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RESEARCH

Impact of Climate Change on Agriculture in Kazakhstan

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Using the Global IMPACT model, we investigate the probable effect of climate change on the performance of agriculture and socio-economic conditions in Kazakhstan under five climate-change scenarios. These include a baseline and four climate-change scenarios (MIROC, Hadgem, GFDL, and IPSL) from the Intergovernmental Panel on Climate Change (IPCC). More specifically, we focus on climate-change impact on the production of wheat, potatoes, cotton, maize, rice, and barley. The results suggest that increased temperatures and precipitation will hurt spring crop yields such as wheat and barley. Climate change will probably positively impact the yields of winter varieties of wheat and barley and enable farmers to practise multiple cropping during a farming season. Rice yield is also expected to increase due to climate change, but the yield of potatoes is projected to be adversely affected. Therefore, climate change will be one of the critical challenges for improving agricultural productivity, household welfare, and ensuring food and nutrition security in Kazakhstan.

Keywords: climate change; agriculture; food security; nutrition; Kazakhstan; food policy

1 Introduction

This article investigates the effect of climate change on agriculture and food security in Kazakhstan using the Global IMPACT model. This integrated modelling system links data from climate models, crop simulation models, and water models to a core global, partial equilibrium, multimarket model focused on the agriculture sector (Rosegrant et al. 2008; Robinson et al. 2015). The model is supplemented by extensive literature that focuses on predicting future climate changes and their effects on agriculture, including literature that uses the IMPACT model. This research's primary focus is the potential effects of climate change on the main crops grown in Kazakhstan. While the IMPACT model enables us to see the impact of major climate-change scenarios on crop yields as well as crops' harvested areas, price, and net exports, we complement this with an empirical investigation of the impact of temperature and precipitation on wheat yields.

Another focus of climate-related research is the interplay of a wide variety of factors that affect agriculture along with climate change. These factors are assessed using the scenario analysis technique. For example, Strokov et al. (2016) examine the effect of climate change and the development of irrigation as a response to climate change for Russia until 2030 using the IMPACT-3 model under three scenarios. The base scenario assumes no climate-change effect, and that areas of irrigated cropland do not change. The irrigation scenario assumes the expansion of irrigated areas by 15 per cent along with climate change. The dry scenario considers global warming and no increase in irrigated area. The study found that the irrigation scenario projection shows the doubling of gross agricultural output by 2030 compared to the dry scenario.

So far, there has been no scenario-based research on climate-change effects on agriculture in Kazakhstan. This article aims to fill this gap using the IMPACT-3 model to consider four possible climate scenarios. We focus on the impact of climate change on wheat, cotton, maize, and potatoes. Wheat is a major crop for Kazakhstan, and comprises 42 per cent of total crop output, 76 per cent of cereals and pulses output by weight, 58 per cent of the total harvested land, and 81 per cent of harvested land used for growing cereals and pulses. Potatoes are often referred to as a 'second bread' in Kazakhstan, and 120–130 kilos are consumed on average per person per year.

We do not explicitly consider other interrelated factors that also matter for understanding and predicting the agricultural situation, such as glacier melting, desertification, and epidemic risks. However, they implicitly contribute to the uncertainty of our scenario analyses' outcomes and could potentially be considered in future research.

The rest of this article is organized as follows. We provide an overview of Kazakhstan's climatic conditions, economic and demographic trends, and agricultural development in section 2. The analysis of the impact of temperature and precipitation on wheat yields is presented in section 3, and discussion on climate-change adaptability strategy is presented in section 4. The results of the IMPACT model are provided in section 5. Section 6 concludes.

2 Overview of Climatic Conditions and Agricultural Development in Kazakhstan

2.1 Economic and Demographic Conditions

Kazakhstan emerged as a newly independent country in 1991. The country faced significant economic transformation and structural reforms during the 1990s. It experienced negative GDP growth through most of the 1990s (see **Figure 1**). Inflation surged to over 1000 per cent in the early years after independence. The service sector's share in Kazakhstan's GDP significantly increased, mostly at the expense of agriculture and manufacturing; agriculture's share dropped from 34 per cent to 11 per cent while construction's share declined from 12 per cent to 4 per cent. The share of trade rose from 8 per cent to almost 16 per cent. From 1998 to 2009, the share of agriculture continued to decline from 9 per cent to 6 per cent. However, construction recovered slightly from 5 per cent to 8 per cent. Throughout 2010–2015, the share of services continued to rise from 52 per cent to 59 per cent. During this period, the share of agriculture remained stable (**Figure 2**). The increase in the service sector's share was mostly driven by a declining share of manufacturing from 33 per cent to 25 per cent.

Kazakhstan lost a significant part of its labour force during the 1990s. Total emigration amounted to about 5.3 million people. Immigration during the same period was about 3.4 million. Thus, the net loss was more than 1.8 million people. By 2004, Kazakhstan had reached migration balance (**Figure 3**).

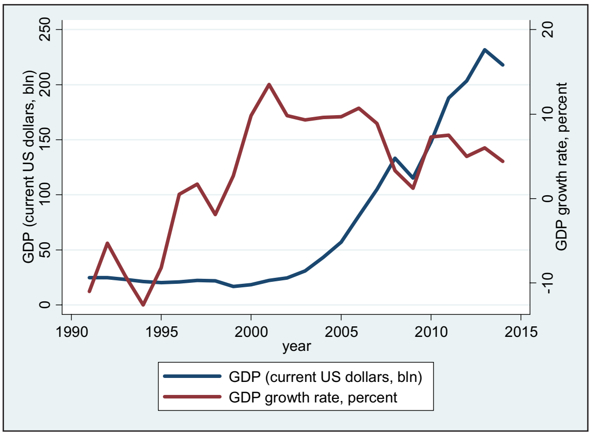

Figure 1: GDP and GDP growth of Kazakhstan in 1990–2014. Source: World Bank 2017.

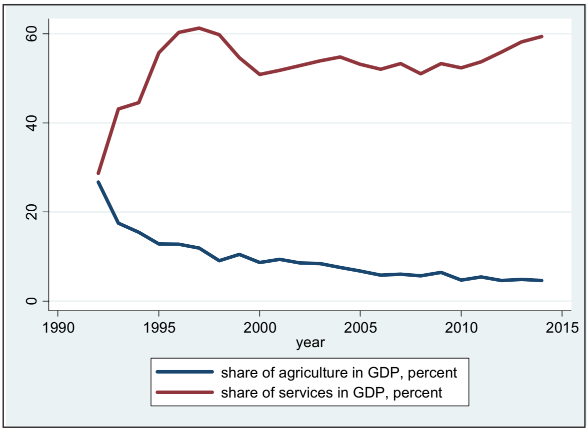

Figure 2: Share of agriculture and services in GDP. Source: World Bank 2017.

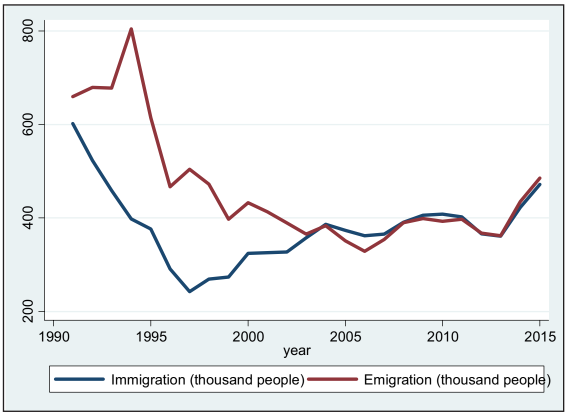

Figure 3: Immigration and emigration in Kazakhstan, 1990–2014. Source: National Statistical Agency of Kazakhstan (n.d.).

Kazakhstan experienced rapid economic growth in 2000–2007, primarily due to the booming energy sector. Price and trade liberalization, privatization, the promotion of entrepreneurship, and the development of the banking system also played a role in the growth (Wandel and Kazbogarova 2009). The world financial crisis in 2008–2009 slowed the Kazakh economy, which recovered during 2010–2014. However, falling commodity prices in 2015–2016 significantly affected the country. In 2015, the growth rate fell to 1.2 per cent (World Bank 2017), and the inflation rate rose to 13.6 per cent (NSA 2017).

Unemployment was a considerable problem in the years following independence. It has since decreased to 5 per cent in 2014 compared to 13.5 per cent in 1999. About 20 per cent of the national labour force was employed in agriculture in 2015, producing only 5 per cent of the national GDP (NSA 2017). In contrast, the mining sector employs about 3 per cent of the labour force but accounts for 13 per cent of GDP. The gross national income per capita in PPP terms has been increasing since independence. The poverty rate has dramatically declined.

2.2 Developments in Agriculture

In the early 1990s, agriculture accounted for about one third of GDP. Wheat has been the main agricultural crop and a vital export commodity. Nearly half of the cultivated land was under wheat. Between 1990 and 1998, the wheat harvest fell dramatically to 4.7 million metric tons due to the adverse weather conditions. Wheat production recovered to 11.2 million tons in 1999. However, due to an infestation of locusts, the harvest fell to 9 million tons in 2000. Since 1999, Kazakhstan has seen a gradual recovery of wheat production. Currently, Kazakhstan is the ninth largest wheat exporter (13.9 million tons in 2013) and fifteenth largest wheat producer globally.

Wheat is mainly grown in three northern regions: Akmola, Kostanai, and North Kazakhstan (**Figure 4**). The total area under wheat is 12.4 million hectares (2006–2007). Out of these, 3.3 million hectares are in Akmola, 3.3 million in Kostanai, and 2.8 million in North Kazakhstan. The area used for wheat is mostly non-irrigated, with the irrigated area comprising less than 3 per cent of total wheat area. Land used for wheat production is also primarily unfertilized; fertilized land amounts to only 525,000 hectares.

Most of the wheat grown in Kazakhstan is soft spring wheat. The area under soft spring wheat is about 93 per cent of the total wheat area. Soft winter wheat occupies only about 5 per cent of the sown area. Hard spring wheat occupies a mere 236,000 hectares. Winter wheat is mostly grown in the southern regions of Zhambyl, Almaty, and South Kazakhstan (NSA 2007).

The regions of Akmola, Kostanai, and North Kazakhstan are climatically well suited for wheat growing. The growing period for wheat in this climatic zone begins in mid-May and lasts until July. During this period, the region experiences a lot of rainfall. The optimal temperature for

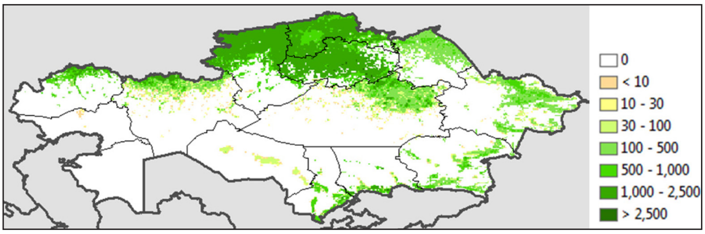

Figure 4: Wheat production distribution (hectares per pixel),[1] circa 2005. Source: You et al. 2014.

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[1] A pixel has roughly 6,600 hectares at 40 degrees north and around 5,500 hectares at 50 degrees east.

spring wheat is 12–15°C. Soft spring wheat is relatively robust to temperature drops and can tolerate short frost spells with temperatures dropping to −13°C. Only during anthesis is it sensitive to temperature drops, when even −1°C to −2°C frosts can cause damage. For tilling, the optimal temperature is 10–12°C. Cold temperatures are beneficial for the formation of the root, and thus for yields.

From 1990 to 1995, the average decline of agricultural production amounted to 18 per cent (Europa Publications and Bell 2002). **Figure 5** shows a considerable decrease in cereal production and land under cereals throughout most of the 1990s.

Similarly, value-added per worker in agriculture and cereal yields declined until the end of the 1990s. A positive trend has been observed since 1999. Interestingly, from 2010 onward, cereal production and yields have been characterized by high volatility. One can see large upswings and downswings in cereal yield and output (**Figure 6**).

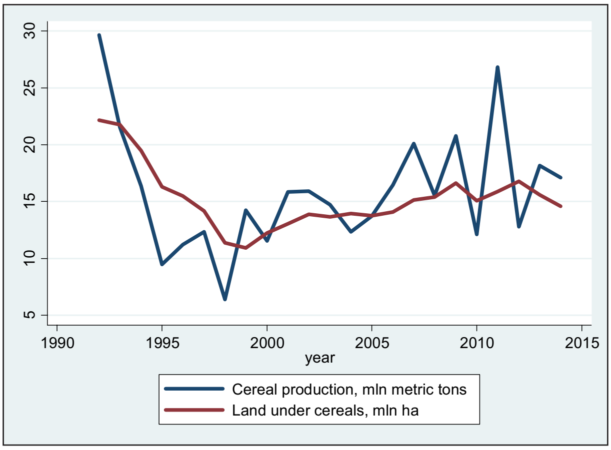

Figure 5: Cereal production data, 1990–2014. Source: National Statistical Agency of Kazakhstan (n.d.).

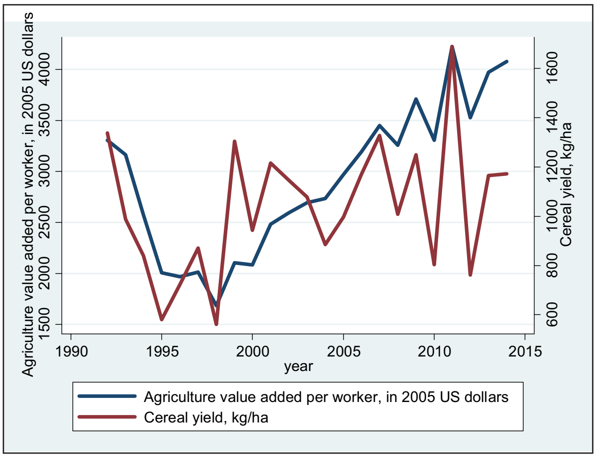

Figure 6: Yield and value added, 1990–2014. Source: National Statistical Agency of Kazakhstan (n.d.).

The data on agricultural production reveals a similar picture for other crops. **Figure 7** shows that potato production declined during the 1990s. Nowadays, potato exports, the second most important export crop, are considerably lower than wheat exports, despite the fast growth of potato production over the last ten years. From 2004 to 2014, the cultivated area for potatoes increased from 168,200 to 186,800 hectares. More importantly, potato production surged from 2.3 million tons in 2004 to 3.4 million tons in 2014. The major potato-producing regions (**Figure 8**) are Almaty (38,300 hectares, 682,800 tons), North Kazakhstan (27,300 ha, 517,200 tons), and East Kazakhstan (24,100 ha, 458,500 tons). However, the regions with the highest yield are Pavlodar (24 tons/ha), Karaganda (21.6 tons/ha), and Zhambyl (21.4 tons/ha).

Unlike wheat and potatoes, melon and vegetable production declined only slightly during the early 1990s. However, this trend changed in the early 2000s, and the current output is significantly higher than during the early 1990s.

A different picture is observed for sugar beet and sunflowers. Sunflower production declined only marginally in the early 1990s. Since then, its production has been increasing

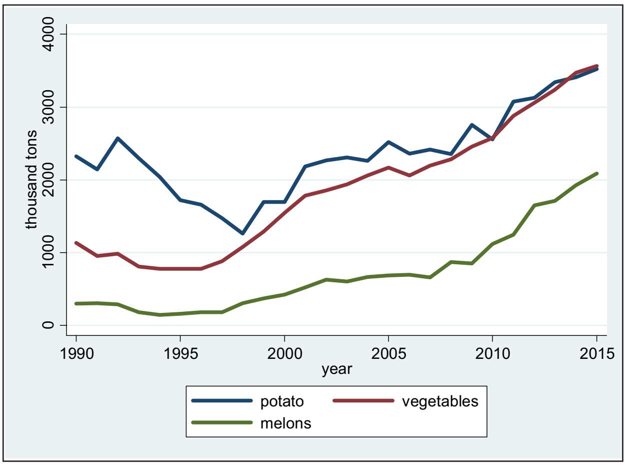

Figure 7: Production of potatoes, melons, and vegetables. Source: National Statistical Agency of Kazakhstan (n.d.).

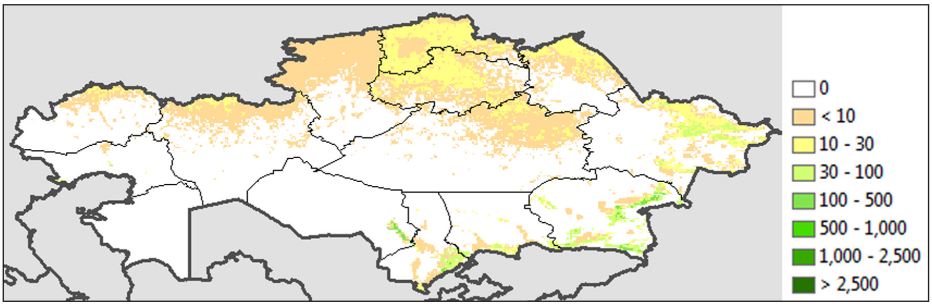

Figure 8: Potato production distribution (hectares per pixel),[2] circa 2005. Source: You et al. 2014.

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[2] A pixel has roughly 6,600 hectares at 40 degrees north and around 5,500 hectares at 50 degrees east.

(see **Figure 9**). The current output is six times larger than output in the early 1990s. Sugar beet production, on the other hand, dropped fourfold between 1990 and 2000.

Vegetable production has become increasingly popular in Kazakhstan, increasing by 70 per cent from 2 million tons in 2004 to about 3.5 million tons in 2014. Open-ground vegetables are grown mainly in the southern regions of Zhambyl (18 per cent of the cultivated area), Almaty oblast (23 per cent), and South Kazakhstan (25 per cent). The total open-ground vegetable production in 2015 was 3.4 million tons, while greenhouse vegetable production was about 148,000 tons (NSA 2007).

The livestock sector was severely damaged during the first decade of independence. Stocks of cattle, sheep, poultry, pigs, and horses saw considerable reductions during the 1990s. Since the early 2000s, the cattle, sheep, horse, and poultry population has been gradually recovering. A changing ethnic composition explains the reduction in pig headcount and pork production in Kazakhstan. Pork was mostly consumed by ethnic Russians, Ukrainians, and Germans who left the country in large numbers during the first emigration waves in the 1990s (see **Figure 3**).

2.3 Climate and Weather Conditions

Kazakhstan experiences four seasons during the year. On most of its territory, the climate is continental, with high daily volatility of temperatures and large differences between summer and winter temperatures. The average rainfall is relatively low, between 100 and 500 mm. The exception is the mountainous region in the south of Kazakhstan, where due to mountain temperature inversions, there are relatively mild winters and a lot of rainfall.

To the south of the 43rd parallel, the climate is subtropical with hot and dry tropical air masses dominating. The weather in the south of Kazakhstan is very volatile, with a high average temperature of around +10°C. The north of Kazakhstan has long winters with Siberian-like frosts and short summers, while the south experiences short winters and long summers.

Average sunshine ranges from 2,100 hours per year in the north to 3,000 in the south. The number of sunny days is 120 per year in the north and 260 per year in the south. The average temperature in Kazakhstan varies from +0.4°C in the north to +15.2°C in the south. Outside of the mountain regions, Kazakhstan has low rainfall, mostly occurring in spring and at the

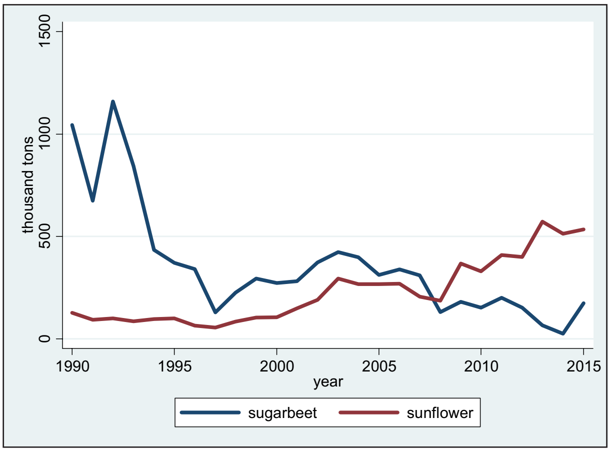

Figure 9: Production of sugar beet and sunflowers, Source: National Statistical Agency of Kazakhstan (n.d.).

beginning of summer. Most of Kazakhstan's territory is steppe (26 per cent), semi-desert (14 per cent), and desert (44 per cent). Forest makes up only 5.5 per cent.

For the sake of our scenario analysis interpretation, it is convenient to divide Kazakhstan into five regions based on climatic differences: north, including North Kazakhstan, Kostanai, Pavlodar, and Akmola provinces; central, including Karaganda; east, including East Kazakhstan province; west, comprising Aktobe, West Kazakhstan, Atyrau, Kyzyl-Orda, and Mangistau; and south, including Almaty, Zhambyl, and South Kazakhstan.

Northern Kazakhstan is mainly steppe with a temperate continental climate, featuring harsh and long winters and warm summers. The average temperature is about −18°C in January and +19°C in July. The average yearly precipitation is 350 mm. More than 80 per cent of the precipitation falls during the warmer months (April–October), making the region favourable for growing grains.

Eastern Kazakhstan is a mountainous region with cold, snowy winters and hot, dry summers. The average temperature is –20°C in January and +30°C in July, and average yearly precipitation is 410 mm. Mining and agriculture dominate the economy of the region. Animal husbandry comprises more than 60 per cent of the region's agricultural output. Cropland is non-irrigated and represented mostly by sunflowers, grains, and fodder crops.

Central Kazakhstan is steppe with a temperate continental climate, featuring hot summers and cold winters with little snow. The average temperature is −13°C in January and +20°C in July. The average yearly precipitation is 332 mm. The mining industry dominates the economy of the region, and agriculture's contribution to value-added is negligible.

Southern Kazakhstan is characterized by a continental climate with mild winters and long hot summers. The average temperature is –7°C in January and +28°C in July. The region's economy is dominated by industry (18 per cent of value-added) and agriculture (11 per cent). Horticulture comprises 53 per cent of agricultural output, while animal husbandry comprises 47 per cent. Horticulture development is enabled by the region's hot climate and an abundance of sunny days. Horticulture provides 23 per cent of the region's agricultural output, cereals 8 per cent, and fibre crops about 4 per cent.

West Kazakhstan's landscape is characterized by low-lying flatlands, mostly semi-desert and desert. The climate is temperate continental with a high variation in temperature during the day. The average yearly precipitation is about 100 mm. The oil and natural gas sectors dominate the region's economy, accounting for 45 per cent of gross regional product, while agriculture's role is negligible (about 2 per cent of value-added).

Kazakhstan's hydro-meteorological service has observed a temperature increase in Kazakhstan over the last seventy years of weather observations. They observed not only a yearly average increase but also an increase in temperature during each season of the year. The average annual temperature increase is about 0.27°C every ten years. The highest increase has been observed for the autumn months (0.32°C/decade), the lowest in the summer months (0.2°C/decade).

Ranking the warmest years in the world reveals that the 2000s have seen the warmest years, based on meteorological observations (**Table 1**). Kazakhstan is relatively typical in this respect (see **Figure 10**). Apart from the anomalously warm year of 1983, the climate has become warmer in Kazakhstan over the last two decades. **Figure 10** also reveals the increasing trend in average temperature over the seventy-year period.

In the north and central regions of Kazakhstan, the highest temperature increase has occurred during the spring period (0.33–0.37°C every ten years, see **Table 2**), and in the south and east during the autumn period (0.30–0.40°C every ten years). Further, the west and south have experienced increased number of heatwaves (days with temperatures above 35°C). Every ten years, the number of such days has increased by between one and five. At the same time, the number of frost days (temperatures falling below 0°C) has decreased across

Table 1: Ranking of warmest years.

Rank	Global	Kazakhstan	Anomaly of yearly average temperature (in KZ)
1	2014	2013	1.69
2	2010	1983	1.56
3	2005	2002	1.33
4	1998	2004	1.33
5	2003	2007	1.27
6	2002	1995	1.21
7	2013	2008	1.17
8	2007	1997	1.05
9	2006	2006	0.99
10	2009	2005	0.88

Source: *Yearly Bulletin of Climate Change Monitoring in Kazakhstan*, 2012, National Hydro-meteorological Service of the Republic of Kazakhstan 2012.

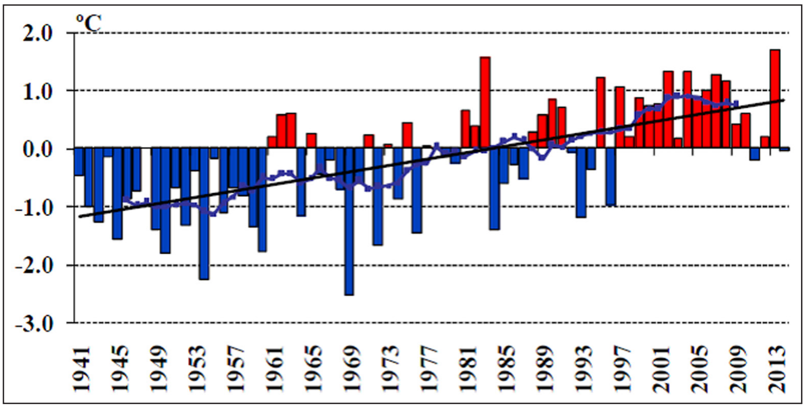

Figure 10: Anomaly of yearly average temperature in Kazakhstan. Source: *Yearly Bulletin of Climate Change Monitoring in Kazakhstan*, 2012, National Hydro-meteorological Service of the Republic of Kazakhstan 2012.

all regions by five to six days every ten years. Concerning precipitation, no clear pattern is observed. On average, precipitation has been declining by 1 mm every ten years, but the result is not statistically significant.

3 Climate Change and Wheat Yields

How does climate change affect agriculture? Do temperature increases harm or benefit agricultural producers? According to the World Bank's *Adapting to Climate Change in Europe and Central Asia* report, in Kazakhstan, areas projected to see increasing rainfall could see expanding opportunities for rain-fed, high-yielding winter wheat. In contrast, other parts of the country are likely to face reduced water availability, and periodic drought could see lower crop yields (World Bank 2017). According to the report, winter and spring precipitation will see respective increases of 9 per cent and 5 per cent by mid-century. However, the models predict that precipitation intensity will increase, and the precipitation increase will partially

Table 2: Climate change, linear trends.

Region (Oblast)	Year		Winter		Spring		Summer		Autumn	
	coeff[3]	R^2	Coeff	R^2	Coeff	R^2	coeff	R^2	coeff	R^2
Kazakhstan	0.27	0.38	0.27	0.06	0.31	0.17	0.19	0.25	0.31	0.24
Kyzyl-Orda	0.29	0.32	0.21	0.02	0.33	0.16	0.27	0.34	0.3	0.22
South Kazakhstan	0.21	0.27	0.16	0.02	0.21	0.11	0.17	0.18	0.32	0.27
Zhambyl	0.29	0.39	0.27	0.05	0.23	0.12	0.27	0.37	0.4	0.34
Almaty	0.23	0.31	0.27	0.07	0.22	0.12	0.13	0.13	0.29	0.25
East Kazakhstan	0.25	0.25	0.27	0.05	0.28	0.12	0.14	0.11	0.31	0.18
Pavlodar	0.26	0.25	0.26	0.04	0.37	0.17	0.14	0.08	0.28	0.13
North Kazakhstan	0.3	0.31	0.3	0.05	0.37	0.16	0.2	0.12	0.32	0.15
Akmola	0.28	0.31	0.25	0.04	0.38	0.16	0.18	0.11	0.32	0.16
Kostanai	0.31	0.33	0.3	0.05	0.37	0.14	0.24	0.15	0.32	0.17
Karaganda	0.28	0.31	0.24	0.04	0.35	0.16	0.2	0.17	0.32	0.19
Aktobe	0.29	0.31	0.3	0.05	0.33	0.12	0.21	0.14	0.3	0.16
West Kazakhstan	0.38	0.39	0.46	0.1	0.43	0.2	0.27	0.16	0.34	0.21
Atyrau	0.29	0.34	0.38	0.09	0.32	0.17	0.2	0.19	0.27	0.17
Mangistau	0.25	0.35	0.26	0.08	0.24	0.13	0.23	0.21	0.25	0.16

Source: *Yearly Bulletin of Climate Change Monitoring in Kazakhstan,* 2012, National Hydro-meteorological Service of the Republic of Kazakhstan 2012.

come from extreme storm events. According to current climate change trends, an increase in average temperature is expected (IPCC 2001).

In the next section, we attempt to estimate the effect of climate change on wheat production, a primary agricultural export commodity. Given the data on wheat yields, temperature, and precipitation in the key wheat-producing regions, we estimate the sensitivity of yields to temperature and precipitation. The tilling and stem elongation period occurs from mid-May to June. Up to 80 per cent of total water consumed throughout the growing period is consumed during tilling and stem elongation. Wheat is relatively robust to temperature changes. It is resistant to short frosts not exceeding –8°C to –9°C during this period. It is also resistant to high temperatures, but only if enough moisture has accumulated in the soil.

To understand how future temperature increases and precipitation changes might affect wheat production, we analysed the effects of temperature and precipitation changes on wheat yields using historical data. We have data on average maximum temperatures (in °C), precipitation (in mm), and yields of wheat (in tons/hectare) in three key wheat-producing regions of Kazakhstan (North Kazakhstan, Kostanai, and Akmola) for the years 2004–2014.

The descriptive statistics are shown in **Table 3**.

The basic regression specification we estimated is: $Y_{it} = \beta_0 + \beta_1 T_{it} + \beta_2 P_{it} + \in_{it}$, where Y_{it} are yields, T_{it} is average daily maximum temperature from mid-May to end of June, P_{it} is total precipitation level from mid-May to end of June, and $\in_{it}$ is the error term which we assume to

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[3] Coeff – coefficient of the linear trend (degrees Celsius/ten-year period).

Table 3: Descriptive statistics.

Variables	North Kazakhstan	Akmola	Kostanai	Whole sample
Average daily max. temperature	23.3	25.1	25.6	24.6
Precipitation	71.8	53.0	45.3	56.7
Number of observations	11	11	11	33

Table 4: Wheat yield sensitivity to temperature and precipitation.

Variables	Model 1	Model 2	Model 3	Model 4
Temperature	−1.13***	−1.32***	−1.28***	−1.35***
Precipitation	0.042***	0.044***	0.11***	0.09***
Precipitation variation	–	–	−1.28***	−1.09***
Temperature variation	–	–	0.77	–
Akmola dummy	–	–0.53	–0.42	–
Kostanai dummy	–	2.02**	1.99***	2.39***
Constant	36.64	40.72	40.72	41.61
R^2	0.64	0.73	0.79	0.78

be identically and independently distributed (iid). The subscript i represents the region and t the year. Other specifications of the model include precipitation and temperature standard deviations as well as regional fixed effects.

Our results indicate that an increase in average maximum daily temperatures in mid-May–June by 1 degree reduces yields by 0.11 tons per hectare. An increase in total precipitation in mid-May–June by 1 mm increases yields by 0.004 tons per hectare. The results of the regression model are presented in **Table 4**.

Given the linear trends of temperature change, we can estimate the effect on wheat yields. In North Kazakhstan, in spring and summer, the temperature is expected to increase by 0.2–0.37°C every ten years. Concerning precipitation, the picture is not clear. According to Model 4, yields will decline by 0.27–0.5 tons per hectare every ten years if precipitation levels do not change. In Kostanai, in spring and summer, the temperature is expected to increase by 0.24–0.37°C/decade, implying that yields will decline by 0.3–0.5 tons per hectare every ten years. In Akmola, in spring and summer, the temperature is expected to increase by 0.18–0.38°C/decade. This translates into a yield decline of 0.24–0.5 tons per hectare every ten years. This means that by 2050 yields might decline in the wheat-producing regions by up to 0.18 tons per hectare. This is all conditional upon precipitation levels not changing during spring and summer. If precipitation levels increase during that period, the adverse effects of rising temperatures may be partially offset. However, the positive impact of an increase in spring precipitation might be offset by precipitation variance. On the other hand, one possible adaptation strategy would be to shift sowing to earlier months when the temperature is lower.

4 Climate Adaptation Strategy in Kazakhstan

The literature suggests that farmers change their production decisions in response to climate change (Mendelsohn and Dinar 1999). Smit and Skinner (2002) provide a typology of a variety of adaptation options, drawing on the case of Canada. Howden et al. (2007) show that implementing readily available adaptation options should be very useful for moderate climate change; however, under more severe climate-change outcomes, the standard measures will not work. Adams et al. (1990) studied climate change's effect on the USA's agriculture industry. They discovered that the regional patterns of the agriculture industry would shift under the climate-change scenario, but the overall effect on economic well-being depended on the model they used. Lobell et al. (2008) studied the effect of climate change in South Asia and southern Africa. They conclude that without proper adaptation strategies, climate change will negatively affect the productivity of key crops, and, consequently, food security.

The focus of the government of Kazakhstan's climate-change adaptation strategy is limited to the land desertification problem. To address desertification, Kazakhstan has been financing a programme aimed at developing land management schemes by focusing on the regeneration of degraded soils and the restoration and improvement of irrigated land.

The programme seeks to achieve the following objectives, grouped into three phases. The first phase includes taking an inventory of and assessing degraded land, informing and engaging with groups involved in combating desertification, and designing and implementing pilot projects focusing on land rehabilitation or degradation prevention.

The second phase includes developing legal requirements and economic mechanisms for sustainable land management, which ensure the preservation and rehabilitation of Kazakhstan's resource base, ensuring consolidated implementation of international environmental conventions and reducing the scale of and preventing further desertification and the negative impacts of droughts.

The third phase includes the integration of desertification-combating measures into the country's economic and social development and protecting land from desertification while maintaining sustainable conditions. The outlined anti-desertification programme has been put into action along with a broader strategic concept, *The Strategy for Development of the Republic of Kazakhstan until the Year 2030* (Nazarbayev 1997).

5 Future Scenarios of Climate Change and its Impact on Development

5.1 A Short Description of the IMPACT Model and Climate Change Scenarios

The IMPACT model was developed by the International Food Policy Research Institute and consists of a partial equilibrium multimarket model that uses information from water, crop, and climate models. The outcomes of the model are crop yields, commodity prices, trade, consumption and production levels, and harvested areas. Some of these outputs can be used as inputs in further models to create a large modelling system (Robinson et al. 2015). The production of crops is modelled at the level of Food Production Units (FPUs) for a given harvested area. The latest version used in our model included 159 countries and 320 FPUs. The territory of Kazakhstan included seven FPUs. Many studies into national and regional analysis of food security, thematic and interdisciplinary analysis, and commodity analysis have used the IMPACT model (Robinson et al. 2015). Model outputs allow for the study of parameters such as the proportion of people at risk of hunger and the number of undernourished children.

We use climate-change scenarios developed by institutions in the UK, France, Japan, and the US. Each climate scenario is introduced within the framework of a scenario analysis of the simulation model with timespans until 2050. The parameters of the model, such as elasticities, are drawn from various databases such as USDA, GTAP, OECD, SSP, and expert opinion.

The long-run change in climate is the main factor of uncertainty for the future development of agriculture in Kazakhstan. We entertain four climate-change scenarios developed by major institutions from around the world, namely GFDL, MIROC, IPSL, and HGEM. The scenarios' descriptions and implications for precipitation and temperature in Kazakhstan are presented in **Table 5**.

Table 5: Climate-change scenarios.

Climate-change scenario	Implications for Kazakhstan in terms of temperature and precipitation
GFDL: The Geophysical Fluid Dynamics Laboratory, Princeton University, US.	Predicts the smallest possible temperature increase of the four and increased precipitation in north-eastern Kazakhstan.
MIROC: Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (University of Tokyo), and National Institute for Environmental Studies	Higher temperature but with decreased precipitation in the south and increased precipitation in the north of Kazakhstan.
IPSL: The Institute Pierre Simon Laplace, France.	Higher temperatures and decreased precipitation are expected in southern and central Kazakhstan as well as the rest of the Central Asian region. The driest scenario.
HGEM: Hadley Centre for Climate Prediction and Research, UK	The hottest scenario. The highest temperature increase is expected in the eastern part of the country.

Table 6: Climate model projections on precipitation.

Region/Climate model	Change in annual rainfall in mm, 2000–2050			
	GFDL	HadGEM	IPSL	MIROC
Almaty	28	34	–22	29
Akmola	38	17	29	46
Aktobe	11	16	1	19
Atyrau	14	3	7	13
East Kazakhstan	78	6	8	47
Mangghystau	–3	8	–5	1
North Kazakhstan	52	26	32	68
Pavlodar	79	4	32	48
Karaghandy	30	22	4	20
Kostanay	14	21	14	44
Kyzylorda	0	18	–8	–6
South Kazakhstan	–12	48	–32	–19
West Kazakhstan	5	0	21	28
Zhambyl	–3	42	–12	5
Total	**26**	**18**	**4**	**25**

Overall, for Kazakhstan, temperature is expected to increase under all scenarios, and precipitation is expected to increase in the north and to decrease in the south in all scenarios except HGEM's. More detailed information is presented in **Tables 6** and **7**.

Table 7: Climate model projections on temperature.

Region/Climate model	Change in mean daily maximum temperature in degrees Celsius for the warmest month, 2000–2050				Change in mean daily maximum temperature in degrees Celsius for the coldest month, 2000–2050			
	GFDL	**HadGEM**	**IPSL**	**MIROC**	**GFDL**	**HadGEM**	**IPSL**	**MIROC**
Almaty	2.4	5.8	4.4	5.3	3,4	4,5	3,4	5,7
Akmola	1.3	4.9	3.6	4.5	3,7	5,5	4,4	6,7
Aktobe	2.3	4.6	3.8	4.1	3	6,5	4,4	4,5
Atyrau	3	4.2	3.7	4.2	1.9	4.7	4.1	3.4
East Kazakhstan	1.3	6.2	3.6	5	3.6	4.2	3.6	6.7
Mangghystau	2.5	4.4	4.2	4.2	1.4	3.7	2.8	2.8
North Kazakhstan	0.9	4.8	3.7	4.3	4.1	5.6	4.8	6.7
Pavlodar	0.7	5.6	3.3	4.9	3.8	5.5	4.4	7.2
Karaghandy	1.8	5.1	4	5	3.4	5.3	3.6	4.9
Kostanay	1.7	4.5	3.7	4.1	4.1	6	4.6	6
Kyzylorda	2.3	4.6	4	4.7	2.6	6.4	2.8	3
South Kazakhstan	2.7	5.2	4.4	5.4	2.8	5.6	2.7	3
West Kazakhstan	2.8	4.6	3.5	3.7	2.7	5.7	5.4	4.5
Zhambyl	2.6	5.4	4.4	5.5	3.1	5.5	3.1	4.3
Total	**2**	**5**	**3.9**	**4.6**	**3.2**	**5.4**	**3.8**	**5**

Next, we discuss the effect of climate change on agriculture, starting with wheat, followed by cotton, potatoes, and maize.

5.2 Projections for Economic and Demographic Development

For this scenario exercise, we used the SSP2 (middle of the road) projections for population and GDP. Under SSP2, population is projected to grow at a rate of 0.5–0.6 per cent per year and reach 20.2 million people by 2050.

Economic development, defined by the growth of real GDP in tens of millions of USD, is presented in **Figure 11**. This is an OECD SSP2 average or middle of the road projection for the years 2015–2050. GDP per capita is not expected to grow with the same speed as GDP due to positive rates of population growth.

5.3 Projections for Agricultural Production and Productivity

5.3.1 Wheat production

To obtain results for the impact of climate change on wheat yields, the IMPACT model uses the results of the biophysical model as inputs. The economic model is then used to derive the impact of changes in global prices, trade barriers, and market conditions on wheat yield and wheat area. The final output, therefore, represents the full impact of climate change on wheat production. The same argument applies to all the other crops considered in this study.

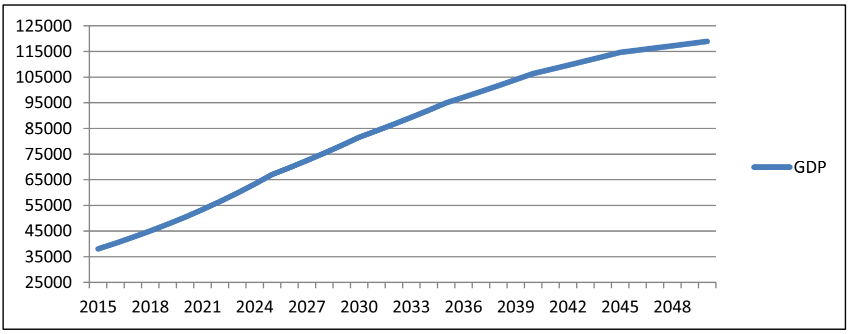

Figure 11: GDP projections for Kazakhstan. Source: *OECD SSP2* (n.d.).

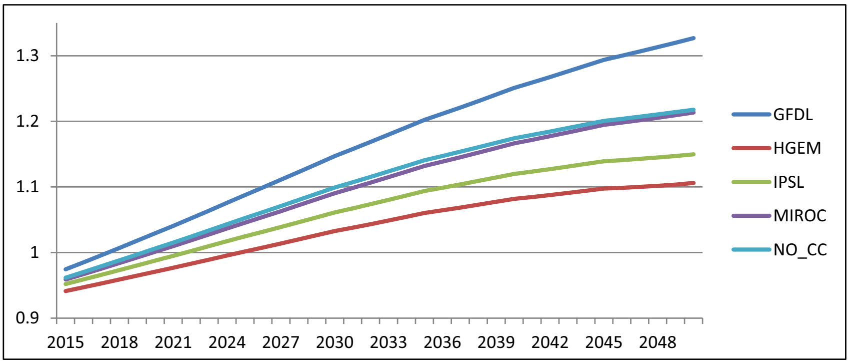

Figure 12: Wheat yield in Kazakhstan.[4] Source (and figures 13–23): Results of the simulations using the IMPACT model.

Consequently, caution should be used when comparing the IMPACT model results with the results of other studies that omit the economic component.

Wheat yields are expected to grow under the baseline scenario (which ignores climate change) and the climate-change scenarios. On average, wheat yield grows at about 1 per cent per annum over the next thirty-five years under the baseline scenario (**Figure 12**). As most of the wheat in Kazakhstan is rain-fed, the most favourable scenarios for wheat yield from climate change are those with higher increases in precipitation in the northern wheat-growing regions of Kazakhstan.

However, the advantage of higher rainfall is mitigated by the disadvantage of higher temperatures in the summer months when spring wheat is still maturing. In particular, GFDL, which has the lowest projected temperature increase, performs better than the baseline by 8.9 per cent in 2050. On the other hand, HGEM and IPSL perform worse than the baseline, with 9.3 per cent and 5.7 per cent lower yields by 2050, respectively. The performance of yields under the MIROC scenario is approximately the same as that of the baseline. In this case, the negative impact of higher temperatures is counterbalanced by the positive impact of more precipitation.

The impact of the climate scenarios on the harvested wheat area is small – less than 2 per cent more for any climate-change scenario above the baseline in 2050 (**Figure 13**). The global

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[4] Yield is given in metric tons per hectare.

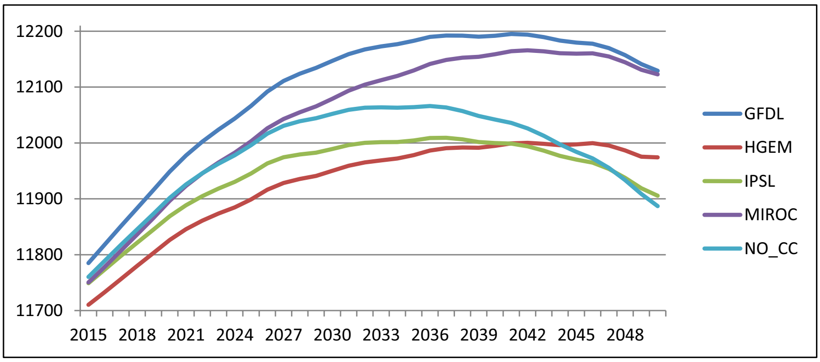

Figure 13: Wheat area in Kazakhstan.[5]

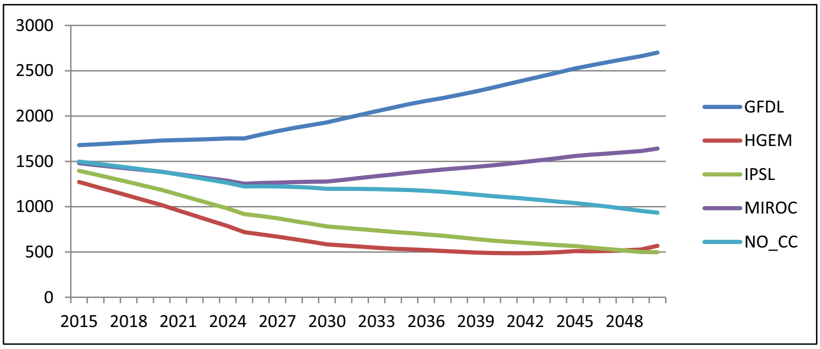

Figure 14: Net exports of wheat from Kazakhstan (in thousands of metric tons).

price of wheat increases most under the HGEM and MIROC scenarios. Prices, together with productivity changes, influence area choices. As a result, MIROC and GFDL result in higher areas under cultivation than under the baseline scenario, with the MIROC area being driven primarily by price and GFDL area by yields.

In **Figure 14**, we note the changes in net exports. The results are derived from the difference between production and consumption, which, to a large extent, reflects differences in total production, which is driven by changes in both yield and cultivated area. Since GFDL had the highest yields and was essentially tied for the highest cultivated areas among the GCMs, it is no surprise that the highest net exports are found under the GFDL scenario. This also explains why MIROC is placed second for net exports. For the baseline, IPSL, and HGEM, net exports actually decline between 2015 and 2050, as a result of domestic production not rising as fast as domestic consumption.

The seminal paper by Asseng et al. (2015) shows that global wheat production is expected to drop by 6 per cent for each 1 degree Celsius increase in temperature, and become more variable across space and time. The wheat yield loss is explained by the decline in the number of days to anthesis and maturity with increasing temperatures.

Our results differ in that there are some projected increases in yields for wheat in Kazakhstan, and even for the climate models with projected reductions in yield, the degree of yield loss is not as high. The differences can be explained in two ways. First, Asseng et al. (2015) do not account for changes in global prices, which tend to increase for wheat due to climate

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[5] Harvest area is given in thousands of hectares.

change, but which we control for in IMPACT. Second, in the context of the climate change in Kazakhstan, in many locations the negative effect of increases in temperature is offset by the positive effect of increases in precipitation.

5.3.2 Cotton production

The model shows a modest difference in cotton yields under the climate-change scenarios when compared to the baseline scenario in 2050, with changes ranging between increases of 2.2 and 6.3 per cent (**Figure 15**). Globally, climate change will raise the price of cotton. Together with the increases in yield from climate change, IMPACT projects that harvested areas will be higher under all climate models than under the baseline in 2050, with the GFDL and HGEM models having 4.2 per cent and 6.7 per cent more area respectively, and the other two having just under 6 per cent more area (**Figure 16**).

Increased area and yields drive up total production which also results in higher net exports under climate change than under the baseline model.

5.3.3 Potato production

The potato yield is lower under all climate-change scenarios than the baseline scenario in 2050. Three of the four GCMs point to losses of more than 28 per cent, with only the GFDL having a more moderate loss of just under 9 per cent. The yield in 2050 under all climate scenarios except GFDL falls to below the baseline 2015 levels (**Figure 17**). We can see that potato yields grow by about 15 per cent by 2050 under no climate change and fall by about 15 per

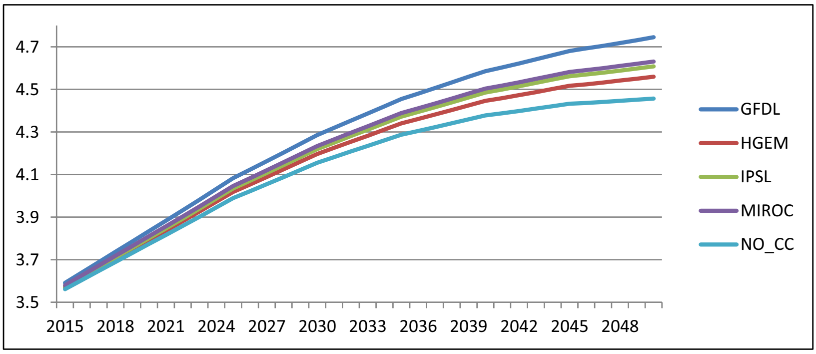

Figure 15: Cotton yield in Kazakhstan.

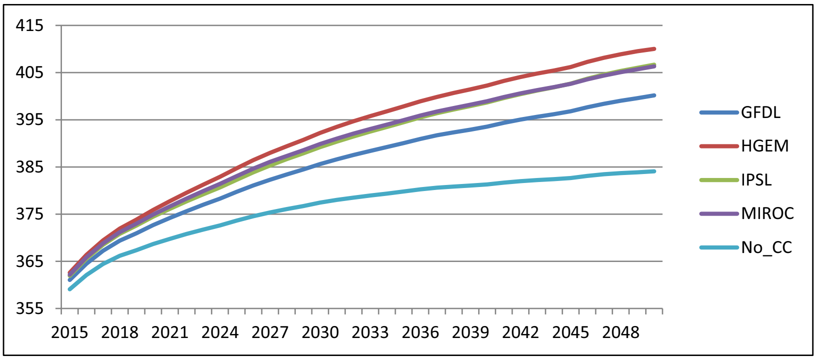

Figure 16: Cotton area in Kazakhstan.

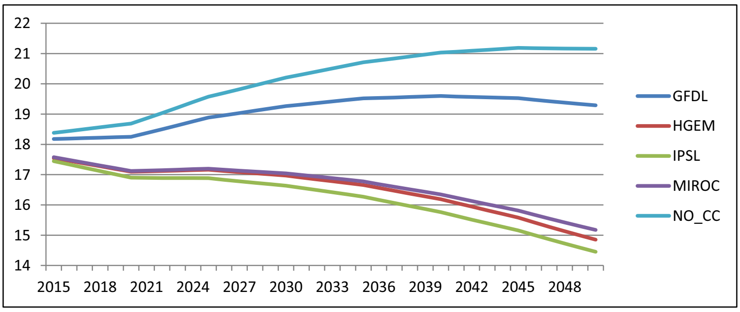

Figure 17: Potato yield in Kazakhstan.

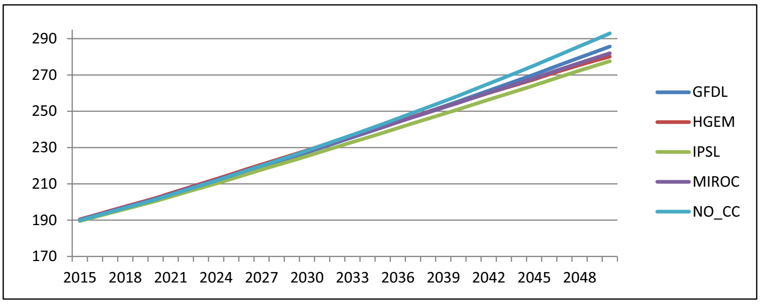

Figure 18: Harvested area of potatoes in Kazakhstan.

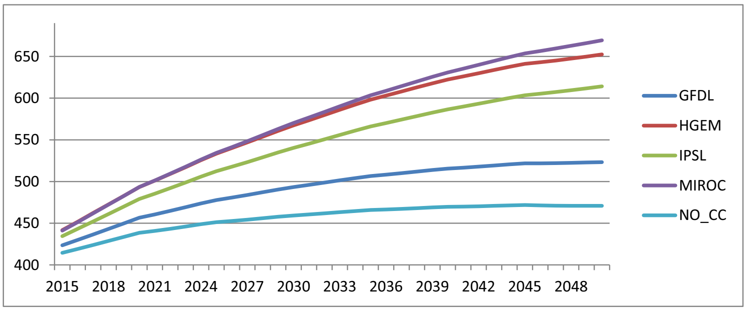

Figure 19: Consumer price of potatoes in Kazakhstan.[6]

cent on average under MIROC, IPSL, and HGEM. Yields seem to be negatively affected by the increase in temperature under GDFL (the scenario with the smallest temperature increase), performing better than the other climate-change scenarios.

Over the same period, the harvested area of potatoes is expected to increase by more than 50 per cent under the no-climate-change scenario (**Figure 18**). Even though climate change will have a significant negative impact on yields, the increase in the global price of potatoes under climate change will almost overcome the large losses in productivity to drive the harvested area only slightly below the baseline scenario, ranging from drops of 2.5 per cent to 5.2 per cent by 2050 (**Figure 19**).

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[6] Yields are given in metric tons per hectare, the harvested areas are in thousands of hectares and the consumer prices are in US dollars per metric ton.

It should be noted that potatoes are grown in temperate, subtropical, and tropical climates and are sensitive to climate fluctuations. Consequently, higher temperatures could lead to different harvesting patterns. In particular, if temperature increases, earlier spring sowing and a more extended harvesting season could potentially be used as an adaptation mechanism, reducing some of the losses that the models project.

Since the potato model used in this study did not account for CO_2 fertilization, it is possible that it was overly pessimistic about yield losses, since potato yields are expected to be boosted by higher concentrations of CO_2 in the atmosphere (Hijmans 2003). Nonetheless, it is unlikely that CO_2 fertilization would be able to compensate for the magnitude of yield losses projected due primarily to temperature increases.

Like our study, long-run forecasts in Hijmans (2003) predict a decline in potato yield due to an increase in the average temperature. In particular, potato yield is expected to shrink by 38.4 per cent from 2040 to 2059 if no adaptation is implemented in Kazakhstan. However, with adaptation strategies, potato yields fall by only 12.4 per cent (Hijmans 2003).

5.3.4 Other crops

The yield of maize will fall relative to the baseline under all scenarios of climate change except GFDL (with the smallest increase in temperature and precipitation rate in the north-eastern part of Kazakhstan). Maize grows mainly in the northern regions of Kazakhstan and therefore, like wheat, the HGEM and IPSL scenarios are the most grim for maize yields (**Figure 20**). Under HGEM, the climate impact on yields could be a reduction of 15 per cent by 2050.

All climate-change scenarios see more land allocated for maize relative to the baseline (**Figure 21**). The largest increase is under MIROC at 13.2 per cent, while the smallest is under

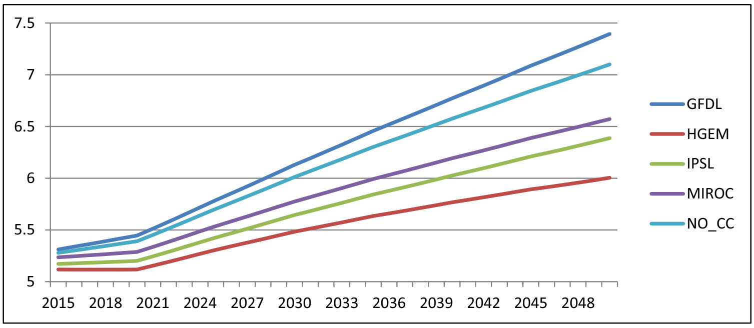

Figure 20: Maize yield in Kazakhstan.

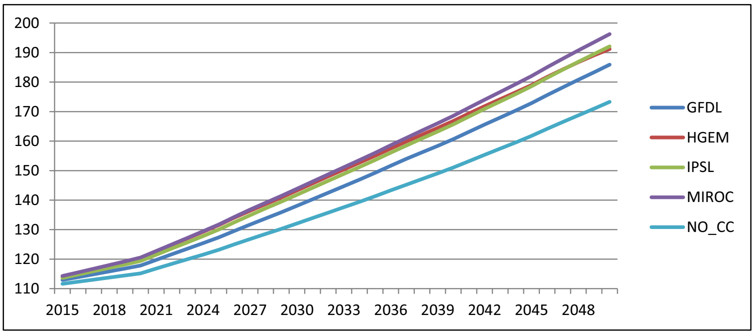

Figure 21: Maize area in Kazakhstan.

GFDL at 7.3 per cent. The expansion in area, despite yield losses, is driven by global price increases under climate change. For example, the largest climate effect on prices in 2050 for maize is under the HGEM model, which has a 55 per cent premium in 2050. IPSL and MIROC have price increases more than 40 per cent higher than the baseline in 2050, while under GFDL price only increases by 17.5 per cent.

Rice grows mainly in the Kyzylorda region of central–south Kazakhstan as well as in the northern regions. The four climate models show almost identical impacts on rice yields relative to the baseline in 2050, each suggesting 24 per cent higher yields (**Figure 22**). This causes the global price of rice to be 13 to 25 per cent higher than the baseline. Together with the productivity effect, prices lead the cultivated rice area to be 12–16 per cent higher than the baseline in 2050. With both area and yield rising, production is 39–45 per cent higher than the baseline in 2050, which in turn leads to nearly 90 per cent more of the rice produced in 2050 under climate change.

Barley yields are projected to grow by almost 50 per cent between 2015 and 2050, not taking climate change into account (**Figure 23**). However, by 2050, climate change will reduce yields relative to the baseline by 1.7–10.1 per cent. Under all climate scenarios growing areas will be lower compared to the baseline in 2050, and will also be lower in absolute terms compared to 2015, though there will be a small increase over that period under the baseline scenario. Overall, while climate change will put a damper on production in 2050 relative to the baseline, production will still have expanded from 2015 levels to anywhere from 22 to 44 per cent higher.

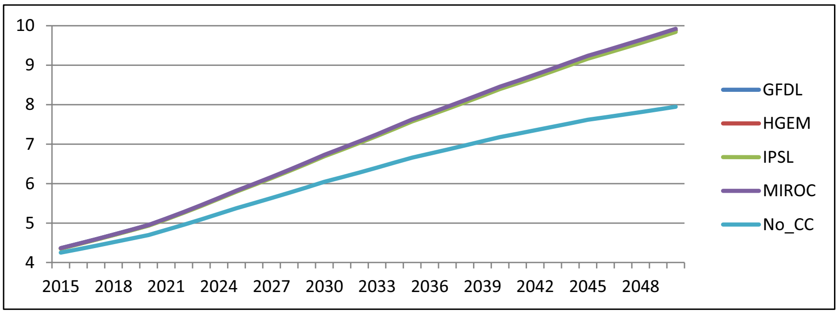

Figure 22: Rice yield in Kazakhstan.

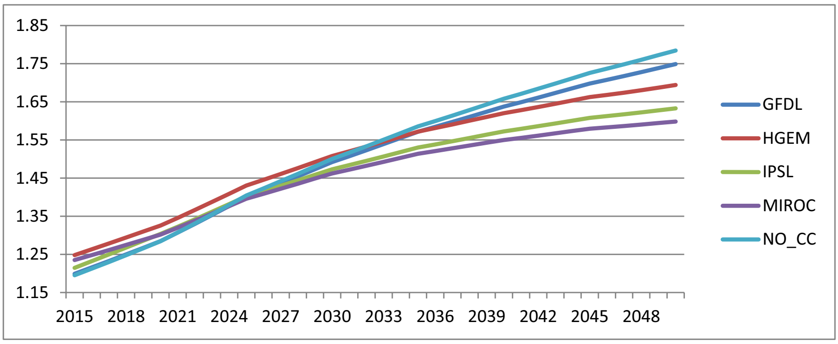

Figure 23: Barley yield in Kazakhstan.

We summarize our study by assembling data on the average effects of predicted climate change on the yields of the main agricultural commodities for Kazakhstan, and data on the level of uncertainty for different geophysical model predictions of the effect of climate change on yields (**Table 8**).

Table 8: The average effects of climate change on crops.

Commodity	Yield increase if no climate change (%, by 2050)	Average increase of the yield due to climate change (%, by 2050)	Uncertainty of prediction (Standard deviation, %, by 2050)
Cotton	25	4	2
Wheat	27	–2	8
Maize	35	–7	8
Potatoes	15	–25	11

The average increase of yield is calculated by finding the average impact of the four climate-change scenarios relative to the no-climate-change scenario. The effect of climate change on cotton is not very significant, +4 per cent, and the magnitude does not depend much on the climate scenario model. The climate change effect for wheat yield largely depends on the climate model, and on average is close to zero. The climate effect for maize yield is –7 per cent. The largest negative effect of climate change for the four crops in **Table 8** applies to potato yield, –25 per cent. There is important variation among the climate models for wheat, maize, and potatoes, since all of them have higher standard deviations, especially compared to that of cotton.

6 Conclusion

In this article, we have analysed the impact of climate change on crop production in Kazakhstan. Understanding the consequences of climate change requires a comprehensive analysis of both economic and population trends as well as evaluation of desertification, glacier melting, epidemic risks, and climate-change adaptation strategy. We used the IMPACT model to analyse the impact of climate change on the production of wheat, potatoes, cotton, maize, rice, and barley.

Asseng et al. (2015) found that climate change is expected to reduce global wheat production. However, our results suggest that Kazakhstan could witness gains in some areas and under some conditions and losses in others. The regression results also confirm that wheat yields are negatively correlated with temperature and positively correlated with precipitation. In light of temperature increases, a possible adaptation strategy for wheat would be to shift planting to earlier months when temperatures are lower. Under the IMPACT model, wheat yields are expected to grow gradually until 2050 under both climate-change and no-climate-change scenarios, driven primarily by improved seeds and management practices, as well as a rise in global prices.

Another strategy that should be investigated is increased planting of winter wheat. With higher temperatures under climate change, Kazakhstan could potentially see significantly higher yields of winter wheat than has been the case historically. The same could be said for barley, which is similar to wheat in many ways and would see some yield increases for the winter variety, and some small to moderate reductions for the spring variety.

Shifting to winter crops could produce some challenges for farmers, many of whom are used to only one harvest per year, and so they might require some training and technical advice to switch to a more complicated system. But winter crops allow for the possibility of more complex crop rotations that might potentially increase yields for crops that have been monocropped in the past, due to the benefits of crop rotation. Income could potentially double for farmers if they are able to harvest two crops each year.

Apart from the impact of climate change, the IMPACT model projects very high growth in yields for rice, increasing almost 90 per cent without climate change and more than 125 per cent with climate change between 2015 and 2050. Barley is also expected to see rapid yield growth, increasing 48 per cent without climate change, though a more modest 36 per cent with climate change (on average), from 2015 to 2050.

Of the important crops for Kazakhstan, potatoes are projected to be most adversely affected, with yield projected to grow only 15 per cent between 2015 and 2050 without climate change, but to decline 10 per cent over the same period on average with climate change. Therefore, it is essential to emphasize the need for further agricultural research on mitigating the negative impact of climate change on potato yields in Kazakhstan and the Central Asian region as a whole.

Competing Interests

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