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RESEARCH

Climate Change, Agriculture and Adaptation Options for Uzbekistan

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Climate change is likely to reshape agriculture in an irrigated, water-scarce transition economy like Uzbekistan. We use the International Food Policy Research Institute'ss International Model for Policy Analysis of Agricultural Commodities and Trade and evaluate the direct effects of climate change on Uzbekistan's agriculture through 2050. We assume the changes in GDP, population, and technological change to be exogenous. We find that climate change and the corresponding temperature increase will have significant adverse effects on the yields for cotton and wheat in the long term through the availability of water, precipitation patterns, crop yields, and the use of land, water, and other natural resources, but harvested area responses may differ. All climate change scenarios are similar in predicting an increase in harvested area for temperate fruits and vegetables, but their yield gains remain conditional on market prices, policy reform, water use, and institutional constraints. For policymakers, this makes climate change adaptation actions an opportunity for incentives and structural reforms as much as one for technology to adjust to the changing environmental circumstances and to ensure food security.

Keywords: climate change; agriculture; adaptation; water; IMPACT model; Uzbekistan
JEL classification: Q11; Q15; Q18

Introduction

At the time of independence in 1991, Uzbekistan was a predominantly agrarian country with a heavy reliance on cotton production. In the years since then, the country has gone through big changes in its industries and agricultural sectors. Aiming to achieve industrialisation, the government has invested heavily in mining and manufacturing. In agriculture, the government of Uzbekistan has pursued self-sufficiency in wheat and significantly increased the area under wheat at the expense of other crops.

Agriculture has gradually declined in importance compared to manufacturing and service sectors, but it still employs 25% of the labour force and provides livelihoods to the majority of

the population residing in rural areas (World Bank 2025). The new government of Uzbekistan adopted a five-year development plan—"Action Development Strategy of Uzbekistan"—for 2017–2021, followed by the Development Strategy of New Uzbekistan for 2022–2026. In 2023, the new "Uzbekistan – 2030" strategy was approved (Development Strategy Center 2025). According to the new strategy, conservation of water resources and environmental protection is one of the key priorities. The strategy emphasises the impact of climate change and the drying of the Aral Sea on the development of agriculture and the livelihoods of people. Recognising the importance of climate change, Uzbekistan joined the Paris Climate Agreement in 2017.

Uzbekistan's agricultural sector is vulnerable to climate change because of its geographical location and aridness of the climate. In some parts of the country, summer temperatures may reach 44°C to 45°C and winter temperatures 25°C to 30°C. In the last 20 years, the average temperature has increased by more than 1°C (Uzhydromet & UNDP Uzbekistan 2015). A total of 90% of agricultural land in Uzbekistan is irrigated, making the sector very much dependent on water availability, especially in peak summer months. Water has become more scarce during the summer months, when it is most needed, due to the changes in precipitation patterns in the region: more rain and snow are falling in spring and early summer months and less in winter months. This also means that Central Asia is receiving more rainfall and less snow than in the second half of the 20th century. Climate change and the resulting melting of glaciers and loss of ice cover over time have had consequences for water use and agriculture in the region (Luterbacher et al. 2008). All climate change studies for Uzbekistan predict that the mean temperature will continue to increase in the next 40–50 years (for example, ENVSEC 2015; Spektorman 2015; Sutton et al. 2013; Uzhydromet & UNDP 2015; World Bank 2010). However, the variability of temperature will differ across the seasons and regions of Uzbekistan. It is expected that summer will become warmer (Uzhydromet & UNDP Uzbekistan 2015) and the number of hot days across the country is forecasted to grow (Spektorman & Plocen 2015). Although there is pretty much a consensus on trends in mean temperature, assessment of the precipitation levels differs depending on the assumptions of the models, geographical zones, and seasons. Precipitation is likely to increase during spring and autumn and decrease during summer (Gupta et al. 2009; Sutton et al. 2013; World Bank 2010). Increase in rainfall level is projected for the desert, steppe, and piedmont zones, while a decrease is expected in the highlands zone (Sutton et al. 2013). Accelerated melting of mountain glaciers will likely compensate for lower snowfall and irregular precipitation patterns.

Most studies project that climate change will affect Uzbekistan's agricultural sector adversely. Impacts on wheat, alfalfa, and pasture are the smallest, while impacts on cotton, vegetables, and fruits are substantial (Gupta et al. 2009; Sutton et al. 2013; Uzhydromet & UNDP Uzbekistan 2015; World Bank 2010). Higher temperatures are expected to increase the mortality rate of livestock, especially cattle and chickens, due to widespread diseases (Sutton et al. 2013; World Bank 2014). Thomas et al. (2021) showed that Central Asia, compared to other regions, is projected to experience greater climate shocks, primarily through temperature changes.

In this study, we contribute to the literature in three ways. First, we apply the Intergovernmental Panel on Climate Change (IPCC)'s Fifth Assessment Report (AR5)-based International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) simulations to a heavily irrigated, water-constrained transition economy in which climate impacts are filtered through institutional legacies of state-led crop allocation and the trade-off between food security and export earnings. Second, we show that climate change adaptation responses may differ. Under the simulated climate change scenario, yields for cotton and wheat fall in the long run, but the harvested cotton area can still grow when global price

incentives dominate, whereas wheat loses both yield and area. Third, we highlight that the effective policy response to climate change is not only biophysical adaptation, but also the result of trade-offs among export earnings, producer incentives, employment opportunities, domestic food availability, water scarcity, and rural livelihoods. In this sense, Uzbekistan provides an analytically useful country case for understanding rapidly changing environmental and economic conditions where institutions, incentives, and reforms remain in transition.

We start the paper by providing a geographic and socio-economic overview. This is followed by discussing the agricultural development and current and future climate trends of Uzbekistan. Then, we present the methodology and assumptions used for the simulations and examine the results. We conclude the report by emphasising the main implications of climate change on agriculture and proposing potential actions for policymakers.

Demographic, Socio-economic, Agricultural, and Climate Overview of Uzbekistan

Uzbekistan is a landlocked country located primarily in the lowlands of Central Asia. The country has common borders with Kazakhstan (to the north-east), Kyrgyzstan and Tajikistan (to the south-east and east), Turkmenistan (to the west), and Afghanistan (to the south). The total area is 448,900 km^2. The major portion of the territory is occupied by desert plains, while the north-eastern and eastern landscapes are characterised by mountains and foothills of the Tyan Shan and Hissar. Plains are situated in the south-west and north-west and consist of the Ustyurt plateau, the Amu Darya delta, and the Kyzylkum desert. The eastern Hissar range is the highest point in Uzbekistan, reaching 4643 m. Most of the country is located between the two biggest rivers in Central Asia: Syrdarya in the north-east and Amudarya in the south-west of the country. Both rivers spring from the Tyan Shan and Pamir mountains in neighbouring Kyrgyzstan and Tajikistan and flow into the Aral Sea. The Aral Sea is located in the north-east of the country on the border with Kazakhstan. Amudarya and Syrdarya are the two major rivers providing the agricultural sector with water. Due to the usage of river waters for irrigation, water flow into the Aral Sea has diminished considerably.

Demographics

Uzbekistan is the most populous Central Asian country; its population reached 38 million in the middle of 2025. The government aims to reduce the national poverty rate to 6% by the end of 2025 from 8.9% in 2024. Most of this progress has come from rural areas (Gazeta 2025).

The population density is approximately 85 people/km^2, compared to 14 people/km^2 in Central Asia. However, population distribution varies within the country. **Figure 1** demonstrates that the most densely inhabited territory is in the Fergana valley (Andijan and Ferghana regions): 500 people/km^2. Population growth rates are highest in the Kashkadarya (46.7 thousand people per year), Samarkand (45.8 thousand people per year), and Andijan (37.2 thousand people per year) regions (Uzhydromet & UNDP Uzbekistan 2015). In the north-west of the country, the Karakalpastan and Navoiy regions have the lowest population density of 7–9 people/km^2 (State Statistics Committee 2024). The population primarily resides in fertile oasis regions and tends to avoid deserts with saline soil and water scarcity.

Figure 2 shows the distribution of population by age group. Uzbekistan has experienced a significant decline in population growth rate, from about 4% in the 1980s to 2% in the 2020s. As a result, the share of children in the total population (population ages 0–14) has gradually declined from 41% in the 1990s to 30% in the 2020s. As the share of the elderly (65 and above) has stayed virtually unchanged, the working age population (15–64 years old) has increased from 56% in 1991 to 63% in 2023.

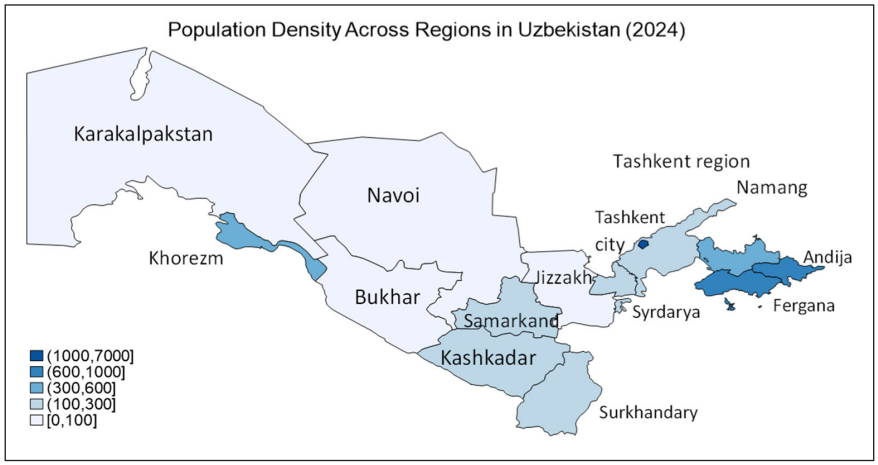


Figure 1: Population density in Uzbekistan.
Source: National Statistics Committee of the Republic of Uzbekistan (2024). Authors' visualisation.

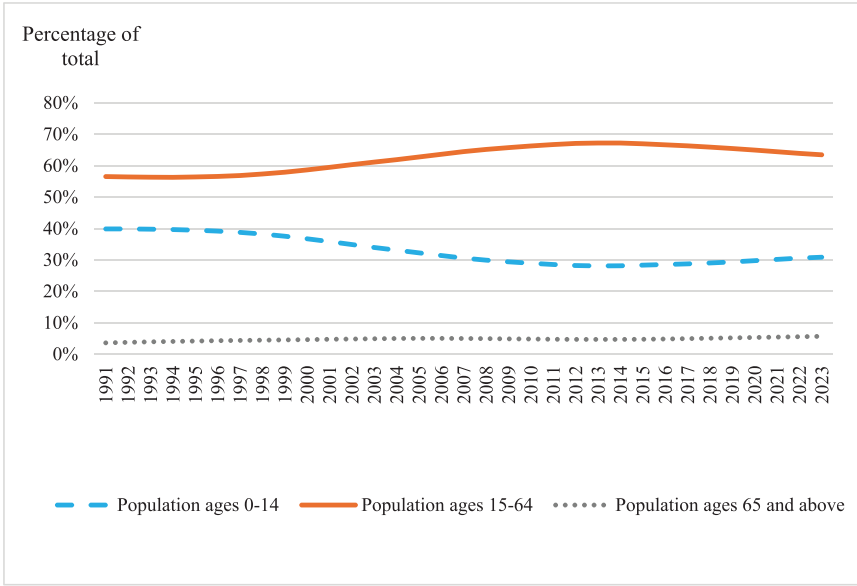


Figure 2: Population trends in Uzbekistan: population aged 0–14 years, 15–64 years, and above 65 years as a share of total, 1991–2023.
Source: World Development Indicators (World Bank 2025).

In the last decade, the population of Uzbekistan has become more mobile internationally. According to Ajwad et al. (2014), about 7% of the population lives outside of Uzbekistan. This indicator of mobility is more than twice the average world indicator (3.2%). The majority of Uzbek citizens residing in foreign countries have migrated in search of jobs and better livelihoods. According to Ahunov et al. (2015), who use data from the 2013 World Bank/GIZ

survey on jobs, skills, and migration and depict a profile of Uzbek migrants, the average age of migrants is lower than the average age of the population. Migration is biased towards men, with 86% of migrants being male and the rest female. Respondents of the survey primarily cite the difficult monetary situation (push factor) and employment opportunities abroad (pull factor) as the main reasons for migration.

Since the early 1990s, agriculture has shed jobs at high rates: agricultural employment has declined from 45% in 1993 to around 25% of total employment in the 2020s. At the same time, the share of industries in employment has remained virtually unchanged. Service sectors have significantly expanded and absorbed most of the labour shed in agriculture. However, the economy's absorption capacity has remained relatively low, and migration to Russia, Kazakhstan, Turkiye, South Korea, and European countries has become a lifeline for hundreds of thousands of households.

Figure 3 shows the number of Uzbek citizens who have received work permits in the Russian Federation. The number of work permits obtained by Uzbek citizens in the Russian Federation started growing dramatically in the mid-2000s, increasing from <70,000 in 2006 to nearly 1,254,000 in 2013. For the period through 2023, as shown in **Figure 4**, remittances have increased from 1 billion USD to about 15 billion USD (World Bank 2025). Remittances are mainly spent on consumption, ensuring food security, and reducing poverty rates in rural areas.

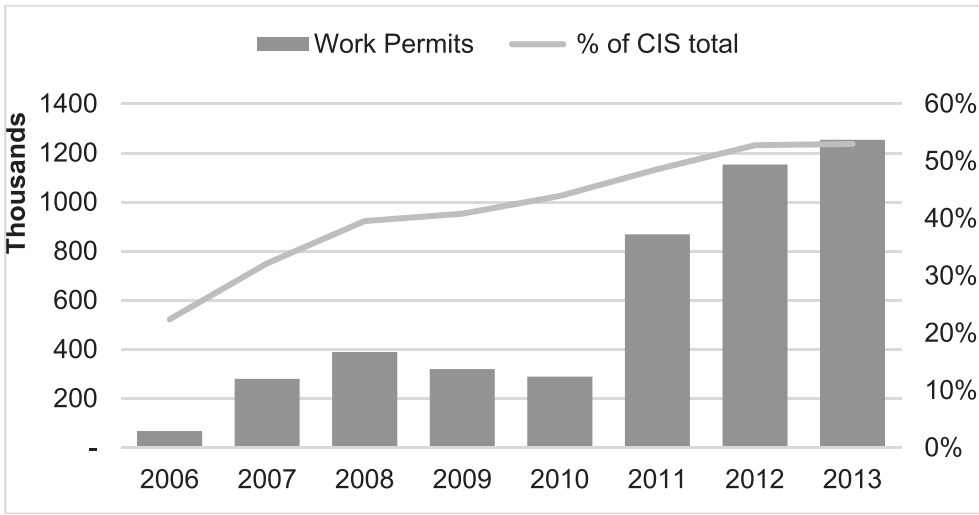


Figure 3: Labour migration of Uzbek citizens to the Russian Federation, 2006–2013. Source: ROSSTAT (2014). Note: CIS = Commonwealth of Independent States.

Population trends

The United Nations (2015) predicts that the population of Uzbekistan will continue growing until 2050. The population growth up to 2050 will be primarily due to the increase in the number of people in the 15–64 age category. The portion of children is forecasted to decrease, while the share of the elderly population over 65 years old is expected to increase (**Figure 5**). The demographics in Uzbekistan will be favourable, as the dependency ratio (the ratio of non-working-age population to working-age population) will continue to fall until

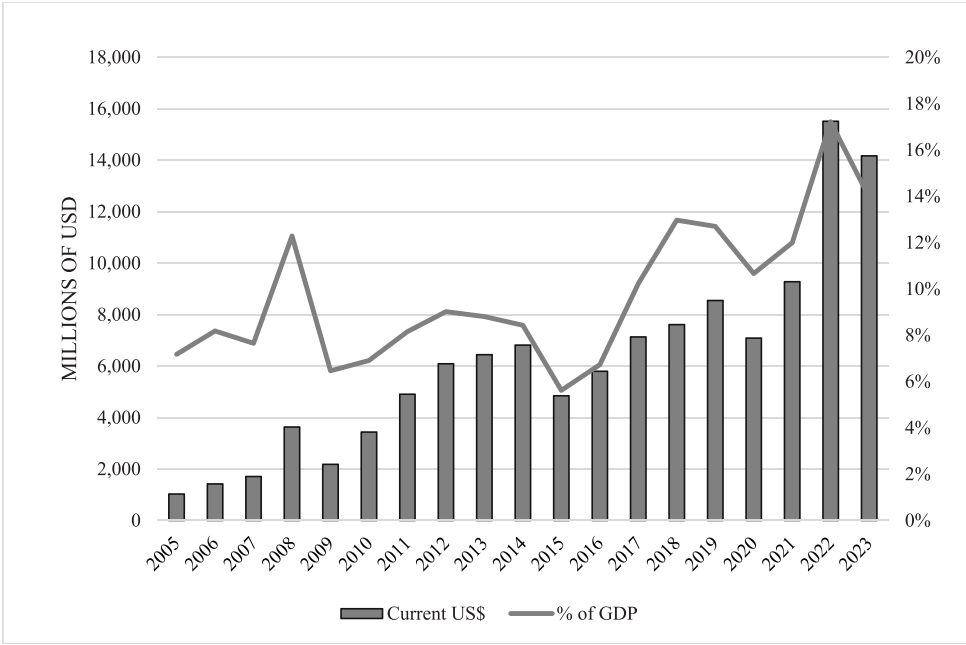


Figure 4: Personal remittances received from Uzbek migrants, 2005–2023.
Source: World Bank (2025).

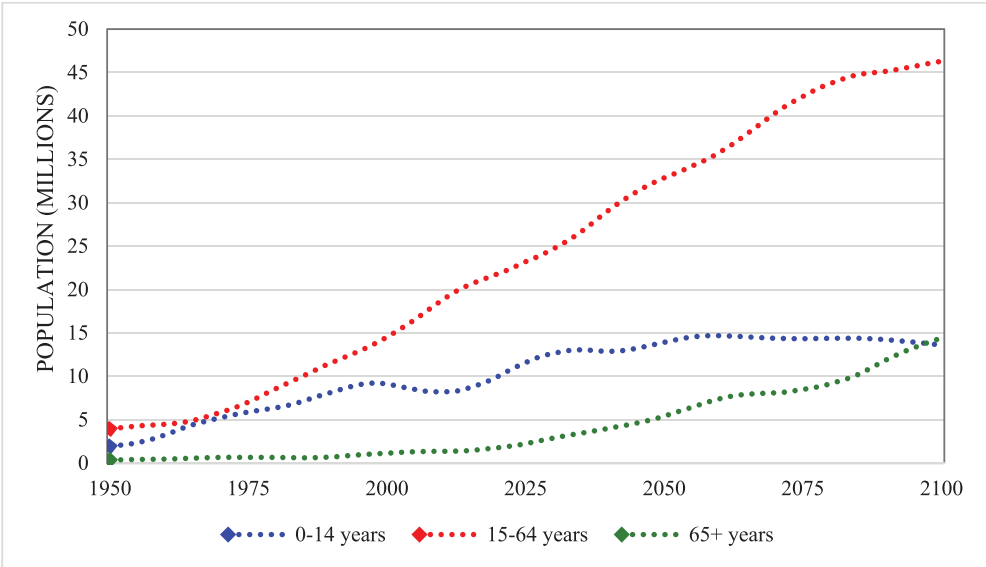


Figure 5: Total population projections by broad age group for Uzbekistan, 2010–2100.
Source: United Nations, World Population Prospects (2024 revision), accessed February 2025.

2050. This provides a unique opportunity to reap benefits in the form of higher economic growth.

Economic development

Past and present

After the collapse of the Soviet Union and the centralised economic system, Uzbekistan's output plummeted. After falling in the first half of the 1990s, output resumed growth in 1996 (**Figure 6**). In the next two decades, economic growth in Uzbekistan was one of the highest in the post-Soviet region.

In 1990, Uzbekistan's agriculture was the largest contributor to GDP (33%), primarily specialising in the production of cotton (**Table 1**). After the collapse of the Soviet Union, the government of Uzbekistan adopted a new agricultural policy aimed at achieving self-sufficiency

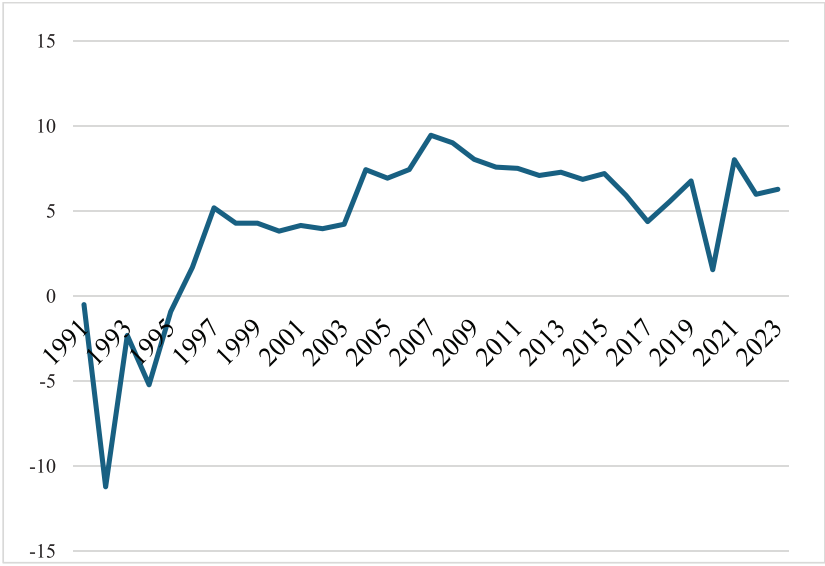


Figure 6: GDP growth rates in Uzbekistan, 1991–2023.
Source: World Development Indicators (World Bank 2025).

Table 1: GDP structure: trend for the period 1990–2023 (% of GDP).

Year	1990	2000	2010	2015	2020	2023
Total	100	100	100	100	100	100
Industry	17.6	14.2	24.1	24	25.6	26.2
Agriculture	33.4	30.1	17.6	17	23.4	19.4
Construction	5.8	6	6.1	8	8.5	7.2
Transportation	5.2	7.7	11.7	43	39.7	43.4
Trade	4.5	10.8	8.8			
Other	22.2	18.7	24.0			
Net taxes	11.3	12.5	7.7	9	6.7	6.2

Source: State Committee for Statistics Yearbook, various years, and World Bank (2015).

in wheat production and food security. At the same time, an industrialisation policy was pursued through massive investments in the industrial sector and import substitution policies. As a result, by 2023, the share of agriculture in GDP decreased to a mere 19%, while the share of industry in GDP increased from 17.6% in 1990 to 26% in 2023. Despite obvious successes in decreasing dependence on agriculture, agriculture still directly employs about 27% of the workforce, and indirectly supports the livelihoods of half of the population living in rural areas (Ajwad et al. 2014).

Well-being of the population

Over the 25 years since independence, GDP per capita (purchasing power parity adjusted, current international) increased from 2,644 USD in 2000 to 11,878 USD in 2024 (World Bank 2025). The prevalence of undernourishment declined from 19% in 2001 to 3% in 2023 (World Bank 2025). In 2015, Uzbekistan was included by the Food and Agriculture Organization (FAO) in the countries that had fulfilled the food security UN Millennium Development Goals.

Positive changes have been observed in the life expectancy and child mortality indicators. **Figure 7** shows that the under-five mortality rate has decreased from 71 in 1991 to 13 per thousand in 2022. Life expectancy at birth has increased slightly from 65 in 1995 to 72 in 2022.

Agricultural Development

Country-specific land, institutional, and policy reforms in agriculture

In Uzbekistan, 46% of the total area is categorised as agricultural land suitable for crop and livestock production (State Statistics Committee 2024). Harvested land constitutes about 20% of this area. Since 2010, total harvested area has shown a downward trend, mainly due to soil salinisation and erosion. Lack of replacement investment in irrigation systems has led to the abandonment of large plots of land in remote areas.

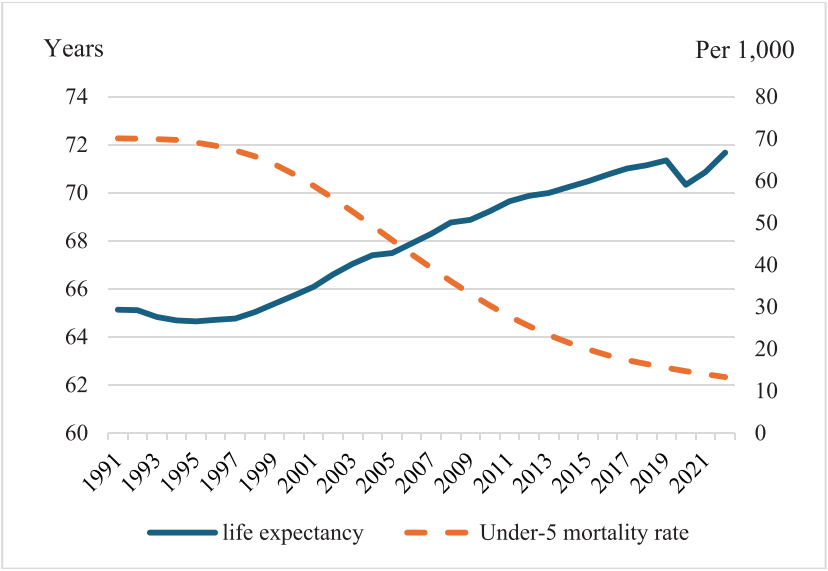


Figure 7: Life expectancy and child mortality rates for Uzbekistan, 1991–2022.
Source: World Development Indicators (World Bank 2025), World Health Organization (2024).

In recent years, there have been over 80 thousand large commercial farms, specialising in growing cotton and wheat, and millions of small dekhan farms.[1] These dekhan farms produce the majority of all crops, including more than 65% of all the country's horticulture crops (Asfaw 2020).

All agricultural land in Uzbekistan is owned by the state. Local khokimiyats (district governments) control cropping patterns at large commercial farms, while dekhan farms are allowed to grow whatever the farmers wish. Additionally, unlike larger farms, where leases must be renewed, leases for dekhan farms are lifetime holdings and can be transferred through inheritance. On paper, household plots cannot be sold, but in reality, they are routinely sold and bought, with transactions disguised as the selling and buying of property on land, not land itself.

Table 2 shows the share of crop farming and livestock production in total agricultural production. In recent years, crop farming has made up about 50% of agricultural production, while livestock accounts for the other half. This ratio has remained stable over the past four to five years.

In the last two decades, agriculture has gone through significant changes in terms of harvested area, production, and yields (**Table 3**). In terms of harvested area, the acreage planted with cotton and wheat has reduced, while fruits, vegetables, melon, and potato have gained acreage. Not only have the latter crops expanded in terms of cropping area, but their yields have also increased by a range of 10% to 30% for the decade. On the contrary, cotton yields have risen modestly, while wheat yields have barely inched up.

Table 4 shows the average numbers of livestock in Uzbekistan between 2005 and 2020 and a dramatic increase in cattle, sheep, and chicken numbers. From 2005 to 2020, all types of livestock registered double-digit increases, while the number of chickens grew at triple-digit rates. The increase in livestock has affected the availability of meat and dairy products positively, better satisfying the needs of the growing population. More than 95% of livestock production is concentrated in dekhan farms, making it difficult to further increase productivity due to the lack of economies of scale. Due to the dramatically decreased production of fodder crops, the absolute majority of livestock is grazed on pastures, leading to overgrazing and erosion of pastures in the country.

Table 5 demonstrates the share of agricultural products for export. The share of cotton in total exports declined between 2000 and 2023 by almost 70%, while the share of food products almost doubled and the contribution of fruits and vegetables increased by more than four times. As a group, fruits and vegetables have become the major export commodity and, by 2023, the export values of fruits and vegetables equalled that of cotton.

Table 2: Agricultural production in 2010–23.

	2010	2015	2020	2023
Total value added	100%	100%	100%	100%
Share of crop farming	58.72%	55.65%	49.49%	50.09%
Share of livestock	41.28%	44.35%	50.51%	49.91%
Growth rates, %				
Crop farming	5.9	5.5	3.2	4.3
Livestock	6.9	6.9	2.1	3.7

Source: State Statistics Committee statistical bulletins, various issues.

[1] In Uzbekistan, all rural households that have household plots are considered dekhan farmers. It is difficult to verify the exact number of such households, but their number is estimated to be around 4.8 million households.

Table 3: Changes in harvested area, production, and yield for leading agricultural commodities in Uzbekistan, 2011–2020.

	Rank by Area Harvested	Thousand Hectares Harvested. Mean for 2011–2020	% Change 2011 to 2020. Hectares Harvested	Thousand Tons Produced. Mean for 2011–2020 (000 mt)	% Change 2011 to 2020. Thousand Tons Produced	Yield (mt/ha). 2011–2020	% Change 2011 to 2020 Yield
Wheat	1	1406	–4.9%	6355.02	–7%	4.55	–2%
Cotton	2	1200.3	–19.2%	2956.89	26%	2.51	10%
Fruits	3	406.2	6.5%	4314.02	35%	10.53	27%
Vegetables	4	203.3	21.8%	10090.6	34%	48.68	10%
Potatoes	5	83.8	22.8%	2793.67	54%	28.28	4%
Barley	6	98.4	37%	142.69	16%	1.69	2%
Melons	7	54	22%	1911.20	50%	34.9	23%
Rice	8	61.9	34.3%	337.76	12%	5.52	–17%
Maize	9	40.1	54%	417.48	63%	10.43	6%

Source: State Statistics Committee, various issues, and FAOSTAT (2015).

Table 4: Livestock in Uzbekistan (million animals).

Item	2005	2013	2020	% Change
Cattle	6.25	9.63	12.17	+95%
Sheep	10.60	16.22	18.09	+71%
Chicken	19.05	42.68	52.01	+173%

Source: State Statistics Committee (2021).

In the last 10 years, Uzbekistan has undergone several waves of agricultural reforms. Under the Agricultural Strategy 2020–2030, Uzbekistan has been moving from administratively controlled cotton and wheat production toward a more market-oriented model. Major reforms have included the abolition of the state cotton order in 2020, abolition of the wheat quota in 2022, liberalisation of cotton and wheat farm-gate prices toward market prices, and relaxation of export restrictions for horticulture (World Bank 2020; World Bank 2022). Cotton-textile clusters and contract farming were introduced. These reforms have helped accelerate incentives for producers and for rebuilding agricultural knowledge and innovation systems (AKIS). The government has also initiated stronger incentives for effective water use and irrigation.

Direct Climate Impact on Yields

The agricultural sector in Uzbekistan is highly dependent on irrigation, with 90% of all crops being produced on irrigated lands. Thus, increasing annual temperature results in growing evaporation and rising demand for irrigation. It is expected that climate change

Table 5: Export values of agricultural products in Uzbekistan, 2000–2023.

	2000	2005	2013	2014	2023
Export value (million USD)					
Total exports	3,264.7	13,044.5	15,080.8	14,663.0	17,739.4
Cotton	897.1	1,474.0	1,162.9	1,036.6	1,380
Food products	176.4	1,265.3	1,479.0	1,559.8	1,287.7
Fruit and vegetables	68.7	1,155.2	1,346.0	1,498.5	1,338
Share in total exports (%)					
Cotton	27.5	11.3	7.7	7.0	7.8
Food products	5.4	9.7	9.8	10.6	7.3
Fruit and vegetables	2.1	8.9	8.9	10.2	7.5

Source: Ministry of Investment, Industry and Trade; State Statistics Committee (2023).

impact will be exacerbated by the decreasing efficiency of irrigation systems and changes in the precipitation regime. Ultimately, this will have a negative impact on yields, reversing the technology gains of recent decades. Uzhydromet and UNDP Uzbekistan (2015) predicts that the negative impact of climate change on individual crop yields will vary from 9% or more in the case of a low-impact scenario to 36% or more in the case of a high-impact scenario (**Table 6**).

Earlier projections from the Hydro Meteorological Office of Uzbekistan (Uzhydromet 2008) are in line with the above-mentioned forecasts. Even without accounting for the impact of climate change through water balance, the Uzhydromet model predicts about a 10% loss in yields for alfalfa, rice, and vegetables and more moderate yield reductions for winter wheat.

The key water resources of Uzbekistan are the Syrdarya and Amudarya rivers. Other water resources are reservoirs and groundwater. **Table 7** shows the water supply in 2025, as well as forecasted water availability by 2050.

Increasing temperatures and reduced precipitation are affecting water availability in summer months. The United Nations Development Programme (UNDP, 2023) predicts that the forecasted water supply by 2040 will be lower, ranging from 8% in a no-climate-change-impact scenario to 33.5% in the high-impact scenario (**Table 8**). The considerable reduction in the water supply comes from increasedwithdrawal of groundwater and decreased flow of water in the Syrdarya and Amudarya rivers. Deteriorating water supply will exacerbate the climate impact on the agricultural sector even more.

Climate change

Current climate

Steady warming of the temperature in Uzbekistan has been observed since at least 1990. **Figure 8** shows that, in comparison with the 1960–1990 period, during the 1990–2020 period, the mean monthly temperature increased in all months but December. The United Nations Environment Programme (UNEP) reports that the mean annual temperature in Uzbekistan has increased nearly three times above the global average compared to the previous 60 years due to climate change (UNEP 2025).

Table 6: Assessment of reduction in crop yields by 2050 (%) by different climate change scenarios.

Type of Crop	Climate Change Scenarios		
	Low	Considerable	Extreme
Fruits	12	18	51
Cotton	11	15	37
Potato	11	17	47
Vegetables	12	16	42
Wheat	9	12	36

Source: Uzhydromet and UNDP Uzbekistan (2015).

Table 7: Current and forecasted water supply in Uzbekistan.

River Basins	Forecasted Water (90% Flow Probability)	Surface Water (Share of Uzbekistan at 90% Flow Probability)	Groundwater	Collector:Drain Water	Available Resources
2025					
Syrdarya	25.7	19.9	1.6	2.6	24.1
Amudarya	60.42	32.5	0.3	2.3	35.1
Total		52.4	1.9	4.9	59.2
Total consumption					52.7
Forecasted for 2050					
Syrdarya	24.4	15.9	1.8–2.0	2.8	22.0
Amudarya	51.36	26.0	0.3–0.5	2.5	30.0
Total		41.9	2.1–2.5	5.3	52.0
Total consumption					62–63
Water deficit					11–13

Source: Asian Development Bank (2022).

In addition, the standard deviation of mean temperature has changed its pattern: in cold months, the standard deviation has decreased, while in warm months, it has increased. The change means that seasonal shift, that is, the shift from autumn to winter and from winter to spring, is happening more rapidly. **Figure 9** demonstrates lower precipitation in March, April, September, and October, which used to be rainy months, but higher rainfall levels for

Table 8: Assessment of irrigation water shortage by 2040 according to climate change impact scenarios.

Basin	No Impact of Climate Change		Moderate Impact		High Impact	
	000 m³	%	000 m³	%	000 m³	%
The east of Syr Darya	615927	11.6	940601	17.5	3627991	51.6
The west of Syr Darya	122023	1.9	325942	4.7	2817031	34.4
Amudarya	2174069	8.7	4087848	17.8	8405243	28.9
Total	2912019	8	6074391	15.4	140850265	33.5

Source: UNDP (2023).

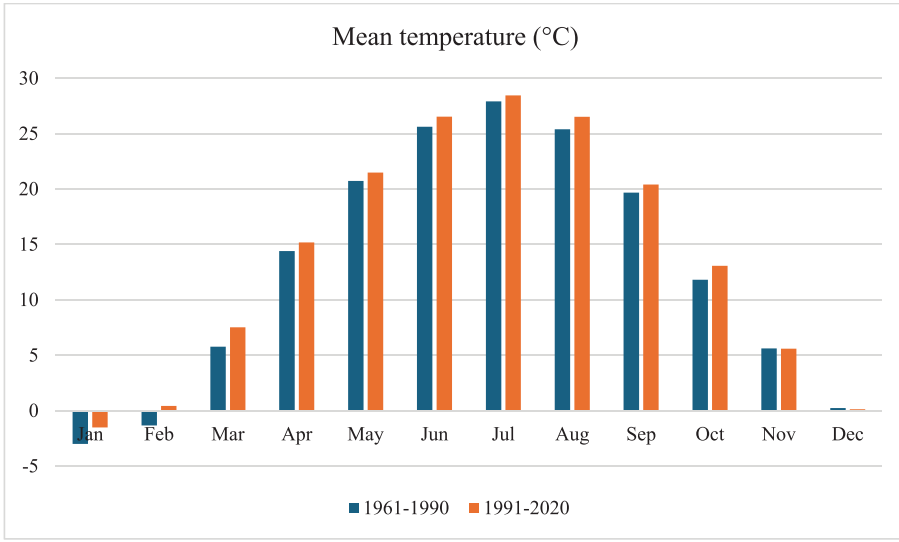


Figure 8: Mean historical monthly temperature in Uzbekistan.
Source: Climatic Research Unit of the University of East Anglia, cited by World Bank Group, Climate Change Knowledge Portal.

all other months. During the driest three months (July–September) precipitation levels fell; in the wettest (February–April) they rose.

Mountain glaciers in Central Asia are an important source of fresh water, providing 10–20% of river flows in the Amudarya and Syrdarya basins. In Central Asia, the average rate of deglaciation is estimated to be about 0.6% to 0.8% per year in area and about 1% per year in volume (UNDP 2011). The total area of the glaciers is estimated to have decreased by three times since 1900 (World Bank 2010; World Bank 2014). Rising temperatures are expected to accelerate glacier melting, jeopardising their long-term use as a source of fresh water.

Fresh water is a scarce good in Uzbekistan, but it is also misused extensively through inefficient and wasteful irrigation practices. Water is frequently over-allocated to cotton and wheat, and under-allocated to environmental flows into the Aral Sea. Because soil in Uzbekistan is

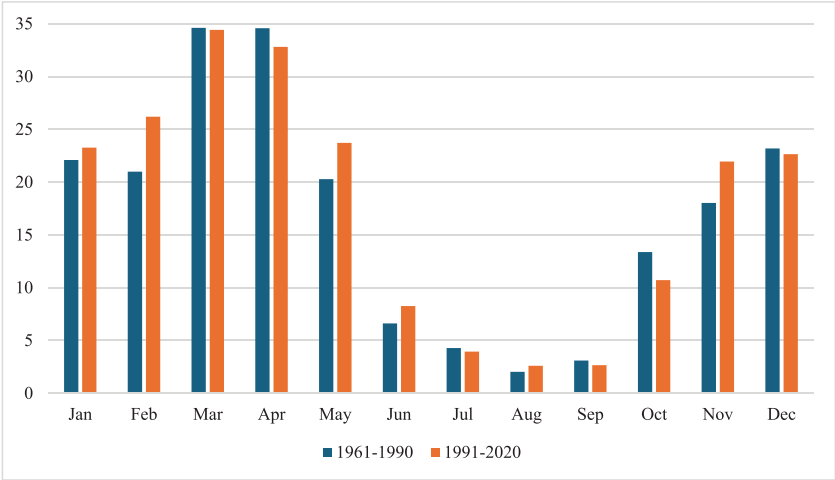


Figure 9: Mean historical precipitation level (mm) in Uzbekistan.
Source: Climatic Research Unit of University of East Anglia, cited by World Bank Group, Climate Change Knowledge Portal.

excessively salinised, water is frequently used to leach salt and minerals by methods such as waterlogging. More than 51% of the irrigated land is salinised to some degree, with 4% strongly saline, 17% moderately saline, and 30% slightly saline (UzHydromet 2008). Due to changes in the temperature and precipitation regime, crop yields may decrease as a result of exposure to new pests and diseases.

Temperature variations are not even across Uzbekistan. In big cities (Tashkent and Ferghana), temperature growth is considerably higher due to the urbanisation effect (Gazeta 2026). For example, the increase in annual mean temperatures in Tashkent is two to three times higher than in other regions (Uzhydromet 2015; Uzhydromet & UNDP Uzbekistan 2015).

Uzhydromet indicates, based on various climate scenarios, that the Ferghana valley is one of the most climate-vulnerable regions in Uzbekistan. Precipitation tends to grow the most in the Ferghana valley and the Tyan Shan ridges. As for river flows, temperature variations will be highest along the Amudarya river, while precipitation level will be highest along the Syrdarya river (Spektorman 2015).

According to Uzhydromet (2015), the largest temperature variations are expected in spring and summer months (the standard deviation of temperature from its mean is expected to steadily increase). This will increase the number of extremely hot days in summer and exacerbate the instability of spring weather. Nighttime temperatures are expected to grow more than daytime temperatures. However, day temperatures may soar to levels that pose risks for people's health, food, and energy supply. In addition to more prolonged periods of hot weather, the number of extremely cold days may also grow.

Regarding precipitation level, in the northern part of Uzbekistan, the level of rainfall is projected to increase during winter and decrease during all other seasons. In the south, winter precipitation is expected to stay unchanged, while during all other seasons it will decrease. Such changes may result in an increased frequency of floods and torrents.

Methodology and Assumptions for the IMPACT Simulations

Our simulations of climate change's impact on agriculture are based on the IMPACT model, which was developed by the International Food Policy Research Institute (IFPRI) researchers at the beginning of the 1990s (Robinson et al. 2015). Over time, IMPACT's core multimarket

economic model has been improved and additional modules have been added to simulate global production, trade, demand, and prices for agricultural commodities. Additional modules include climate models (Earth System Models, ESMs), water models (hydrology, water basin management, and water stress models), crop simulation models (Decision Support System for Agrotechnology Transfer, DSSAT), and welfare analysis.

IMPACT is better suited for simulations of development scenarios. In this respect, IMPACT is not a forecasting model. It is a partial equilibrium model in that it covers only agricultural commodities, and therefore cannot be used to simulate such variables as GDP and factors of production. Different versions of IMPACT have been used in several important research publications to examine the linkage between the production of key food commodities and food demand and security at the national, regional, and global levels (Ignaciuk & Mason-D'Croz 2014; Nelson et al. 2010; Rosegrant et al. 1999; Rosegrant et al. 2005; Scott et al. 2000).

General circulation models (GCMs, sometimes referred to as climate models) are developed by climate scientists to determine how a climate might change in response to greenhouse gas (GHG) accumulation in the upper atmosphere. The IMPACT simulation model run in this study uses the following climate models from the IPCC's AR5:

- GFDL-ESM2M, which was produced by the National Oceanographic and Atmosphere Administration General Fluid Dynamics Laboratory (GFDL; Dunne et al. 2012);
- HadGEM2-ES, the Hadley Centre Global Environmental Model (HadGEM), from the Met Office Hadley Centre (Collins et al. 2011; Martin et al. 2011);
- IPSL-CM5A-LR, generated by Institut Pierre-Simon Laplace (IPSL; Dufresne et al. 2013); and
- MIROC-ESM-CHEM (MIROC) from the Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (University of Tokyo), and National Institute for Environmental Studies (Sakamoto et al. 2012).

In the IPCC's AR5, each GCM was produced with four different representative concentration pathways (RCPs), which indicate the pattern of emissions and accumulation of GHGs. RCPs (RCP2.6, RCP4.5, RCP6.0, RCP8.5) show the different climate scenarios corresponding to the amount of accumulated GHGs, with those with higher numbers associated with higher emissions. In our study, the GCMs are based on RCP8.5.

Most papers that have studied climate change and its impact on agriculture in Central Asia and Uzbekistan agree that the impact of climate change on agriculture will be largely negative. Some previous studies have suggested that the average temperature in Uzbekistan is expected to increase by 2–3°C over the next 50 years (ENVSEC 2015; Sutton et al. 2013). The GCMs used in this paper project an even higher increase in temperature by 2050 (Thomas 2017), with the mean daily maximum temperature of the warmest month rising by between 2.7°C and 4.9°C on average across Uzbekistan. Precipitation levels are forecasted to increase during fall and winter, but are expected to decrease during summer. Coupled with higher evaporation rates, this will lead to wetter off-season months and drier summer months, putting additional strain on irrigation infrastructure.

IMPACT takes as inputs GDP and population growth based on the shared socioeconomic pathways (SSPs) developed for the IPCC to analyse the impact of climate change on the global economy and people in general. In this report, we use the SSP2 ('middle of the road') scenario. SSP2 assumes that both GDP and population will take values that are neither too low nor too high. National income and population growth rates will mostly be governed by the trends of recent periods. Per-capita income levels will grow at a medium pace, based on the global average, and income levels in developing and industrialised economies will converge slowly. Population growth will put increased pressure on resources, and improvements in

air pollution and access to energy will be modest. Vulnerability to climate and other global changes will decrease marginally over time.

In addition to economic and climate models, we have also made several assumptions about land and water availability in Uzbekistan. Since 1992, arable land area in Uzbekistan has decreased by about 75,000 ha, or by 1.7%. Most of the decline happened in the 1990s, and since then the arable land area has remained remarkably stable. In our projections through 2050, we assume that the overall arable land area will remain fixed for the period until 2050. This assumption does not seem to be overly restrictive, since, in the context of lower investments into the irrigation system and acute shortage of water, it would be difficult to expand the arable land area.

In terms of basin efficiency, we assume that it will continue to decline until 2020 as it did between 2005 and 2014. We assume that greater investments in irrigation facilities and wider use of new technologies will arrest the decline and slowly improve the basin's efficiency after 2020. In addition to basin efficiency, we also assume that water storage capacity in Uzbekistan will increase by 1% annually between 2015 and 2030, and by a more modest 0.5% annually thereafter. The government of Uzbekistan has been investing heavily in building additional water reservoirs as an adaptation strategy for climate change and expected water shortage in vegetation periods.

Critics of simulation models like IMPACT often claim that simulation models do not take into account policy interventions capable of restricting markets. One implication of this is that in a country like Uzbekistan, with its extensive government regulations and price interventions in agriculture, simulation results need to be interpreted with caution. However, when government decisions and interventions are prompted by economic efficiency motives, outcomes of the government interventions might be similar to the outcomes of market decisions reflecting underlying supply and demand forces. Thus, as long as producers pursue profit maximisation and consumers seek utility maximisation, IMPACT results will be relatively meaningful for detecting overall trends and modelling long-term outcomes given basic pricing and production decisions.

Our IMPACT Simulation Model Projections

Cotton and Wheat Yield and Land Allocation

Demand for cotton and wheat in the long run is determined by global economic growth and population changes, factors which result in increased consumption, trade, and prices of cotton. After all-time high price levels seen in 2009–2011, agricultural commodities have entered a correction phase, and prices for many commodities, including cotton, have significantly fluctuated. Demand for cotton and wheat has remained more or less stable for several years.

Figure 10 shows projections for cotton (lint) and wheat yield in Uzbekistan for the abovementioned scenarios. What is remarkable is that both the no-climate-change scenario and the climate change scenarios predict slow increases and subsequent declines in both cotton and wheat yields over time. All climate change scenarios show lower yields compared to the no-climate-change scenario throughout the period. Variation among different climate change scenarios is smaller in cotton yield, but sizable in wheat yields.

Despite a significant reduction in cotton yields due to climate change, as compared to what would happen without climate change, we also note that the climate change and no-climate-change scenarios are alike in predicting slight increases in harvested area for cotton (**Figure 11**), with a greater increase in area under climate change. The rise is driven largely by the increase in international cotton prices. Global demand for cotton is projected to increase, putting significant upward pressure on prices.

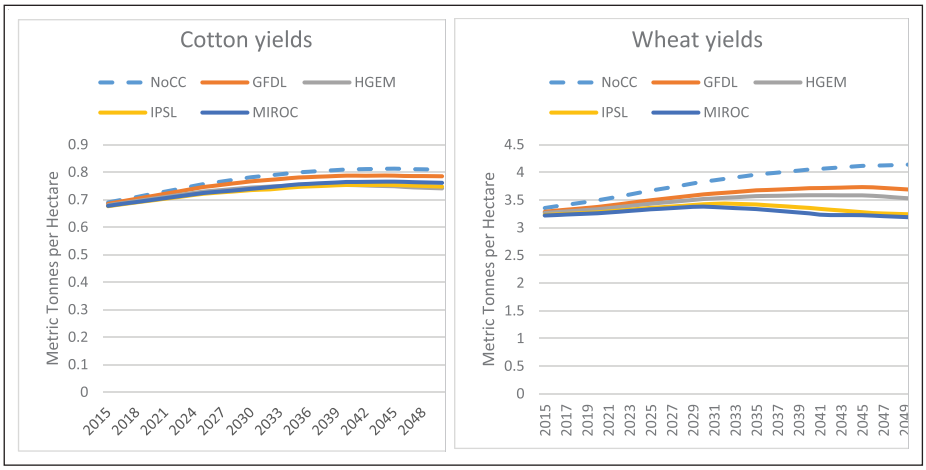


Figure 10: Yield projections from the IMPACT model: cotton and wheat in Uzbekistan, 2015–2050, RCP8.5.
Source: Authors' simulations.
Note: Global Climate Models: NoCC, No Climate Change; GFDL, Geophysical Fluid Dynamics Laboratory; HGEM, High-Resolution Global Environmental Model; IPSL, Institut Pierre-Simon Laplace; MIROC, Model for Interdisciplinary Research on Climate.

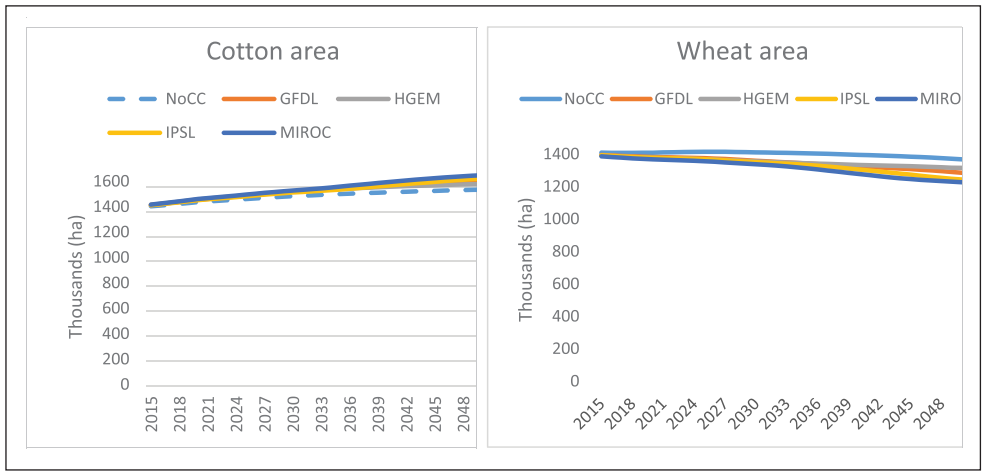


Figure 11: Area projections from the IMPACT model: cotton and wheat in Uzbekistan, 2015–2050, RCP8.5.
Source: Authors' simulations.
Note: Global Climate Models: NoCC, No Climate Change; GFDL, Geophysical Fluid Dynamics Laboratory; HGEM, High-Resolution Global Environmental Model; IPSL, Institut Pierre-Simon Laplace; MIROC, Model for Interdisciplinary Research on Climate.

In the case of wheat, however, all scenarios predict that harvested area will steadily decrease. Climate change scenarios predict greater declines in harvested area than without climate change. Coupled with the decline in yields, the results show that it is economically efficient

to decrease the area under wheat and reallocate the land to other crops better suited for climate change.

Fruit and Vegetable Yield and Land Allocation

Demand for fruits and vegetables has been on the rise worldwide due to population growth and rising incomes. As a result, IMPACT predicts that global prices of fruits and vegetables will increase. Production of fruits and vegetables is expected to keep up with the increase in population. Due to innovations in processing and transportation, trade in fruits and vegetables (both unprocessed and processed) has grown faster than their production, making previously non-tradable varieties tradable. **Figure 12** shows projections for fruit and vegetable yields in Uzbekistan for the above-mentioned scenarios. All scenarios are unanimous in their predictions that fruit and vegetable yields will increase, at least through 2035. However, yields are projected to slow and perhaps even decline by 2050 for both groups. There is small variation among different climate change scenarios, HadGEM being the most optimistic in the long run for fruits and very close to the GFDL GCM for vegetables. MIROC is the most pessimistic for fruit yields and IPSL the most pessimistic for vegetable yields.

Climate change and no-climate-change scenarios are alike in predicting steady increases in harvested area for fruits and vegetables (**Figure 13**). This result is due to higher global prices driven by growing demand for fruits and vegetables.

Summary and Policy Recommendations

The climate change simulation scenarios matter because they imply different welfare effects across crops and across policy objectives. For example, in a water-scarce setting, more land for cotton may help maintain export earnings and textile value chains, yet it may also put more pressure on irrigation systems if water availability and use are weakly monitored. At the same time, lower cotton yields could be offset by price increases or productivity gains.

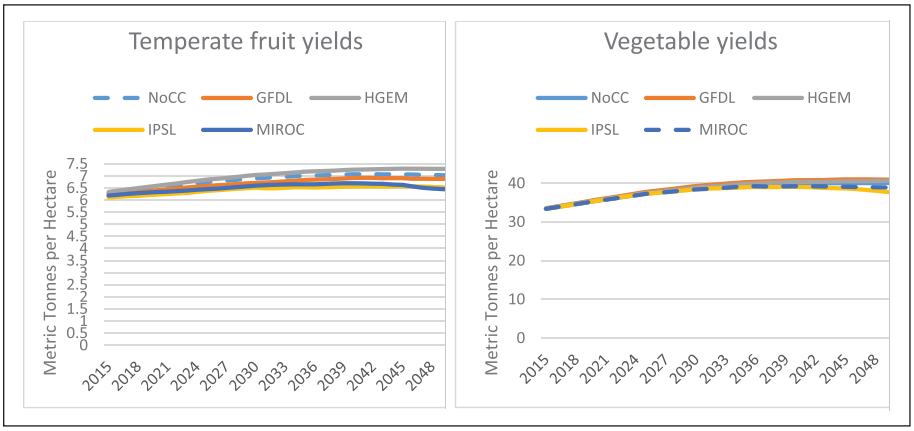


Figure 12: Yield projections from the IMPACT model: fruits and vegetables in Uzbekistan, 2015–2050, RCP8.5.

Source: Authors' simulations.

Note: Global Climate Models: NoCC, No Climate Change; GFDL, Geophysical Fluid Dynamics Laboratory; HGEM, High-Resolution Global Environmental Model; IPSL, Institut Pierre-Simon Laplace; MIROC, Model for Interdisciplinary Research on Climate.

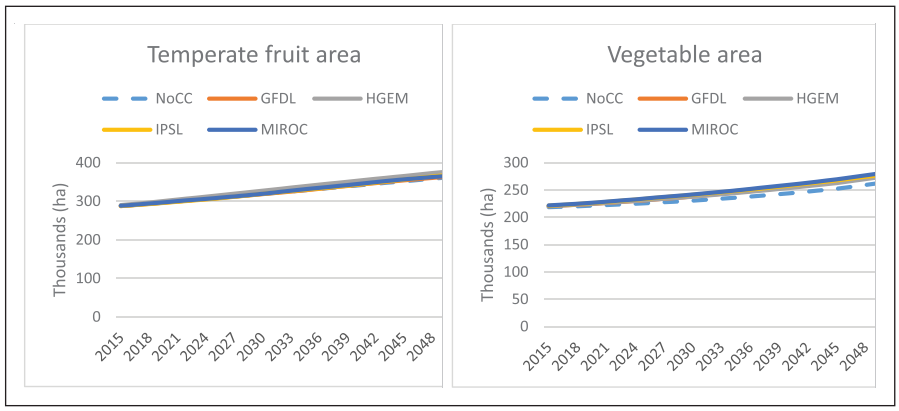


Figure 13: Area projections from the IMPACT model: fruits and vegetables in Uzbekistan, 2015–2050, RCP8.5.

Source: Authors' simulations.

Note: Global Climate Models: NoCC, No Climate Change; GFDL, Geophysical Fluid Dynamics Laboratory; HGEM, High-Resolution Global Environmental Model; IPSL, Institut Pierre-Simon Laplace, MIROC, Model for Interdisciplinary Research on Climate.

For wheat, climate change simulation results show falling yields and declining harvested area. Wheat has long been tied to food security self-sufficiency policy in Uzbekistan. This suggests a higher risk to domestic supply unless offset through higher productivity in yield growth, strategic storage, and trade-based instruments rather than area mandates. There is a central trade-off: cotton area may remain attractive because of stronger global cotton price incentives, while wheat may become more difficult to sustain through traditional self-sufficiency strategies.

The projected results for horticulture are very promising news for both employment and higher value added. The World Bank report (2020) shows that the horticulture sector in Uzbekistan is more productive, uses less water than cotton, and has the strongest job-creation potential if accompanied by modernisation and productivity growth. However, these long-run gains are not automatic; they depend on supply chains, logistics, finance, export facilitation, farmer extension services, public investment priorities, and storage facilities, as well as water scarcity and broader climate damage. Without any climate action and adaptation, the overall economy of Uzbekistan could be about 10% smaller by 2050 in a no-climate-damage pathway (World Bank 2023).

Uzbekistan's rapidly increasing population needs an ever-growing supply of food, and more than one-quarter of households' livelihoods directly depend on agriculture. The high degree of reliance of Uzbek agriculture on water resources for irrigation makes the sector vulnerable to climate change. The wheat self-sufficiency policy the Uzbek government has pursued since the early 1990s has resulted in a duopoly of cotton and wheat and marginalisation of other crops. The government has realised that greater diversification is needed and started increasing the area under fruits and vegetables, primarily at the expense of cotton area (Buriev et al. 2017). At the same time, the government of Uzbekistan has recently implemented significant reforms in its agricultural sector to address climate change, particularly water scarcity and extreme temperatures. For instance, the government has prioritised initiatives like the liberalisation of cotton production and the reduction of the amount of land devoted to cotton. This has boosted the production of fruits, vegetables, and livestock. Efficient irrigation systems and sustainable farming practices have been introduced, such as drip irrigation to

improve water management. However, climate change adaptation constraints persist, particularly in the widespread adoption of climate-resilient farming practices and technologies, due to limited access to finance, outdated infrastructure, and a lack of technical expertise (training) among farmers.

Climate change and the corresponding temperature increases will have significant adverse effects on the production and consumption of agricultural produce. All estimates and forecasts suggest that in the next 40–50 years temperature may increase by at least 2–6°C. The acceleration of warming in the region will have an adverse effect on availability of water, precipitation patterns, crop yields, and use of land, water, and other natural resources.

IMPACT predicts that climate change will negatively affect the yields for cotton and wheat in the long term, but, due to the greater price increase for cotton, harvested areas for cotton and wheat will show differing trends. All climate change scenarios are similar in predicting an increase in harvested area for temperate fruits, but yields are significantly lower compared to the no-climate-change scenario. The impact of climate change on vegetable yield is mixed, but as a result of increases in prices under climate change, it will have a net positive effect on harvested area.

What can and should policymakers do to address future pressure points? Climate change challenges are best addressed by dissecting them for different circumstances and different time lengths. A set of policies should differentiate policies for lowlands and highlands, deserts/steppe and piedmonts/highlands, rural and urban, short term and long term. However, some general mitigation and adaptation policies and priorities can still be developed to better address the challenges associated with climate change. In particular, the government, farmers, and private sector should consider the following measures as a priority:

1. **Improve the climate adaptation capacity[2] of the state, farmers, and extension agents and expand climate-smart transition support**. The challenges climate change poses and the risks it brings cannot be effectively dealt with without mainstreaming climate change into government policies and long-term plans. These policies and plans should be primarily about enhancing the adaptation capacity of institutions, farmers, and individuals under climate stress. Adaptation capacity begins with good research on climate change scenarios and their impact on agriculture, development of plans and adjustment of costs for necessary investments in infrastructure, localised advisory services and on-farm monitoring, and AKIS, and ends with implementation of those plans. In parallel, curricula at agrarian universities and colleges should be revised to reflect the current climate trends and local conditions, challenges, technologies, and market demands. The government should use social protection so that smallholders and poorer rural households can participate in the climate-smart transition and experiment with cropping patterns, continuously adapt to local conditions, and test different seeds and technologies.
2. **Accelerate diversification toward horticulture and other higher-value crop varieties and livestock breeds that are climate-resilient and less water intensive**. Simulation results show that horticulture offers stronger employment and value-added potential than the traditional cotton–wheat scenario. Water requirements for cultivating crops and breeding animals will increase, not only making water scarcer but also

[2] Adaptation (or adaptive) capacity is the capacity of a system to adapt if the environment where the system exists is changing. The adaptation capacity confers resilience to perturbation, giving ecological and human social systems the ability to reconfigure themselves with minimum loss of function.

making its supply less predictable. Introduction of climate-resilient new varieties and breeds must be high on the agenda of policymakers to better adapt to the changing climatic conditions. Introduction of new varieties can be an effective way of adapting to climate change only if it is localised and contextualised. A further measure would be to strengthen smallholder farmers' access to quality seeds and planting material for main crops originating in Central Asia. These would include apple, apricot, pomegranate, grape, carrot, and onion. Agricultural research and extension services are key in identifying the new varieties and breeds with the characteristics farmers want. Furthermore, diversity of crop varieties and livestock breeds is a key adaptation tool in adverse environmental conditions, such as loss of biodiversity, vulnerability to pests and diseases, and yield decline.

3. **Improve efficiency of water use and management and make water saving visible in producer incentives**. In addition to greater demand for water due to the higher temperature and greater seasonal variation, general water runoff is expected to gradually decline in main rivers of the region, the Amudarya and Syrdarya. Coupled with an increase in output relative to water usage, this will require mass introduction of water-saving technologies, including basin-level efficiency as well as on-farm capacity to use water optimally. The World Bank's preliminary analysis shows that the construction of water storage capacity in plain landscape is not cost-effective (World Bank 2015:124). Mass introduction of water-saving technologies at farm level is not possible without introducing a tax (fee) for water first. The existing quasi-fee in Uzbekistan (water-user associations' 'membership' fee) depends on land size, not the amount of water consumed. Therefore, it provides little incentive to farmers to save water or invest in water-saving technologies such as smart monitoring and metering, sprinkler and drip irrigation, and precision agriculture. The most cost-efficient water saving occurs at farm level, and the single most important measure the government of Uzbekistan could implement in a few years would be to mandate farmers to use laser levelling of the irrigated land. Despite numerous pilots showing that laser levelling can on average save 30–40% of fresh water, it is not used widely by farmers. Cotton clusters could be re-oriented toward water-saving incentives.

In sum, Uzbekistan offers a broad lesson for irrigated transition economies: climate change does not reduce yields automatically, but it interacts with water scarcity, price incentives, and ongoing agricultural reforms. Therefore, trade-offs between food security and adaptation options may intensify because they not only depend on agronomy but also on institutional constraints, market prices, and public policies.

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Competing Interests

The authors have no competing interests to declare.

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