

# CLIMATE CHANGE IMPACT ON CROP PRODUCTION IN CENTRAL ASIAN COUNTRIES

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**Abstract:** Increased risk due to global warming has already become embedded in agricultural decision making in Central Asia and uncertainties are projected to increase even further. Agro-ecology and economies of Central Asia are heterogeneous and very little is known about the impact of climate change at the subnational levels. The bio-economic farm model is used for ex-ante assessment of climate change impacts at sub-national levels in Central Asia. The bio-economic farm model is calibrated to ten farming systems in Central Asia based on the household survey and crop growth experiment data. The production uncertainties and the adaptation options of agricultural producers to changing environments are considered paramount in the simulations.

Very large differences in climate change impacts across the studied farming systems are found. The positive income gains in large-scale commercial farms in the northern regions of Kazakhstan and negative impact in small-scale farms in arid zones of Tajikistan are likely to happen. Producers in Kyrgyzstan may expect higher revenues but also higher income volatilities in the future. Agricultural producers in Uzbekistan may benefit in the near future but may lose their income in the distant future. The negative impacts could be further aggravated in arid zones of Central Asia if irrigation water availability decline due to climate change and water demand increase in upstream regions. The scenario simulations show that market liberalization and improved commodity exchange between the countries have very good potential to cope with the negative consequences of climate change.

**Keywords:** bio-economy, climate change, farm income, integrated farm model, Central Asia  
(JEL classification: Q11, Q18)

## Introduction

Central Asia covers an area of 400 million hectares, however, only 20% of that is suitable for farming while the rest is deserts and mountainous areas. Nevertheless, agricultural production forms the backbone of Central Asian economies. Agriculture is the main source of export revenues for these countries except the oil rich Kazakhstan and Turkmenistan. The contribution of agriculture to GDP is lowest at 11% in Kazakhstan and highest at 38% in Kyrgyzstan (Bucknall et al., 2003).

The research focus of further studies in the region was analysing the impact of a changing climate on crop yields and natural resources. There have been no studies investigating the economic consequences of these biophysical changes at subnational levels while taking into account adaptive capacity of agricultural producers to the best of our knowledge. Therefore, this study aims at filling this gap in the region through assessing the impact of climate change at the farm level in Central Asia. Additional contributions of this study are the use of the data based on extensive farm surveys, field trials and inclusion of the risk coping behaviour of the decision makers in representative farms in the analysis.

Climate change adds additional dimensions to the problems in the Central Asia region and increases the vulnerability of

rural producers. Increasing frequency of droughts is causing serious damage to the livelihoods of rural population in semiarid and arid regions of Central Asia. For example, droughts in 2001 and 2008 damaged more than a third of the cropping areas in Tajikistan (Christmann et al., 2009; CAREC, 2011). Furthermore, rainfall is getting heavier and increasing frequency of floods in mountainous regions of Central Asia and the impact is hitting the poorest population the hardest. Rural populations are already suffering from the increasing sequence of extreme events, and projections show even more changes in the future.

The study analyses the role of the Intergovernmental Panel on Climate Change (IPCC) for interest of Central Asia to face declining rainfall during spring, summer and autumn and slightly increased or unchanged precipitation during the winter periods. Also study analyses effects of declining rainfall on the land degradation in this region.

## Material and Method

Available literature broadly distinguishes three types of quantitative assessment methods of climate change impact analysis: Ricardian models, agronomic models and agro-ecological zoning studies. The Ricardian model is one of the most widely used methods that is based on the econometric

analysis of climate change impact on economic indicators (e.g. income or revenues). Flexibility of this approach is that the scale of the analysis (on farm or regional levels) can be selected depending on data availability. Another advantage of this approach is that it enables the drawing of conclusions based on empirical observations derived from long term historical records (or cross sectional data), which already includes adaptation adjustments of the decision makers. However, availability of long-term data is often difficult in developing countries, especially when smaller production units (e.g. farm level) are considered.

Using national or regional level observations may disregard differences in the levels of sensitivity by farm types (e.g. subsistence vs. commercial) (Weersink et al, 2002). Furthermore, this approach may face some difficulties in foreseeing the impact of climate change on agricultural productivity in the far future, especially under changing technology levels and increasing CO<sub>2</sub> concentrations. In contrast, agronomic models could be very suitable to capture complex effects of climate change on crop productivity. This complexity could be well taken into account using agronomic models such as CropSyst and DSSAT (Jones et al, 2003; Stockle et al, 2003).

These models are well-known tools used to analyse the impact of biophysical environment, management practices and climate variation on crop yields. The usefulness of crop simulation models to predict yields have been proven to a large extent and the assessment of farm level impact of climate change is already well investigated with these models. However, one of the disadvantages of this model for impact assessment is the consideration of management as exogenous which disregards the decision makers' adaptation behaviour. The impact of climate change on agricultural producers is very much dependent on available adaptation options (Gibbons -Ramsden, 2008) especially in irrigated systems such as those that exist in Central Asia.

A bio-economic farm model with risk component is calibrated for 10 representative farm types in four Central Asian countries (Kazakhstan, Kyrgyzstan, Tajikistan, Uzbekistan) with different agro-ecological and socio-economic characteristics. We consider the impact of climate change on three main crops which have crucial importance for the rural economies and food security in Central Asia. Cotton is included in this study as it is the main export crop in Uzbekistan, Tajikistan and Kyrgyzstan.

## Results and Discussion

### *Modelling approaches to assess the impact of climate change*

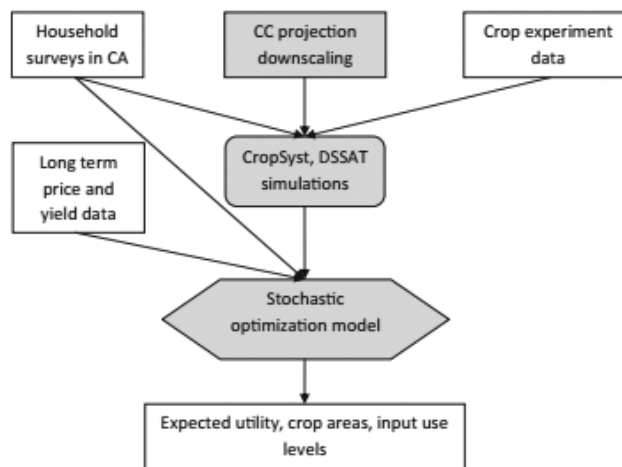
Decision makers' adaptive behaviour could be considered in the well-known integrated models often known as bio-economic farm models when analysis are conducted at farm levels (Janssen - Ittersum, 2007). Integrated models are capable of simultaneous consideration of bio-physical changes and management decisions in different farming systems, which makes this approach suitable for analysing the impacts of

climate change on whole farm or sector levels. Additional advantage of integrated models is the possibility of combining agro-ecological zoning approaches since these models could be made spatially explicit. Integrated models give an opportunity of analysing complex functional relationships between agro-ecological characteristics (e.g. soil type and fertility) and farm level decision making (e.g. input use, technology choice) under climate change scenarios.

This makes integrated models very attractive for ex ante assessment of scenarios (e.g. climate, policy, technology) even with restricted data availability. Consideration of the uncertainties associated with climate change projections plays an important role in ex ante assessment of climate change impact. Clear superiority of these three approaches over the other does not exist and selection of one of these models can be decided based on the objective of the study and data availability. Since this study aims to investigate the impact of climate change of agricultural producers in the far future considering adaptation options we consider bio-economic modelling framework suitable to our context.

Average share of cotton in total crop area in some regions of Central Asia reaches up to 40–50%. Potato and wheat are also included due to their importance in food security and farm income. Wheat is the main export crop in Kazakhstan and is also essential for food security reasons in the entire region. Climate change scenarios are spatially downscaled to the local levels. The crop simulation models then use these downscaled scenarios (Figure. 1). This combination allows consideration of impacts of climate change on the productivity of different crops. These crop simulation models are calibrated with the crop experiment data as well as actual farm management practices collected from farm surveys. The results of the crop simulation models (yields) were then used in a farm-level stochastic-optimization model in order to identify the climate change impact of farm income volatility and potential of different management options to improve farm income (Figure. 1).

Figure 1. Bio-economic farm model components.  
Source: Owned work



Also climate change has influences on the cotton exports,

which significantly contribute to the countries' revenues. For example, cotton fibre exports accounted for about 18% of the total export revenues in Uzbekistan (CEEP, 2005). Many aspects of the agricultural sector, including specialization, farm sizes, land ownership and agricultural production efficiency have been undergoing steady transformation since the breakup of the Soviet Union. (Pomfret, 2007; Bobojonov et al, 2013). Irrational water use during the Soviet Union time have caused several problems in the region including the disappearance of the once fourth largest lake in the world, the Aral Sea. (Glantz, 2005).

The climate change impacts on the land degradation, which also effects on these improper policies as major problems in all Central Asian countries. In this region the land salinization affected about 12% of the total irrigated area in Kyrgyzstan, 50–60% in Uzbekistan and even more than 90% in Turkmenistan (Bucknall et al., 2003; CAREC, 2011). Reduction of the cropping areas in the irrigated lands has been observed during the last decades, which often occurs due to land degradation (Kariyeva-Leeuwen, 2012). Uncertainties during the transition phase combined with land degradation caused high rates of poverty in most of the regions in Central Asia. More than 90% of the population living in the rural areas is defined as poor.

According to IPCC's fourth assessment report, the temperature in Central Asia may increase by 3.7 °C on average by the end of the century and this is mainly expected to occur during June, July and August, which are the most important months in the vegetation period. Higher temperatures during the vegetation period may cause higher probability of drought risk and declining productivity of agricultural production.

Existing studies in Central Asia indicate negative effects of weather shocks on the livelihoods of small-scale farmers who are currently operating at a very narrow margin of profits and who lack access to financial resources and technological knowledge in the region (World Bank, 2009; Akramov, 2011). There is very limited research available on the impact of climate change on agro-ecosystems and analysis of the adaptation strategies in response to the growing urgency in Central Asia. Especially developing integrated assessment tools are becoming very important in order to analyse environmental, economic and social trade-offs in adaptation options in Central Asia.

The current knowledge of the economic impacts of climate change on agricultural production in Central Asia is limited in the existing literature at global levels, and is very limited in the literature at national or sub-national levels (World Bank, 2009; Mirzabaev, 2013). One of the first few assessments was done for the Syr Darya river basin (one of the transboundary river basins in Central Asia) by Savoskul et al. which addressed the adaptive measures to cope with increased drought or flooding but mainly based on the data of crop yields taken from global and regional level models rather than considering parameters observed in Central Asia.

### *Farm surveys and representative farms*

We have identified 10 representative farms for Central Asia (Kazakhstan, Uzbekistan, Tajikistan and Kyrgyzstan) according to agro-ecological and socio-ecological diversity of the regions in Central Asia. Water availability is the main climatic factor constraining crop growth in Central Asia and aridity zones are considered one of the main factors characterizing agro-ecological diversity (Figure 2) within the country according to farming system and bio-economic modelling studies. Moreover, similar aridity zones have been distinguished in different countries as different farming systems due to socio-economic differences such as farm size, land tenure and agricultural policies between the counties.

A household survey with a total sample of 1591 was conducted in the representative farming systems during the last 2 years. The survey covered both family farms (household plots) as well as commercial farms (farmers). The stratified random selection procedure was applied to select several villages from these representative provinces for the abovementioned 10 agro-ecological zones. The number of villages selected from each aridity zone was determined by the number of farms and agricultural areas used for crop production by different producer types.

After identifying the number of villages per each zone, random sampling was used to identify the names of the villages from an available list of villages. Collected data included household characteristics and farm level production characteristics (as farm size, fertilizer use, irrigation practices, input use and fertilizer availability) as well as climate change perceptions. This household data was the main source of information for the identification of representative farms (Table 1) and BEFM calibrations. One representative farm with average production endowments (as farm size, input use) from each farming systems is selected for calibrating the bio-economic model (Table 1).

The study considers two representative medium size farms in Uzbekistan (34.1 ha in the semiarid, 27.1 ha in the arid zone). Three farm types in Kazakhstan were selected: a representative farm with 28 ha of land in the arid zone, 77 ha in the semiarid and 773 ha in the sub-humid zone (including some agricultural areas in humid zones). In the north, the large scale grain cooperatives are predominant with small vegetable plots given to the cooperative workers for subsistence production or others rented out to rural people living in the area. Northern zones produce the largest share of wheat in Kazakhstan and play a very important role for food security in Central Asia. The model is calibrated for a small representative farm of 5.1 ha in the semiarid zones of Kyrgyzstan. Potatoes and wheat producing farm also with 5.1 ha is modelled in the sub-humid areas (including some humid areas) of Kyrgyzstan. The model is calibrated for a farm with 2.1 ha in the humid zone (including per-humid areas) of Tajikistan. Similarly a farm growing wheat, cotton and potato on 4.6 ha in the semiarid zone of Tajikistan is modelled. The selected farm in arid region also have 4.1 ha of land.

Table 1. Representative farm characteristics

Country	AEZ	Farm size, ha	Family size	Fertilizer use per ha	Land ownership
Kazakhstan	arid	28	4,1	134,4	private
	semiarid	77	5,7	52,3	private, cooperative
	sub-humid	773	6,2	-	private, cooperative
Kyrgyzstan	semiarid	5,1	5,6	136,3	private
	sub-humid	5,1	5,1	-	private
Tajikistan	arid	4,1	7,3	119,5	state, private
	semiarid	4,6	7,8	43,5	state, private
	humid	2,1	8,2	166,7	state, private
Uzbekistan	arid	27,1	6,7	138,4	leased
	semiarid	34,1	5,9	120,2	leased

Source: Sommer et al. (2012) and Kato and Nkonya (2012).

### Climate change scenarios

The Intergovernmental Panel on Climate Change (IPCC) developed long-term emissions scenarios. These scenarios have been widely used in the analysis of possible climate change, its impacts, and options to mitigate climate change.

Future greenhouse gas emissions are the product of very complex dynamic systems, determined by driving forces such as demographic development, socio-economic development, and technological change. Their future evolution is highly uncertain. Scenarios are alternative images of how the future might unfold and are an appropriate tool with which to analyse how driving forces may influence future emission outcomes and to assess the associated uncertainties. They assist in climate change analysis, including climate modeling and the assessment of impacts, adaptation, and mitigation. The possibility that any single emissions path will occur as described in scenarios is highly uncertain.

Four qualitative storylines yield four sets of scenarios called “families”: A1, A2, B1, and B2. All are equally valid with no assigned probabilities of occurrence. The set of scenarios consists of different scenario groups drawn from the four families: one group each in A2, B1, B2, and three groups within the A1 family, characterizing alternative developments.

A1b and A2b greenhouse gas emission scenarios of Intergovernmental Panel on Climate Change (IPCC, 2007) are considered in the analyses. There are 23 General Circulation Models (GCM) available and each of them could be used

Table 2. Model scenarios, mean annual temperature and precipitation changes to the baseline scenario

Country	AEZ	A1b(2010-2040)		A2b(2010-2040)		A1b(2070-2100)		A2(2070-2100)	
		Temp °C	Precipitation, mm	Temp °C	Precipitation, mm	Temp °C	Precipitation, mm	Temp °C	Precipitation, mm
Kazakhstan	arid	1,3	8,4	1,4	9,3	3,6	11,5	4,4	5,3
	semiarid	1,3	12,9	1,4	16,5	4	27,7	4,8	19,8
	sub-humid	1,3	10	1,5	16	4,2	25,3	5,1	11,9
Kyrgyzstan	semiarid	1,3	6,6	1,4	8,4	3,6	22,7	4,2	19,3
	sub-humid	1,3	8,1	1,4	10	3,6	36,5	4,2	36,3
Tajikistan	arid	1,3	6,2	1,5	8,3	3,7	9,7	4,3	2,7
	semiarid	1,4	8,6	1,5	21	3,8	13	4,4	7,3
Uzbekistan	arid	1,3	7,7	1,3	12,6	3,5	12,7	4,1	10,4
	semiarid	1,3	14,9	1,4	18	3,6	25,4	4,2	17,1

Source: Sommer et al. (2012) and Kato and Nkonya (2012).

under different emission scenarios. From these GCMs, 7 most advanced models were used to downscale precipitation, minimum, maximum and mean temperature changes under these scenarios for different future time periods by GIS modelling team. The downscaling was implemented by overlaying coarse-gridded GCM change fields into current high-resolution climate grids. The main advantage of this method is that it yields results close to the observed situation, even in areas with complex topography, and directly generates climate surfaces. This downscaling method provided absolute deviation of monthly temperature and relative deviation of monthly sum of precipitation from historic data.

The temperature and precipitation is expected to increase (Table 2) in all considered farming systems but the magnitude of changes very much differs among the farming systems. Downscaled climate change scenarios were used in crop simulation models in order to determine the yield change under climate change scenarios. Average of 7 GCMs are considered for each considered farming system under A1b and A2 scenarios for two different future time periods (2010–2040 and 2070–2100) in the scope of this study.

As it is seen below in the table A1 storyline and scenario family describes how precipitations will have changed with temperature alterations by the end of the first period of 30 years. The A2 storyline and scenario family describes the same trend as A1 does however with a little increasing of temperature in all represented countries with different climate conditions.

Since crop models require daily time step data, stochastic weather generators are commonly used for estimating daily data.

### Climate change impact under market liberalization

Political and ethnic disputes in Central Asia are causing serious constraints to trade between the countries (FAO and WFP, 2012). Restrictions in commodity trade between the countries prevent farmers from planting crops according to their comparative advantages and obtaining increased revenue with the available resources. Furthermore, trade limitation is not only related to agricultural commodities but also limits agricultural input exchange between the countries. Also the international attention should be paid for Sustainability Innovative Low-Carbon investments which were analysed by principles for “Rubik’s Cube” solution (Fogarassy, et al. 2014a; Fogarassy, et al. 2014b). Also instead of fossil energy resources including methane the firms should use renewable energy resources for reduction of methane and other gas emissions.

Therefore, salient price differences in input and output prices in Central Asia countries exist. This scenario investigates how market integration will impact farm revenues under climate change scenarios. Agricultural commodity and input prices are expected to be similar in all four countries under this scenario. Only the price of cotton is treated differently in the simulations due to selling cotton to the world market. The price levels observed in Kazakhstan are used for Uzbekistan and Tajikistan in the case of cotton as considered in similar studies (Bobojonov et al., 2010; Bobojonov et al., 2013).

All other model parameters remain the same in the previous scenario. The results that farmers in Uzbekistan and Tajikistan will particularly benefit from such policy in the future. Thus income gains from market integration will offset negative impacts of climate change. There were no large gains observed in Kazakhstan and Kyrgyzstan since farmers already receive competitive market prices in those countries. However, some gain was still observed which offset income decline under climate change.

Thus, the results of this simulation show that political measures such as market liberalization could increase risk coping potential of farmers under climate change. However, the careful interpretation of results in light of model assumptions and limitation is still needed. The model does not consider the impact of changing income levels and consumption patterns on input and output prices which require careful interpretation of the results of this scenario. Further research is also required on the potential impact of changing world market prices on regional prices under climate change scenarios.

Figure 2. Representative farming systems in Central Asia. Adapted from De-Pauw (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article)



Source: Bobojonov I. and Aw-Hassan A. / *Agriculture, Ecosystems and Environment* 188 (2014) 245–255

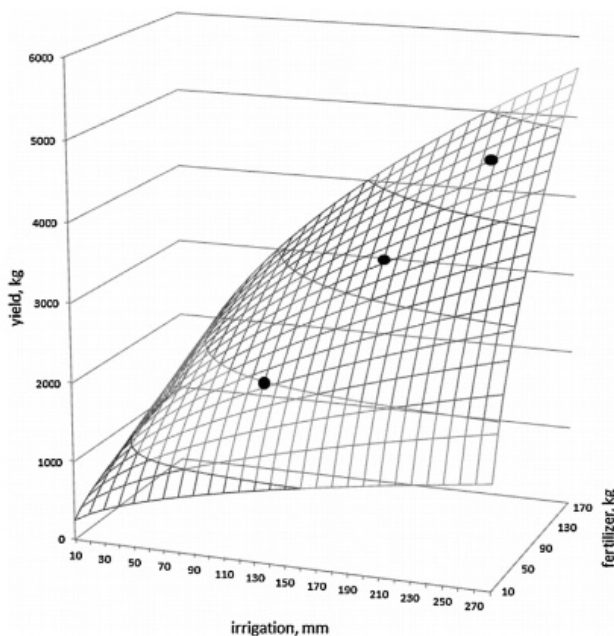
### Crop yield simulation under climate change

CropSyst and DSSAT models are used to assess the impact of climate change on crop yields in Central Asia (Jones et al., 2003; Stockle et al., 2003). These models were calibrated for each of these countries and selection of the locations is done according to the importance of the farming systems in production of wheat, cotton and potato. Data on crop experiments conducted by national research institutes in Central Asia was obtained in order to calibrate the crop simulation models (Kato and Nkonya, 2012; Sommer et al., 2012). The production of wheat was simulated by CropSyst (Sommer et al., 2012) while production of cotton and potato were simulated by DSSAT model (Kato and Nkonya, 2012). Crop yields under these scenarios for the years of 2011–2040 (near future) and 2071–2100 (far future) were analyzed with the help of CropSyst and DSSAT models.

The selection of these models was determined by two independent modelling teams according to data availability and their experience in a certain platform (Kato and Nkonya,

2012; Sommer et al., 2012). The CropSyst model was calibrated with the experimental data with different fertilization rates and irrigation practices (Sommer et al., 2012). Calibrations of crop models were implemented with at least three years of daily weather records and crop growth experiment data conducted at national research stations in selected farming systems. After the calibration of the crop models, crop yields under different management options were simulated for the abovementioned scenarios and time periods. In order to reduce the dimensionality problem, the CropSyst modelling team has selected three management options as presented in Fig. 3.

Figure 3. Illustration of CropSyst yield simulation for different irrigation and fertilizer use in the example of wheat.



Source: (Sommer et al., 2013).

Mean yield and standard deviation of yield for these three management options for all locations and climate change scenarios were available from crop simulation results. These three input use bundles are hereafter named as low, average and high input intensive management options (see Supplementary Material). Only one planting date for each farming system is considered in the crop yield simulations (Sommer et al., 2013)

DSSAT model was calibrated to simulate different mineral fertilizer and organic fertilizer (manure) levels (Kato and Nkonya, 2012). Irrigation water for cotton and potatoes were kept constant in levels observed in the farming systems. An example of crop model mean yield and yield volatilities is given in Tables 3 and 4 in the case semi-arid farming systems in Uzbekistan. The mean yield and volatilities differ between the crops as well as the climate change scenarios (Tables 3 and 4).

Table 3. Crop yields under different management options and climate change scenarios in semi-arid zones of Uzbekistan, ton ha.

Crop	Management option (input use level)	Baseline	A1b (2010–2040)	A1b (2070–2100)	A2 (2010–2040)	A2 (2070–2100)
Cotton	low	3,27	3,33	2,08	3,52	1,63
	average	-	3,6	1,56	3,92	1,06
	high	-	3,79	2,35	4,03	1,73

Potatoes	low	18,9	21,41	23,38	21,47	22,11
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Wheat	low	2,83	2,88	3,27	2,88	4,01
	average	4,3	4,36	4,87	4,42	5,45
	high	5,44	5,69	6,37	5,73	6,87

Source: Source: Sommer et al. (2012) and Kato and Nkonya (2012).

Table 4. Crop yield volatilities (coefficient of variation) under different management options and climate change scenarios in semi-arid zones of Uzbekistan.

Crop	Management option (input use level)	Baseline	A1b (2010–2040)	A1b (2070–2100)	A2 (2010–2040)	A2 (2070–2100)
Cotton	low	0,11	0,14	0,21	0,1	0,23
	average	-	0,17	0,27	0,14	0,31
	high	-	0,14	0,23	0,09	0,24

Potatoes	low	0,32	0,29	0,22	0,29	0,25
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Wheat	low	0,46	0,49	0,48	0,47	0,34
	average	0,31	0,34	0,37	0,33	0,27
	high	0,22	0,25	0,27	0,24	0,21

Source: Sommer et al. (2012) and Kato and Nkonya (2012).

The representative farms considered in the study are assumed to be commercial farms and no constraint associated with household consumption demand is considered. Furthermore, only one farm type per farming system is considered and no differentiation between subsistence and commercial farm is elaborated. All farms are assumed to be price takers and no price changes associated with their production decisions are considered. The mean and variance of output prices used in the climate change simulations are estimated from historical observations. Furthermore, no adjustment to input prices are made due to the lack of data related to future input price changes in the region. Occurrences of rare events are considered on the base of current probabilities which might be one of the shortcomings of this study.

Additionally, simulated yields under climate change scenarios do not consider any impact of changing diseases and pests in the future. Furthermore, the static nature of the model does not consider any accumulation effect of climate change over the years. The study does not provide information

about the effect of technology changes as well as changes in crop varieties in the future. Further information needs to be obtained in order to adjust model parameters to potential improvements of technologies and the crop varieties considered in the study.

## Conclusions

To sum up, climate change impacts on agricultural systems in Central Asia different depending on agro-ecological zones and socio-economic aspects. Farmers in Uzbekistan will benefit from climate change due to more favourable weather conditions for crop growth in the near future (2010–2040). However, revenues are expected to decline in the late future (2070–2100) due to increasing temperatures and increasing risk of water deficit, especially if availability of irrigation water declines.

There might be a slight increase of expected revenues in semiarid zones of Kazakhstan. Some increase in revenues also is also expected in arid areas of Kazakhstan which will not increase the farmers' utility due to expectation of higher variances in crop yields associated with climate uncertainties. In contrast, farmers in sub-humid zones are expected to benefit from increasing temperature and precipitation. Impact of climate change on income of Kyrgyz farmers in semiarid zones will be neutral in the near future, but expected to be positive in the late future. Farmers in sub-humid zones of Kyrgyzstan will probably have higher expected income under all emission scenarios in near and late future scenarios.

However, this might not increase their utilities since additional gain is prone to increased risk associated with weather extremes. In Tajikistan, impact of climate change is crop specific. Wheat revenues may not change in the future, but income from cotton will decline due to drop in yields if current levels of management are maintained. Potato farmers may receive higher revenues in the future as yields are expected to increase. Overall, the impact of climate change is positive in semiarid and humid zones of Tajikistan, but producers in arid regions may suffer from losses under climate change scenarios. Scenario simulations with the condition of market liberalization show great potential for policies to enable producers to mitigate negative consequences of climate change, especially in Tajikistan and Uzbekistan.

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