological Organization finds that the radiative forcing by long-lived greenhouse gases increased by 30 percent from 1990 to 2011, with carbon dioxide accounting for roughly 80 percent of this increase. The current emission trajectory is rising faster than the most pessimistic emission scenarios envisioned in the Fourth Assessment Report of the United Nations Intergovernmental Panel on Climate Change (IPCC AR4) in 2007. Despite uncertainties, it is increasingly plausible that this has put the world on a 4°C average warming path within the twenty-first century.*

Climate change in China is already evident with particular regional patterns. Similar to the global trend, China experienced noticeable warming, with the average annual temperature rising by 0.5°C to 0.8°C during the twentieth century, and most of the temperature increase occurring in the past 50 years. Furthermore, dry areas in northern China are warming faster than wet areas in southern China. By 2050, China's temperature is expected to increase by another 2.5^{o}C to 4.6^{o}C. Rainfall patterns are also changing. Annual precipitation in northern China's five main river basins declined by 50 mm to 120 mm between 1950 and 2000. However, during the same period, the water-rich basins in southeast China saw an increase in annual precipitation ranging from 60 mm to 130 mm.

Regionally different effects on hydrologic cycles, with significant impacts on a rapidly growing human population and ecosystems are expected, even over near- to midterm time horizons. Now is the time to devise comprehensive adaptation strategies for vulnerable societies, especially for the climate-sensitive agricultural sector in regions at risk. China is one of these places for which an assessment study on climate change impacts, extremes, and household adaptation provides an empirical basis through which the nation can develop adaptation policies and implementation plans.

STUDY OBJECTIVES AND APPROACH

The overarching goal of this report is to examine the impacts of climate change on water and agricultural sectors so as to identify best possible adaptation options. It accomplishes this first by assessing China's vulnerability to climate change, then synthesizing a number of empirical assessments under one conceptual framework to identify *pathways toward climate resilience*, and lastly identifying recommended adaptation strategies.

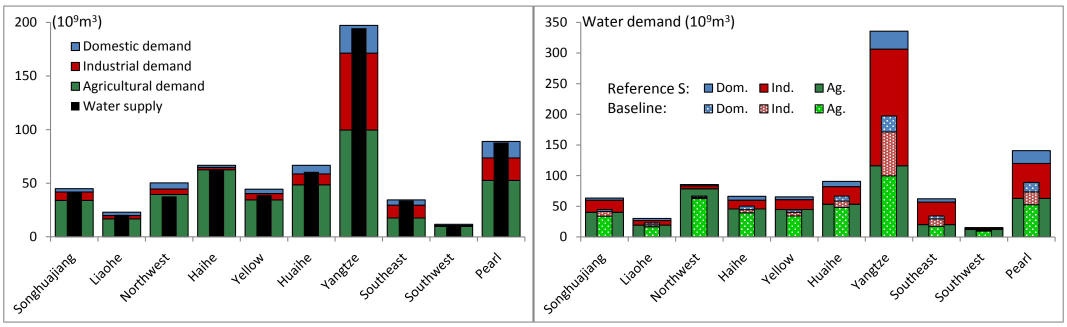
This assessment is motivated by the Chinese government's recent escalation of water resources management and climate change to the top of the nation's policy priorities. In the recent *National Integrated Water Resources Plan 2010 - 2030*, the government formulated strict water resources management guidelines for the 2010–2030 period to address its growing water resources problems. Key targets for water management include (a) limiting water use at or below 700 km^3 per year across the nation, (b) increasing agricultural water-use efficiency by 20 percent or more and decreasing industrial water use per unit of net value by 67 percent, and (c) limiting wastewater discharges to the self-purification capacity levels of water bodies. Several high-level climate change plans have also recently been released.

An additional motivation is the limited evidence base regarding future impacts from climate trends and extremes, as well as limited understanding of the effectiveness of different adaptation measures to climate change for China. An integrated framework is used to investigate macro (sectoral) and micro (farmers and consumers) responses to changes in climate in conjunction with natural and socio-economic system dynamics in this report. This report assesses projected climate change impacts and adaptation options for the near term until 2030, when population figures are expected to peak.

A reference socioeconomic scenario is defined in order to assess the impact of climate change on water and agricultural sectors amidst the nation's current development path. The reference socioeconomic scenario include the use of socio-economic parameters from literature review that are expected to govern growth in water and agriculture sector over the medium term (i.e., population and gross domestic product growth rates, agricultural productivity, water-use efficiency in all sectors, the increase in irrigation coverage, urbanization rates, and water use) for each of the ten main river basins. The socioeconomic scenario allows for the exploration of future trends in water and agriculture sector with or without climate-induced change.

Water use condition assumptions are important to understanding the reference scenario. It is assumed that in absence of the climate change water supply under the reference scenario will remain the same as during the baseline years (2006–2010). At the same time, it is assumed that water demand is increasing according to the drivers of this scenario. Figure A shows the development of water demand under the reference scenario. Under the reference scenario, water demand increases dramatically, regardless of changes in the climate. In other words, the formulation of the reference scenario does not account for shocks from climate change to allow for a comparison of the development trajectory to be affected by climate change.

Figure A: Water supply and demand and sectoral demand values



Note: Water demand and supply in the baseline period (2006–2010) are shown in the left plate. Sectoral demand values for the reference scenario in 2026–2030 are shown in the right plate. Note that water supply is assumed constant.
Sources: Wang et al. 2012a and authors

Three IPCC AR4 emission scenarios (A1B, A2, and B2)[1] were used for the study of precipitation and temperature trends and their implications on China's water security and agricultural economy until 2030. A high-resolution structural and agricultural exposure set was developed to assess the impacts of extreme weather conditions (i.e., with more focus on cyclone given the significant flood and storm surge induced damages) with the purpose of supporting planning and risk mitigation decision making. Exploration of the impact of climate change on the extreme attributes of temperature and precipitation patterns is also assessed. In this type of modeling exercise, uncertainties must be acknowledged. Retrospective analyses indicate that the selected model is the most appropriate in terms of its ability to capture long term climate features over China. Therefore, the most plausible model has been selected to guide the assessment of climate change impact on different sectors. Building an integrated modeling framework that incorporates the micro, meso, and macro scale aspects of adaptation is critical to inform options to build resiliency in the face of uncertainty. Climate models are continuously improving and adapting to adjust for improved scientific understanding and new data and information. The proposed modeling framework lends itself to provide the evidence to underpin policy formulation as it captures the sectoral and scale linkages and it allows for deeper analysis of the tradeoff and uncertainty using different global or regional circulation models.

CHINA'S VULNERABILITY TO CLIMATE CHANGE

Due to high exposure, limits on adaptive capacity, and limitless competing pressures – on households, communities and the central government – China remains vulnerable to climate related impacts. In the water resources sector, acute water scarcity in the north, the pressures of urbanization and its dire water quality problems are among challenges noted in a series of water-related planning and policy documents released since 2010. In the agricultural realm, loss of arable land, low technological levels and the small plot nature of China's farms present challenges for coping with weather shocks and extremes. Although China has long coped with the impacts of flooding, the physical nature of flooding hitting China appears to be changing. A recent study shows that trends in extreme precipitation have been distorted by western North Pacific typhoons which bring rainfall with decreasing frequency and increasing intensity over the Eastern Asian Monsoon region.

China's physical characteristics alone make it highly vulnerable to weather-related extremes. There are 22,909 of the nation's rivers with a catchment area of more than 100 km^2, while 2,221 have areas exceeding 1,000 km^2 . Uneven seasonal and spatial distribution of precipitation results in the regular occurrences of floods, while droughts are also common, especially in China's arid north. Its southern coastline sits in the direct line of the northern Pacific typhoon system compounding its physical complexity through a number of socioeconomic factors. Currently 1.35

[1] A1B represents reliance on a balanced set of energy sources (i.e. fossil fuels, wind solar). It assumes that similar progress is made for all energy supply and end-use technologies. A2 represents medium-to-high emissions, and B2 represents low-to-medium emissions. From the aspect of socioeconomic objectives, the A1B scenario can be treated as the optimistic scenario with the highest income growth, while the A2 scenario is the pessimistic scenario with the lowest income growth. The B2 scenario has a middle level of income growth, ranging between A1B and A2.

billion people live in the country, a number which is expected to grow by an additional 4 percent by 2030, around which time the population will peak.

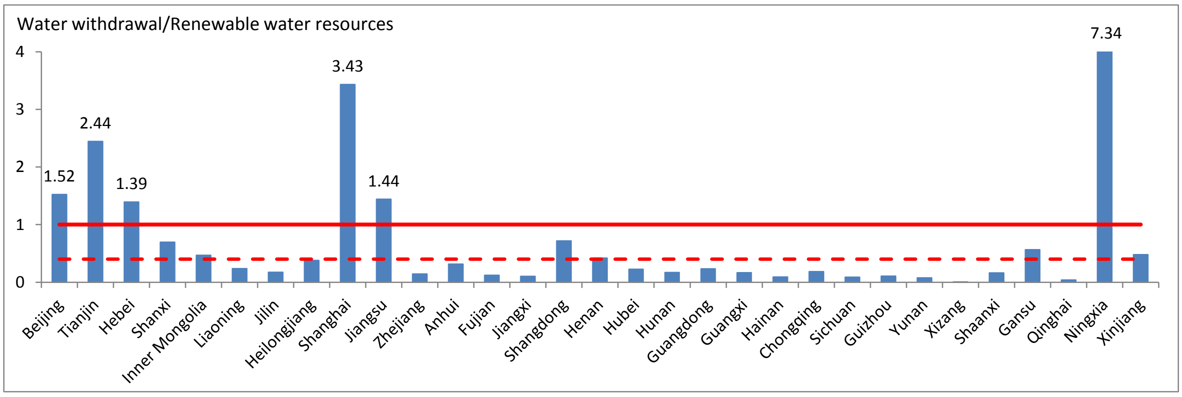
While China's territory extends over an area of 9.6 million km^2, accounting for about one-fifteenth of the global land surface area, only 15 percent of its territory is arable. Given complex and diverse physical and socioeconomic conditions, increases in climate variability and intensity pose significant water resources management challenges, with profound implications for the nation's agricultural sector and food security future.

CLIMATE TREND IMPACTS ON CHINA'S WATER SECURITY 2030

China's status quo water situation in the north is already serious. Water scarcity is most severe in provinces and municipalities located in the northern Huang Huai He (3H) river basin region. In 2010, twelve provinces/municipalities out of 32 in China had severe water stress, as shown in Figure B. Seven of these provinces/municipalities (including Beijing, Tianjin, and Shanghai) had significantly elevated stress indices. These places are either mining groundwater or benefiting from water transfers from other provinces and river basins to meet their water demand (e.g., water transfer from Hebei to Beijing and from the Yellow River to the Hai River).

Southern China, including the Yangtze, Southeastern, Southwestern as well as Pearl River basins, contains more than 80 percent of the nation's total renewable water resources. Despite the apparent abundance of water resources in the south, the hilly landscape leaves very little land suitable for agriculture. Also, there are more people living in the south (i.e., 53.6 percent of the total population), where industry plays a major role and where, on average, 56 percent of GDP is generated. Thus, and the arable land there makes up less than 35 percent of the country's total.

Figure B: Water stress index (water withdrawal/availability ratio) of all provinces in China for 2010.

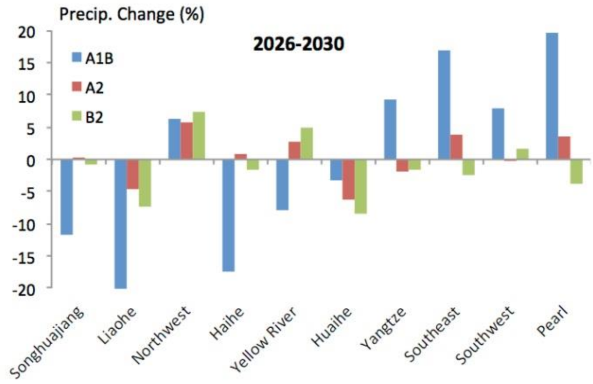


Note: Twelve provinces have severe water stress with an index higher than 0.4 (indicated by the red dotted line)
Source: Wang et al. 2012a and authors

Climate impacts on water resources in 10 river basins

Looking at climate impacts on bio-physical water resource conditions over the medium term, Integrated Assessment Model (IAM) results for China's ten main river basins suggest that projected temperatures are increasing as a function of the emission scenarios over the whole of mainland China. Expected warming by 2030 will be most pronounced between December and May in the northern parts of China. Scenario analysis also suggests regionally specific impacts of climate change on precipitation. Under the A1B scenario, which at this point in time most closely resembles China's emissions trajectory, southern basins will get wetter and the northern basins get drier, on average (see Figure C).

Figure C: Mean annual precipitation changes (percent) in the 2026–2030 period for 10 river basins



Source: Y. Xu et al. 2006; H. Yang et al. 2010; G. Wang 2012, and authors

Changes in river runoff due to joint temperature and precipitation shifts will seriously impact China's water resources and agricultural water use availability. Results suggest that due to climate change, river runoff is expected to decline by 10 percent in the northern basins and increase by almost the same amount in the southern basins, including the Yangtze, Southeast, Southwest, and Pearl Rivers. Such a change will further accentuate the imbalance between water and arable land resources in China over the near term. Such a balance between land and water resources has serious implications for regional food security and sectoral and regional competition over water resources. The impacts of climate change on annual runoff in four river basins raise particular concern.

- **Songhua River Basin:** Annual runoff is projected to present a decreasing trend under the B2 and A1B scenarios, with higher decrease occurring in June–August.
- **Liao River Basin:** Annual runoff is projected to have a decreasing trend for the A1B scenario, with higher decrease occurring in June–August and September–November.
- **Hai River Basin:** Annual runoff is projected to present a decreasing trend for the entire period of 2011–2030 under the A1B and B2 scenarios, with higher decrease occurring in June–August.
- **Yellow River Basin:** Annual runoff is projected to have a decreasing trend under both the A2 and A1B scenarios, with higher decrease occurring in June–August

The demand – supply gap

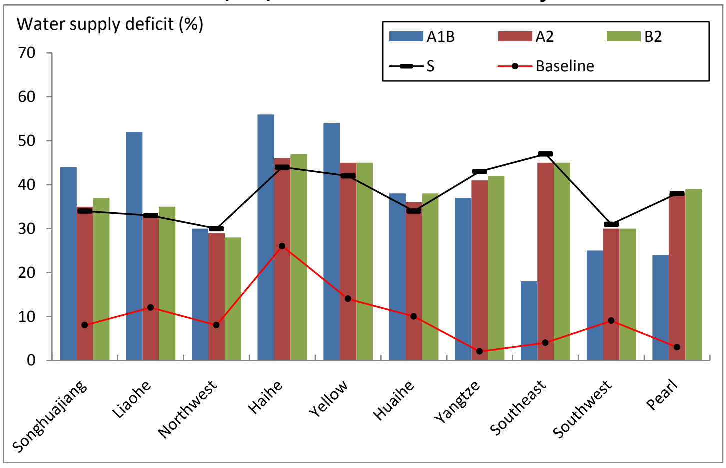
Climate change will also affect water supply levels in each river basin, which must be balanced with demand to avoid economic and livelihood disruption. Increasing demand for water in

China's arid regions is placing pressure on the government and water users to increase water efficiency in order to avoid disruptions to industrial or agricultural production.

Based on model predictions, the northern basins, except for the Northwest River and Huai River basins, are expected to face slight reductions in water supply under all three emissions scenarios, while the southern basins will have slightly higher supplies. All supply changes are expected to be small, except under the A1B scenario, which predicts large-amplitude decreases in the north and increases in the south.

These findings translate into important consequences in terms of water deficiency in the individual river basins. All of China's major river basins already suffer from a positive water gap (that is the difference between demand and supply volumes as shown in the red line in Figure D). Between 2006 and 2010, the water gap comprised 8 percent of the nation's total water demand. In the Hai River basin, this gap approaches 30 percent. By 2030, the current water supply system will only be able to satisfy 88% of water demand on average, even without climate change. For the northern basins, climate change will greatly increase water gaps under the A1B scenario and thus exacerbate the region's already water-stressed situation.

Figure D: Comparison of water supply deficits (water gaps) of each river basin under climate scenarios A1B, A2, and B2 and water use reference scenarios



Source: Y. Xu et al. 2006; H. Yang et al. 2010, and authors

Notes: Water use reference scenario (S) assumes present day climate in 2030; baseline is 2010 actual gap.

At a national level, compared with demand from the reference scenario socio-economic demand drivers (i.e., population, agricultural development, urbanization), the overall sensitivity of agricultural water demand to climate change is small, amounting to between 0.7 and 1.6 percent of the total agricultural demand for water. However, China's most water vulnerable north and northeast exhibit an exception to the sensitivity of agricultural water demand to climate change. The North China Plain may see agricultural water demand increase by as much as 8 to 14 percent due to rising temperatures and drier conditions in those particular regions. Overall, China's rapid pace of development is pushing the nation to its limits in terms of land and water resources. Therefore key climate impacted regions, such as the North China Plain, are highly vulnerable to shocks. An 8 percent increase in demand due to climate change will have a profound impact on a region living close to its water availability margin.

CLIMATE TREND IMPACTS ON CHINA'S ECONOMY 2030

China is a large nation with distinct agricultural regions for growing its main crops of rice, wheat, and maize. Rice is mainly produced in the southern provinces, while wheat and maize are mainly produced in the north. China's water resources are situated far from the bulk of its arable land. More than 80 percent of the nation's total runoff is generated in Southern China, including the Yangtze River basin, yet only one-third of the total arable land area is located in the south.

Two-thirds of the nation's total water withdrawals for supply (approximately 621 km^3 per year with 80 percent from surface and 20 percent from groundwater) go to agriculture, but only 45 percent of this is actively used in production—a low portion by global standards. While crop yields compare favorably with world averages, low crop-per-drop efficiency results in unsatisfactory water productivity in the agricultural sector (3.6 USD per m^3 compared to, e.g., 35.8 USD per m^3 in the United States). Despite limitations on the nation's arable land area, China's grain productivity levels have greatly exceeded population growth rates over the past 60 years. Total grain production increased four times between 1949 and 2009, while the harvested area grew by 38 percent over this time period.

Climate impacts on agriculture manifest themselves in a number of different ways. One way is through direct impacts on biophysical conditions, such as precipitation, runoff, and temperature, and associated crop yield changes. Based upon these direct impacts, systemic adjustments by producers and consumers, such as cropping choices and market –based purchase behavior, respectively, make up a set of indirect impacts. The following findings account for both indirect and direct impacts used in the IAM framework.

Irrigated area

Simulation results show that for those river basins where climate change results in greater water shortages, irrigated land area will fall, while rainfed areas will rise. Agricultural water shortages in five river basins in the north (Liao, Songhua, Hai, Huai and Yellow river basins) will become more serious in 2030 under the A1B scenario. Due to increasing water shortages, the total irrigated area in these river basins will decrease. For example, in the Liao River basin, compared with the reference scenario, the total irrigated area will decrease by 4.45 percent in 2030.

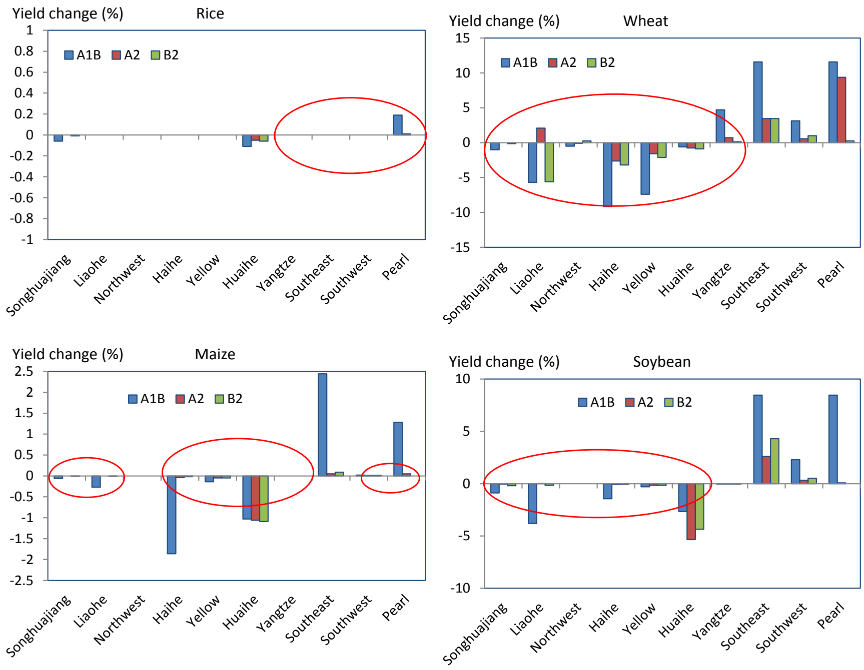
Agricultural water supply and demand gaps will decrease in the Yangtze, Pearl, Southeast, Southwest, and Northwest river basins in 2030. When this occurs, crop irrigated areas in these river basins will increase slightly, while rainfed areas will fall accordingly. A similar trend occurs in the Southeast and Southwest river basins. It was noted that the shift in Yangtze and Northwest Rivers will be towards cultivating crops with high water needs to maximize the net agriculture production rather than expanding irrigated areas. The results show that is more likely that irrigated area decreases slightly even as the agricultural water supply increases in these two river basins due to shift in cropping patterns.

Average crop yield

Results from the IAM show that direct impacts of climate change on grain yields significantly contribute to overall production changes for four out of the reported five crops, including rice, wheat, maize, and other coarse grains. Rice and maize yields decline, while wheat yield results vary between models. Soybeans are over-proportionally impacted by indirect impacts such as rising demand for animal feed-stock. As such, the self-sufficiency level of soybeans is expected to drop remarkably to 17.7 percent in 2030.

When a crop's irrigated area decreases, its average yield also declines due to lower productivity in the rainfed areas. For example, in the Liao River basin under A1B scenario, since wheat irrigated areas will decrease by 40 percent and rainfed areas increase by 80 percent in 2030, the average wheat yield will decrease by 5.69 percent (see Figure E, upper right panel). Similar stories are revealed in those river basins (Songhua, Hai, Huai and Yellow river basins) where crop irrigated areas will decrease and rainfed areas will increase. By contrast, where climate change results in the increase of crop irrigated areas due to the increase of water availability (such as in select southern basins), average crop yields will increase.

Figure E: Crop yield changes in different river basins due to indirect climate impact through water supply



Source: Y. Xu et al. 2006; H. Yang et al. 2010, and authors
Note: The red circles indicate the main planting areas of each crop.

The agricultural sector

The prices of the crops with decreased production will rise significantly. The price of rice, wheat, and maize will be higher by 10.3, 5.3, and 3.1 percent, respectively, in 2030, relative to the reference scenario under scenario A1B (refer to Table A for details). Although the prices will increase less as these crops have smaller yield reductions, the prices of rice and maize still be higher by 3.8 and 1.8 percent, respectively, in the A2 scenario, and by 4.7 and 2.0 percent, respectively, in the B2 scenario.

Table A: Delta changes through direct and direct plus indirect impacts on the agricultural economy.

	Reference	Δ change from direct impacts [%]			Δ change from direct+indirect impacts [%]		
PRODUCTION	**[mil. tons]**	**A1B**	**A2**	**B2**	**A1B**	**A2**	**B2**
Rice	116.8	-3.13	-1.35	-1.65	-2.66	-1.03	-1.08
Wheat	101.1	-1.07	0.33	0.55	-1.24	0.26	0.45
Maize	240.4	-2.58	-1.50	-1.61	-2.75	-1.78	-1.87
Soybean	18.20	-1.33	-0.47	-0.47	-5.84	-3.37	-4.95
Other coarse grain	55.10	-0.28	-0.14	-0.14	-0.29	-0.15	-0.16
MARKET PRICE							
Rice		10.27	3.84	4.65	8.82	2.93	3.01
Wheat		5.32	-0.14	-0.59	5.52	-0.15	-0.66
Maize		3.09	1.82	1.95	3.27	2.13	2.24
Soybean		0.16	0.06	0.06	0.43	0.22	0.34
Other coarse grain		1.07	0.36	0.39	1.03	0.35	0.34
SELF SUFFICIENCY	**[%]**						
Rice	101.4	-0.3	-0.1	-0.1	-0.3	-0.1	-0.1
Wheat	99.9	-0.1	0.0	0.0	-0.1	0.0	0.0
Maize	89.1	-2.1	-1.2	-1.3	-2.2	-1.4	-1.5
Soybean	17.7	-0.3	0.1	-0.1	-1.0	-0.6	-0.8
Other coarse grain	81.5	-1.0	0.5	-0.5	-1.1	-0.6	-0.7

Source: Wang et al. 2012a and authors

Notes: Results for agricultural production, market prices, and levels of self-sufficiency are in percentages, relative to the corresponding reference values. Colors denote magnitude of simulated changes (red: negative, blue: positive).

Due to declines in agricultural output and price changes induced by climate change, China will import more agricultural commodities and export less to the global market. Under the A1B scenario, the export of rice, wheat, and maize will decrease by 19.4, 10.8, and 6.5 percent, respectively. On the other hand, their import will rise remarkably by 24.0, 12.1, and 18.2 percent, respectively.

Grain self sufficiency

Driven by high economic growth, the comparative advantage of some of China's agricultural commodities will erode gradually. China will depend on global markets to meet its fast-growth demand for maize and soybeans. In addition, due to climate change, the self-sufficiency level of grain crops will decline slightly (see Table A for details). Climate change will further challenge the nation's declining self-sufficiency levels, which will decrease in all climate scenarios. It will be reduced to 80.0 percent under the most extreme (A1B) scenario.

A Computable General Equilibrium model (CGE) is used to analyze the implication of the shock induced by climate change on allied economic sectors. Changes in one of the sectors is propagated through the rest of the economy as a ripple effect through their impact on patterns of trade, income, consumption, fiscal/financial accounts, prices and growth. A comprehensive CGE analysis would have required climate impact projections for all agricultural and non-agricultural products. Under the current approach, the partial CGE model seeks to explore the ramification of the changes in the agriculture sector on the overall economy. The modeling under A1B scenario suggests a loss of ½ percentage point (ppt) in the real GDP and an increase in the CPI by 0.12 ppt in China.

CHANGING EXTREMES 2030—IMPACTS AND IMPLICATIONS

It is not possible to discuss the impact of climate change on China without discussing the potential damage to regions, cities, and communities from extreme events. Of the world's deadliest natural disasters in the past 50 years, five occurred in China. In the summer of 2012, three typhoons struck eastern China within one week; the largest, Typhoon Haikui, forced the evacuation of more than 465,000 people in Zhejiang and Shanghai. Typhoons mainly strike the southern provinces, particularly in Guangdong, where about 50 percent of land-falling typhoons strike. Taiwan and Fujian account for 20 percent and 15 percent, respectively. Though the risk decreases heading north, large cities like Shanghai remain under a significant hazard.

Extreme precipitation and temperature

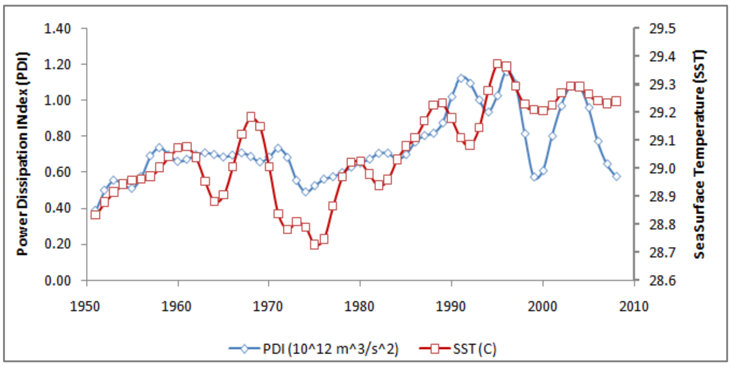
Using Representative Concentration Pathway (RCP) of radiative forcing of 4.5W/m^2 RCP54.5 (i.e., the new IPCC scenario of greenhouse concentration trajectory) the projections of climate change suggest, with high confidence, that maximum and minimum temperatures are increasing in particular regions with a corresponding rise in more frequent, longer, and more intense dry spells. These developments will impact crop yields through added temperature stress, especially at night, when minimum temperatures no longer fall below critical thresholds that are required for optimal plant growth. Added evaporative requirements for crops will contribute to water stress which is likely to become critical in regions such as the North Plain where buffer supplies from groundwater have been depleted.

Slight increases are projected in the number of days with extreme precipitation, while temperature analysis indicates increases in minimum and maximum temperatures. An increase in the number of growing degree days will directly impact crop patterns and growing seasons in key agricultural areas. Overall, results indicate that China is highly vulnerable to the adverse effects of extreme temperature and precipitation.

Changes in typhoons and potential for flooding and storm surge

While the damage associated with typhoons in China is already substantial and underscores the need for adaptive measures to mitigate the impact of these rare and extreme catastrophic events, preliminary evidence suggests that the intensity of typhoons and their ability to cause widespread flooding will only increase in the future as a result of climate change. Figure F shows the strong link between the Power Dissipation Index which is a measure of a typhoon's destruction capacity, and sea surface temperatures (SST) over the main development region for typhoons. This suggests that with rising SSTs, cyclones destructive capacity will increase.

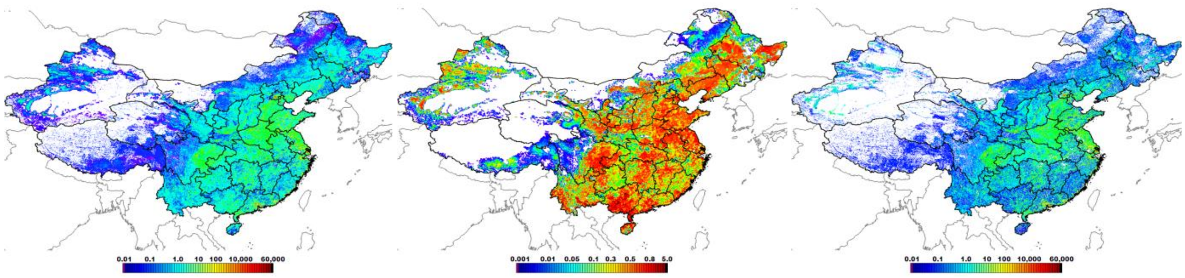
Figure F: Sea surface temperature and power dissipation index near China's coast



Notes: Tropical–North Pacific SST over the period of July to November and 1N-15 N to 160E-150W, versus smoothed total PDI; RCP 4.5 used for analysis.
Source: Authors' calculations.

Changes in typhoons and associated financial losses were assessed (see Figure G). Results suggest an increase in losses due to typhoon wind in the critical coastal provinces (Fujian, Zhejiang, Guangdong) under the climate change scenario A1B. Models agree that in the long term (2081 to 2100), Guangdong will experience more typhoon occurrences. Further analyses show stability in the extremes in Fujian, decrease in extreme typhoon winds in Guangdong, and a slight increase in extremes in Hainan and Zhenjiang. Financial loss analysis projects financial losses in the long-term due to wind damage in Guangdong Province, amounting to up to RMB 2 billion annually given the current exposure levels. As southern China is the hub of the nation's industrial and seaport economy, fortifying logistics centers, ports, and industrial parks against wind and flood exposure will increase the region's resiliency to such events.

Figure G: Structural exposure (left plate), agricultural exposure (center plate), and summed exposure (right plate). Colors encode grid cell values in million RMB.



Note: the different color scaling of the individual plates.
Source: Authors' calculations.

MICRO- AND MACRO-ADAPTATION ASSESSMENTS

Climate adaptation at multiple scales—households, communities, and government—are all critical for China due to its large population and exposure to many forms of climate change impacts. This study examines two distinct sets of adaptation measures, in a number of different ways. First, micro-scale adaptation strategies are assessed by looking at smallholder farmer- and community-level climate change coping strategies to date. Next, an economic comparison is presented of two national-level water resource climate change adaptation strategies currently in development in China, supply- and demand-side management strategies.

The supply-side strategy includes a number of interbasin transfer projects while the demand-side management strategy is a national scale agricultural water-use conservation policy. The two strategies are presented and analyzed using the IAM framework discussed above. Micro and macro strategies are evaluated separately.

Micro-assessment: Existing small-plot holder adaptation strategies

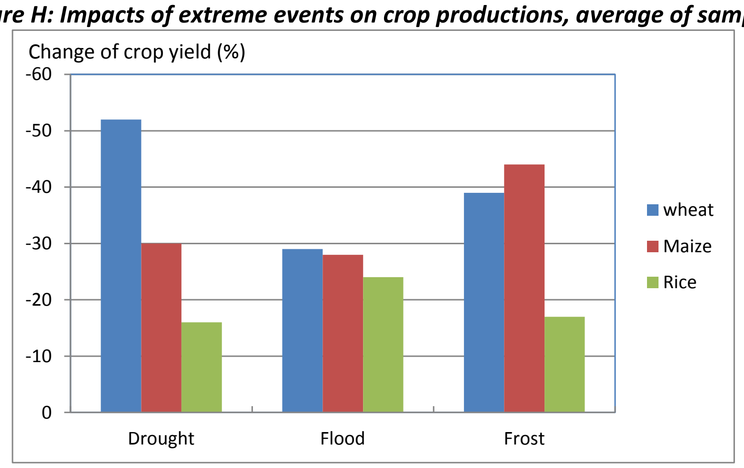
Farmers are important decision makers in the adoption of adaptation practices at the field level. Therefore it is crucial to understand their decision-making process and how they adapt to climate variability, in order to advance agriculture and economic development planning to protect the livelihood of rural households in the face of increased climate risks. Results from two recent large-scale household surveys across 10 provinces were used to better understand current agricultural adaptation strategies and their coverage and effectiveness in China.

Farmers' Perceptions of Climate Change and Weather Impacts

Results indicate that rising temperatures and more frequent droughts are key climate-related changes most farmers have experienced in the past 10 years. 45 percent of the surveyed farmers also report decreases in precipitation. The survey results also indicate that nearly half of the farming households (45 percent) were affected by drought in the past three years.

Droughts seem to translate into more adverse impacts than floods and frosts. Wheat production was most sensitive to droughts, leading to a 52 percent yield reduction, on average (see Figure H). Among all three main grain crops, rice seems the least sensitive crop to extremes, although flood events caused 24 percent reduction in yields in average.

Figure H: Impacts of extreme events on crop productions, average of samples

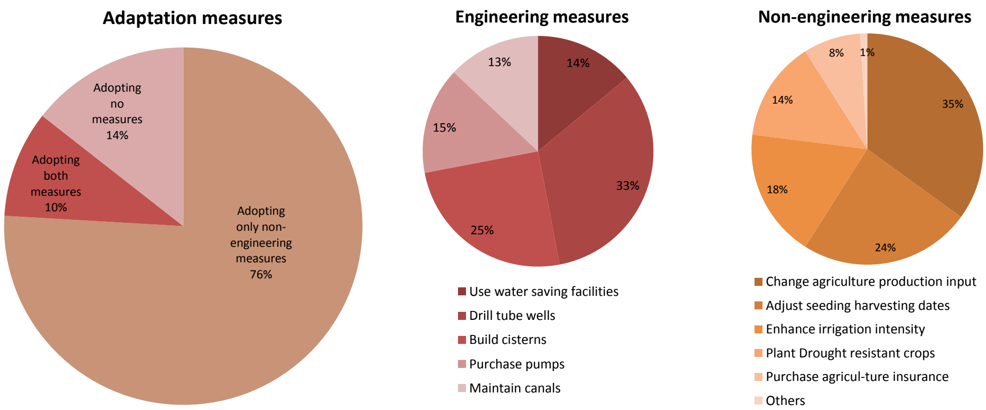


Source: Wang et al. 2012b and authors

Adaptation Measures by Farmers to Cope with Extreme Weather Events

Household survey results suggest that individual households are more active in taking adaptation measures against droughts than against flood or frost in China. The majority, 71 percent, of individual farming households take adaptation measures against droughts, while only 32 percent of farmers take measures against floods and very few against frost (only 3 percent). The reason could be that droughts normally occur over an extended period of time and significant geographical areas, while flood and frost occur more abruptly and are localized. Furthermore droughts can be buffered, for example, by tapping groundwater, whereas flood and frost measures would normally require more substantial measures (such as flood protection dykes and greenhouses) that exceed the intervention capability of households and townships. Non-engineering measures, namely changing agricultural inputs and adjusting seed harvesting dates, are the primary measures taken by households to mitigate impacts of drought (see Figure I).

Figure I: Distribution of household adaptation measures against droughts



Note: (n = 569).
Source: Wang et al. 2012b and authors

Government Support

Information is the main nonmaterial policy support that villages and farming households under extreme weather events received from the local government. Farmers in most villages depended on their own expertise, labor force, materials, and funds to combat drought impacts. Farmers and village leaders were asked about types of climate change adaptation support they received. They report that information on upcoming and recently passed events is the main form of support received from local governments with regard to extreme events.

A total of 38 percent of drought-stricken villages received information before or after droughts, while among the flood-affected households only 34 percent received information before or after a flood. Household surveys, however, reveal a slightly different situation as to receiving information. Household surveys show that more farmers received information with respect to droughts than flood. Among all the surveyed farmers who were affected by various climate extremes, 18 percent of them received warning information from the local government before a drought. A total of 25 percent received information after a drought. These findings are important since they point to the fact that information distributed at the village level does not reach every household.

Determinants of Farmers' Adaptation Strategies: Survey Results

Econometric analysis of the survey results shows that villages with higher levels of economic development, farmer education, and elder experience are more likely to take adaptation measures and for these measures to be effective. Information plays a key role too as the timely provision of early warning information on extreme events for droughts, for example, can increase farmers' willingness to adopt adaptation measures six-fold. The same holds true for flood extremes, where the adoption of adaptation measures increased by up to 26 and 19 percent in pre- and post- extreme situations, respectively, after the release of information. Early warning and post disaster response information are thus very effective hazard risk mitigation strategies.

Farmers' access to both engineering and non-engineering adaptation measures increases the overall effectiveness of mitigating negative impacts from extremes. Hence there is ample opportunity and need for local governments to expand the coverage of non-engineering and engineering measures in a comprehensive and synergistic way. There is no one-size-fits-all solution, but rather numerous sets and combinations of cost- and impact-effective pre- and post-event measures that can be deployed so as to meet region-specific requirements.

Macro-assessment: Supply or demand side management?

The latest water resources strategy document from the Chinese government formulates three macro-scale strategic lines for better supply and demand management so as to address its water challenges. These are (1) controlling water use through setting total supply limits, (2) increasing water-use efficiency in agriculture and industry, and (3) improving water quality. From the government's perspective, the challenge is to design the most effective and least socially disruptive adaptation interventions. Given the results from the coupled modeling approach of how climate change trends impact the water sector over the near term, macro-scale water resource management adaptation strategies one and two are evaluated.

Supply-Side Options

The proposed South-North Water Transfer Project (SNWT) will transfer 44.8 billion m^3 of water (the equivalent of 5 percent of the average annual runoff) from the Yangtze River to four northern river basins, where renewable water availability would be increased by as much as 20 percent. The deficit between projected demand and supply will be reduced at the expense of supply reduction in Yangtze. Despite its massive construction and operation costs, the SNWT is effective in at least partially addressing the water gap in the north.

This analysis of the SNWT project is not exhaustive and provides an economic and technical analysis while excluding other critical assessment criteria such as short and long term ecological and social impacts. This report does not account for risks of structural failure, potential for water pollution issues, and a host of other important aspects. More comprehensive analysis of these issues and associated risks is recommended for the SNWT project and all mega-projects.

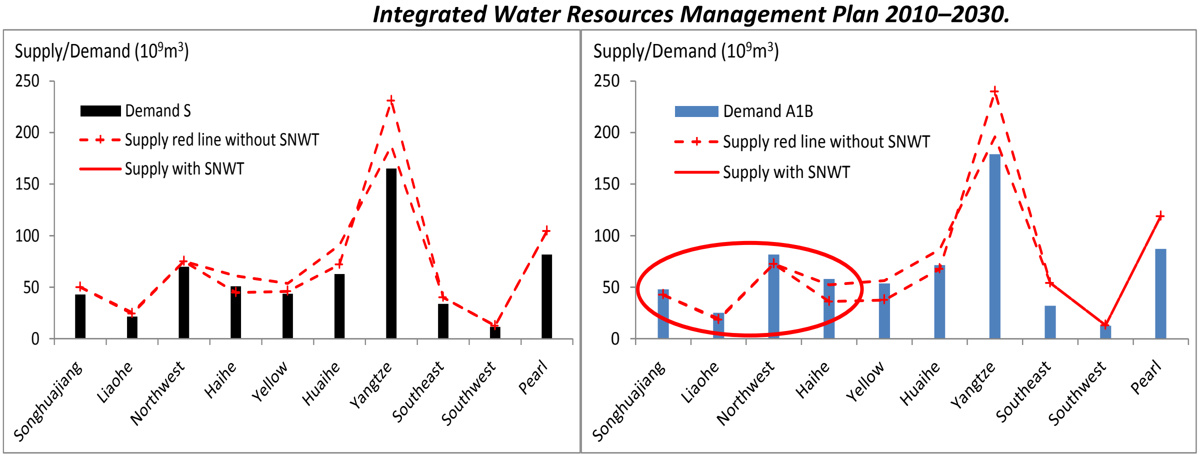
Demand-Side Options

The next option, demand management, refers to methods that avoid water shortages by limiting demand, such as water-saving technology and rational water pricing policies. Water demand management has been promoted not only by international organizations and scholars, but also by the Chinese government. In the past several years, the government has taken great efforts to establish what it refers to as a "water-saving society" through improving water-use efficiency across sectors.

Economic assessment

According to this evaluation of macro-adaptation alternatives, if the demand management goal of increasing agricultural water-use efficiency by 7 to 16 percent in five water deficit river basins (Liao, Songhua, Hai, Huai and Yellow river basins) is met, the water gaps will be closed in all the basins except the Hai River basin in the north, where a deficit of 6.3 billion m^3 per year will persist under the reference scenario by 2030 (see Figure J).

Figure J. Water demand in 2030 under reference socio-economic scenario (left) and climate change scenario A1B (right) when water-use efficiency improvements are adopted according to the National Plan for Integrated Water Resources Management Plan 2010–2030.



Source: Wang et al. 2012b and authors

The relevance of the SNWT becomes apparent if climate change is taken into consideration under which water deficiency will persist in the northern basins without the interbasin water transfer. In these cases, the additional water supply from the SNWT project will be vital, albeit expensive and with profound social and ecological consequences, in mitigating climate impacts and in addressing the water shortages in the receiving northern basins, especially in the 3H basin.

The real challenge for the Chinese government is to make these joint demand and supply strategies work together most effectively at large scales through effective implementation.

Recommendations on Adaptation Strategies

Based on the main empirical findings of this integrated assessment, a set of water and agricultural sector adaptation strategies are proposed. A primary goal of the assessment is to formulate a set of strategies that is well balanced between engineering and nonengineering approaches. The following pages lay out a few of the water and agricultural adaptation strategies emerging from this assessment.

The water sector adaptation strategies are as follows:

1) Balancing Demand versus Supply Strategies through Implementing Effective Demand Management. The conclusion of the macro-scale governmental strategies assessment is that both demand- and supply-side strategies will have to be implemented to solve China's water scarcity problem. The challenge will be to strike a balance between the two because: a) the past demand-oriented management approach has failed to gain traction in the agricultural sector, whereas b) the supply-oriented approach will be expensive and controversial in regions from which water is transferred. Diminishing availability of renewable water in certain basins will make inter-basin transfer schemes more controversial as areas not prone to drought before, are more likely to suffer from longer and intensified dry spells. The more cost effective approach remains demand management through pricing and other market oriented policy measures.

2) **Improving the Management of Reservoir Cascades in Light of Variable, Increasing Multi-Purpose Demand**. It is often the case that water available for storage is less than the reservoir cascade's storage volume, as a result in dry years most of the downstream reservoirs lose their storage function, as upstream reservoirs already retain the available runoff. Irrigation release operations during droughts have often been the cause of conflicts between upstream and downstream water users. Proper management becomes an even more pressing issue as the nation increases its man-made storage capacity. Developing a system of water rights to balance use and guarantee users access to water will improve allocation, while decreasing water related disputes and driving water-related investments. Under such a rights-based system, priority should be given to the restoration and preservation of rivers' health with a clear definition of instream flow requirements in different river sections. Second, cascade planning and development should be integrated into basin-wide planning. Ecosystem and watershed restoration provide natural buffers to extreme events, both flooding and droughts.

3) Improving Water Quality. Water pollution is one of the major causes of insufficient supply. Prioritizing water quality improvements is clearly a first line in combating the water scarcity problems and is a standing environmental priority, regardless of climate change impacts. Higher water quality translates into more water available for human and ecosystem use alike, and thus decreases water scarcity pressure points and contributes to the nation's adaptive capacity. Attention should not only be directed to point source pollution but also to non-point source pollution from excessive fertilizer use as the ramification of this on both surface and groundwater quality is significant.

4) Increasing Decentralized Water Storage. A potential option here is to increase artificial re-charge of aquifers. Groundwater could be recharged artificially and strategically through releases from surface reservoirs during non-growing seasons. However, one should be aware that artificial groundwater recharge is a technical challenge due to clogging, short duration of excess water availability, and other reasons. Given sufficient time and attention, artificial groundwater recharge and storage could potentially provide an effective and localized adaptation solution for individual farmers coping with droughts.

5) Increasing Rainwater Harvesting Coverage. In addition to increasing decentralized storage, rainwater harvesting, which is currently practiced in arid areas of China, will continue to provide important supplementary water at the household and village levels, and provide another tool to mitigate adverse impacts from droughts. In general, such small-scale, distributed projects show great promise in providing low-cost, low-technology adaptation. Rainwater harvesting storage includes rain retention ponds, rainwater harvesting tanks, and other simple storage devices. Rainwater catchment ponds have been found to increase recharge to shallow aquifers by up to 30 percent over normal recharge values from precipitation.

6) Establishing a Comprehensive Real-Time Monitoring & Early Warning System for Extremes. Household surveys reveal that farmers currently receive limited information regarding climate extremes. The surveys also show that even though the information dispersed is very limited, upon receipt of such information, farmers' motivation to take adaptation measures rises. China has a long record of national monitoring systems for both surface water and groundwater. Plans for climate related disaster and risk monitoring systems are also in development. With support from remote sensing and weather forecasts, it should not be difficult for China to set up an information platform similar to the Famine Early Warning System Network (FEWS NET)[2], to provide timely and accurate information regarding climate extremes and potential food-insecure conditions.

7) Improving the Balance between Material and Non-Material Support to Weather Extreme Affected Communities. The results from the two large-scale surveys provided hard evidence of the usefulness of material (e.g. structural and financial) and non-material (e.g. forecast information, information on best response strategies, etc.) governmental support. When such support is provided to vulnerable and affected communities they are able to anticipate and deal with adverse effects from weather extremes more effectively than control groups who do not receive such support. Yet, the surveys also show that there is a significant imbalance between material and non-material government support and outreach.

Hence, it is advisable that local governments work with vulnerable communities to strike a balance in the provision of these two types of support so as to ensure their timely availability in the field (see also The World Bank 2009 for more on this). Ideally, region-specific adaptation measures should be integrated into the national planning agenda for local development activities.

The agricultural sector adaptation strategies are as follows:

1) Investing in Water Saving Agriculture and Minimizing Evapotranspiration Losses. Together with other off-farm efficiency improvements, e.g. in water deliveries, continued development of cost-effective and efficient water use is critical to achieving integrated water resources management, especially in irrigated agriculture. The key benefit of gains in efficiency

[2] The Famine Early Warning System Network (FEWS NET) was established by USAID in 1985 after the shock of famine in Ethiopia, to provide timely and rigorous early warning and vulnerability information regarding climate extremes and potential food-insecure conditions. http://www.fews.net

is that it allows for lowering per area water requirements while at the same time stabilizing and improving yields.

Water-saving agricultural technologies should aim to reduce non-productive evaporation in conveyance and on fields. Traditional irrigation technologies practiced by farmers, such as flood, border and furrow irrigation methods, are still used widely throughout China and limit the efficiency of agricultural water utilization. Traditional flood irrigation loses one third to one half of the irrigated water supplied through seepage. But this part of water remains in the soil or flows back to an aquifer, and should not necessarily be considered water lost. Only the amount of water evaporating directly from flooded soil, wet bare soil, or from the storage and transfer system, does not contribute to the crop growth and that should be the target of efficiency based management.

2) **Indirect Water Demand Management through Economic Incentives**. Economic incentives, i.e. via price signals for input pricing through volumetric, non-volumetric and marked-based tariffs, present an effective means for getting farmers to save water. This is especially true since irrigation water appears to be severely underpriced in many places in China with tariffs well below actual resource scarcity values. Research shows that rural households are quite responsive in reducing water usage when water prices rise. It also shows that informed water pricing policy with real market value as the target is more effective in reducing water usage through non-market based policies.

However, caution must be exercised before introducing full-cost pricing to farmers in the possibly water-abundant upstream communities. Farmers in China's western regions are typically poor and thus higher water prices will cut into already thin agricultural profit margins, and jeopardize their agricultural livelihoods. Also, water pricing requires measuring water volumetrically, with a meter (to charge on a per cubic meter basis) and volumetric meters are not widespread at the field level in China; therefore an incremental water pricing policy is warranted.

3) **Shifting to High-Yield and Stress-Resistant Crops**. The household adaptation surveys showed that more than ten percent of farming households changed crop varieties to more drought resistant crops to mitigate the negative impacts of potential droughts. This indicates that farmers are willing to adopt new crop varieties to adapt to climate change once such technologies are available to them. High-yield, water-stress resistant crops will increase efficiency of both land and water use and reduce the pressure to produce food in the most marginal and water scarce places. Other examples of preliminary trial experiments, for example, show that under normal weather conditions, drought tolerant 'Hanyou-3' rice saves on average 33 percent of irrigation water with yield increases of up to 7.8 percent. These are impressive numbers and their robustness can be tested when brought to scale.

4) **Increasing Farm Size & Modernizing Agricultural Equipment**. The shift from small farms to larger farms is taking place in limited areas in Chine. Large farms are created by aggregating land parcels through rental agreements with many households. This has become more common in China's economically developed regions like in Zhejiang province.

However, such loosely arranged land rental agreements are exposed to the risk of land use policy changes. No farm will make long-term adaptation investments or strategic planning efforts to increase farm productivity under such circumstances. More flexible and transparent policies would allow land users to enter more secure agreements for long-term rent or land utilization, encourage the merging of small farms, and thus, the adoption of more advanced technologies.

5) Sound Supply Chain Management of Agricultural Products. Growing more food in the future is threatened by climate change due to its expected differential impacts across regions and times. This shift is occurring at a time of increasing commodification of the global food regime. Global commodity markets are exposed to technological developments, such as agrofuels and emerging development options, such as land grabbing for growing crops, which can lead to violation of local rights and deprive population's access to indigenous resources.

An idea to increase the resiliency of China's agricultural sector is to enable more place-specific agricultural production within a framework of general agrological modernization, and with attention paid to the ecological dimension of agricultural production. The key to this concept is the tightly-knit web of market opportunities that enable lucrative produce transfers, even for small volumes, while guaranteeing high quality and minimal losses during transport. The government can create an enabling policy environment at the central levels, which informs proper institutional and technical as well as infrastructural support (e.g. sufficient cold storage facilities) at local levels.

Policy Implications & Conclusions

To progress China's climate change adaptation agenda, the government ought to create an enabling policy environment at the central level, which informs institutional and technical as well as infrastructural support at local levels (from credit institutions to land use to water projects). Projects and policy actions at local levels including those by county governments, village committees, irrigation districts, and water user associations should likewise be aligned with climate adaptation decision-making at higher levels of government to ensure coordination of local projects with national goals. A strong enabling environment in one that engages local governments and stakeholders in resilience building strategies and policy development – from deployment of new technologies to development of information sharing systems to local credit unions – with the end result being a resilient community of farmers and citizens prepared to cope with change and variability in weather systems.

In light of the findings presented in this study and given the complexity of the challenges in China—its vast geographic differences as well as significant uncertainties with regard to future climate—it is important to acknowledge that there is no single best one-size-fits-all solution for building pathways towards climate resilience.

- From the government's perspective, the key will be to design and deploy a range of effective strategy portfolios that (a) are tailored to local conditions, (b) fit into the overall context of socioeconomic development, and (c) are environmentally and socially sensitive.

- One of the additional challenges will be to create an enabling environment for proactive, adaptation, which is flexible enough to accommodate unknown and unanticipated future climate challenges. Under the guidance of the central government, ongoing local and regional stakeholder consultations could identify best strategies per locale and design implementation pathways that integrate input from the general public.

- There is a need for material (funds) and non-material (information, education) support for household and community adaptation to provide greater flexibility to cope with uncertainty. In this regard, engineering and other technical measures, while vital for flood protection, for example, are inflexible once they are built and will do little to help households adapt unless coupled with education, awareness building, and information.

- Prior to further investing in high cost water supply development, focus must be placed on increasing water use efficiency and water savings in the agricultural sector. Reducing demand is more cost –effective and is critical to help minimize climate shocks, particularly in regions and communities living on the water availability margin. Improving water quality will help reduce pressure on the current water supply systems. Therefore, designing implementation plans and policies, feasible at the local level, to save water and curb pollution are vital to the nation’s future sustainabilit