Climate Inaction Report

Implications of Climate Inaction across the Water-Agriculture-Energy Nexus and Potential Benefits of Improved Intersectoral and Regional Cooperation

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Disclaimer:

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In brief

Climate change has profound implications for the economies of Central Asian nations. While changing temperatures may not impact water adequacy for key sectors in the medium term, a looming water shortage threatens agriculture, energy generation, and more in the long run. **The overall cost of inaction in the short and medium term is projected to reach $76 billion.** This estimate draws from data on the potential economic losses in each country's sectors and the untapped benefits of regional cooperation until 2050.

The effective management of climate change in Central Asia hinges on decision-makers' understanding of the risk management approach across sectors and its efficient implementation. As outlined in this study, the anticipated consequences of climate inaction do not encompass potential spillover effects such as climate-induced migration and health impacts. While this study provides a comprehensive overview of climate change's impact on the water, agriculture, and energy sectors in Central Asian countries, future in-depth research that incorporates detailed macroeconomic considerations is essential for devising and enabling appropriate responses to climate change's consequences in the region.

This study recommends the following national-level actions in the water sector: **modernize infrastructure, improve the maintenance and monitoring of water facilities, enhance climate risk-related decision-making and preparedness, enhance research and the digitalization in the water sector, and implement flood-control measures.** This study also proposes the following national policy actions in the agriculture sector: **introduce new approaches in wheat cultivation, promote crop diversification, encourage climate-smart agricultural practices, improve pasture management, and implement agroforestry and soil conservation measures.** Additionally, this study outlines national-level policy actions in the energy sector that **include capitalizing on solar and wind opportunities, promoting energy conservation and awareness, and developing climate-resilient energy infrastructure**.

Crucial regional actions by Central Asian countries include **the establishment of a regional climate change cooperation framework, increased investment in transboundary infrastructure, and the initiation of regional data-sharing practices**.

The effective implementation of the outlined national and regional climate actions necessitates a thorough analysis of national contexts and their sectoral risk assessments. This calls for national and regional capacity-building workshops aimed at comprehending contextualized climate change measures in the region.

Executive Summary

Climate change, without a doubt, presents additional headwinds to already strained water resources that affect agricultural productivity and energy infrastructure in Central Asian countries. Strained water resources is already having ripple effects on these economies. The medium- and long-term projections suggest the consequences of climate inaction in Central Asia might get progressively calamitous.

The combined costs of climate inaction across the three sectors, coupled with the untapped benefits of regional cooperation, total $76 billion for the Central Asian economies in the short and medium term, equivalent to 22% of the region's current gross domestic product (GDP). Although this estimate is based on available data and information, the actual impact of climate change may surpass these projections and lead to multifaceted transformations in the region's economies.

The water, agriculture, and energy sectors stand as foundational pillars of economic development in Central Asia, and their effective management has been a critical aspect of interstate relations since the region gained independence. The unequal distribution of energy, water, and land resources creates significant interdependencies, tensions, and conflicting interests among the upstream and downstream countries. The consequences of climate change exacerbate these challenges with the potential to escalate regional tensions; however, amidst these challenges lie opportunities for collaboration. Concerted climate action can serve as a key driver in unlocking these possibilities.

This study aims to offer stakeholders insights into the potential climate impacts on five Central Asian countries by emphasizing the repercussions of climate inaction on the water, agriculture, and energy sectors. The various sections of the report collectively contribute valuable perspectives for stakeholders involved in this work.

The introduction provides an overview and outlines the study's methodology. The analysis is based on two emission pathways: the highest emissions pathway (SSP5-8.5/RCP8.5) and the lowest emissions pathway (SSP1-2.6/RCP2.6). Utilizing information from diverse sources, the study aims to scrutinize and discern the implications—both financial and non-financial—of climate inaction. While economic modeling was not utilized, the author conducted a desk review and interviews to gather, organize, and analyze country-specific data with sufficient detail for informed recommendations.

The regional context section delves into tends in climate change and their impact on the water, agriculture, and energy sectors at a regional scale. The section outlines the aggregate sectoral impact of climate change and depicts changes in Central Asian countries' resilience to climate change between 2016 and 2021 based on the Notre Dame global adaptation initiative (ND-GAIN) country index.

In the country overview section, this study presents the specific impacts and consequences of climate change on the water, agricultural, and energy sectors of each Central Asian country, shedding light on their economic and social implications. The key messages of this section are as follows:

Kazakhstan The potential consequences of climate change in Kazakhstan include a 1.6% reduction in its economy by 2050, a 3% increase in poverty rates, and a 2.1% decline in real wages. By 2040, water shortages amounting to 50% of the country's needs may occur, which will affect various sectors and potentially leading to a 6% decrease in GDP by 2050. Additionally, spring wheat yields in certain regions are projected to decrease by 13%–37% by 2030 and 20%–49% by 2050. The reduction in areas under cultivation will cause economic losses of up to $1.3 billion in the agriculture sector. The energy sector could also face considerable costs, reaching $1.5 billion annually. The country's average annual flood-related losses are estimated at $419 million, with the potential for further increases due to the escalating impact on infrastructure.

Kyrgyz Republic. In the SSP5-8.5 scenario, the Kyrgyz Republic faces a potential loss of 50% of the Tien Shan glacier's volume by 2050, which will have a significant impact on water resources. The estimated 40% reduction in runoff poses a serious threat to agriculture, which relies heavily on irrigation (92%–96% of total water usage). This will jeopardize public health, food security, and Kyrgyz Republic's national economy. The fertility of arable land is expected to decline steadily, with desert and semi-desert areas expanding from 15% (in 2000) to 23.3%–49.7% (in 2100). Consequently, wheat, sugar beet, and fruit crops in the Chui region, as well as wheat and barley in Talas, may experience decreased yields. Hydropower, a vital source of energy source—about 90% of Kyrgyz Republic's electricity), faces a 20% reduction in generation due to the negative impact if climate change. In addition, the country is at risk of an average annual flood-related loss exceeding $73 million.

Tajikistan. Tajikistan, 95% of which encompasses mountainous terrain, serves as a water source for 60% of Central Asia, which also relies on water for 95% of its electricity. Glacial volumes are projected to decrease by 25%–30% by 2050 with a concurrent 6%–15% increase in river runoff, which increases the risk of floods. Potential glacial lake outburst flood (GLOF) events may incur economic costs of up to 20% of GDP or an estimated annual loss of $48 million from all flood types. Climate vulnerability hinders the full utilization of hydropower potential and contributes electricity shortages of 2.2–2.5 billion kWh during winter, equivalent to 15.5% of annual production. A climate-induced decline in hydropower can exacerbate energy scarcity. In agriculture, key crops like wheat, barley, maize, vegetables, and fruits, may experience yield declines of 5%–10% by 2050.

Turkmenistan. Due to its arid climate, more than 80% of Turkmenistan's territory lacks a constant source of surface water. More than 95% of Turkmenistan's water originates outside the country. Approximately 90% of this water is derived from the Amudarya River, which flows through multiple international boundaries and is set to diminish in scale of available water. Over 90% of this water is consumed by the agriculture sector. Yet, around 50% of the water is lost between withdrawal and ultimate delivery due to the inefficient water supply chain. The low water levels of rivers are aggravated by climate warming, a decrease in precipitation, which increases the risk of hydrological drought and desertification. This increases the scarcity of water resources and has negative impact on agriculture. The losses in crop production alone due to augmenting drought years could cost for Turkmenistan $20 billion until 2030. Climate change also leads to a 10% annual increase in floods and mudflows, a 5% annual increase in heavy rainfall, and gradual increases in the frequency and intensity of heatwaves. In the RCP8.5 scenario, Turkmenistan's annual loss from floods is $140 million.

Uzbekistan. Uzbekistan's agricultural water use held steady at 89%–92% of the total between 2009 and 2017, with about one-third lost due to inefficiencies at a cost of approximately 8% of the GDP. Projections suggest a potential decrease in the Syrdarya and Amudarya's downstream inflows of 22%–28% and 26%–35%, respectively, by mid-century, which will lead to severe water shortages with up to 50% unmet demand. Half of Uzbekistan's 4.3 million hectares of irrigated land faces soil salinity, reaching 100% salinization in Karakalpakstan. Without proactive adaptation, climate change may reduce crop yields by up to 50% by 2050. In the energy sector, rising temperatures could alter the duration of heating and cooling seasons by 9% and 16%, respectively, by 2030 under high emissions. Although 15% of the country faces high seismic risk, over half the population resides in high-risk areas. These areas also generate 65.5% of Uzbekistan's GDP. Floods impact 1.4 million people and causing nearly $3 billion in losses.

The next section illustrates the advantages of regional cooperation and a nexus approach, and emphasizes the potential gains from collaborative efforts and intersectoral initiatives. Recognizing the pivotal role of water amidst rising temperatures and its historical significance in fostering regional collaboration, this study proposes the formulation of a regional cooperation framework with water at its core—an essential element for both the agriculture and energy sectors across countries. With 70% of the region's developmental challenges attributed to water scarcity, this process necessitates a strategic framework that is informed by projected climate hazards and past and contemporary lessons in regional cooperation models, and with Afghanistan actively engaged as a key stakeholder. The framework should be designed to bring value through a shared-resources approach, establishing water as a common regional resource. Importantly, forums for cooperation discussions should evolve beyond mere talk conferences to ensure that reports and strategies result in tangible accomplishments.

Capacity-building interventions can facilitate the development of regional frameworks and the identification of national-scale climate actions. The study's recommendations outline three categories of capacity building interventions for countries that span short-, medium-, and long-term periods. Given the uncertainties associated with climate change, such activities at both national and regional levels play a pivotal role in addressing impending climate-related challenges. Consequently, the formulation of climate-proof policies and growth strategies emerges as a critical imperative for these nations.

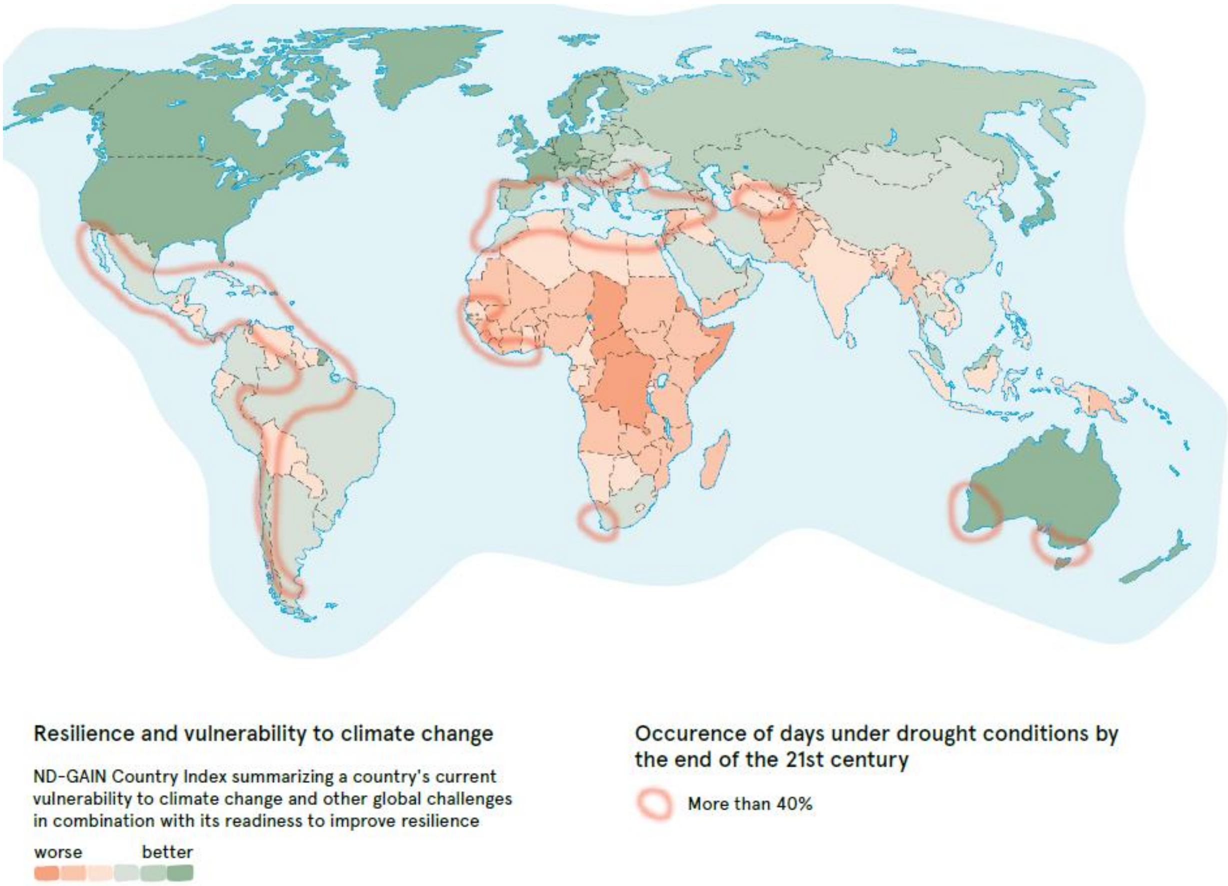
Introduction: Overview of the Study and its Purpose

Climate-associated risks, which are poised to grow at a greater intensity and frequency under global warming, cause human, environmental, and economic losses. Therefore, climate change is a risk multiplier for many economies worldwide. It has compounding nonlinear effects for Central Asia as well, which will exacerbate existing economic, environmental, financial, and social stressors under an RCP8.5 scenario (Akhmedov, 2022; Asian Development Bank [ADB], 2023a; Umirbekov et al., 2022).

Population growth and economic development that is overly reliant on extractive resources will heighten water, energy, and food demand throughout Central Asia in the coming decades. The effective management of natural resource access and utilization, coupled with improved infrastructure efficiency, and a rapid transition to renewable energy sources are essential for sustainable regional development.

This study of climate change inaction in the water, agriculture, and energy nexus in Central Asia seeks to analyze current trends in climate change’s impact in the region. Central Asia faces significant challenges in these sectors owing to its arid and semi-arid climate, limited water resources, and dependence on agriculture and hydro energy for economic development. This makes Central Asia one of the most vulnerable regions in the world to climate change (Figure 1).

Figure 1: Vulnerability to Climate Change



Source: Regional Environmental Centre for Central Asia (2020)

This study aims to illustrate the consequences of inaction in addressing climate change in the water, agriculture, and energy nexus and explore potential solutions. The ultimate goal is to provide insights and recommendations for policymakers, stakeholders, and practitioners to enhance climate resilience and sustainability in Central Asia's water, agriculture, and energy sectors.

Approach and Methodology

This study examines the implications of climate inaction, the negative consequences of climate-induced damage to water, agriculture, and energy sectors, and their implications for individuals, ecosystems, the economy, and society at large. It also highlights the untapped benefits and missed opportunities of a more integrated approach to climate mitigation and regional cooperation. These negative impacts may extend beyond the economic realm and encompass health effects, migration of productive factors, and other social consequences. These impacts can be measured quantitatively in monetary terms and qualitatively in metrics related to the affected areas.

This assignment builds on the Central Asia Regional Economic Cooperation (CAREC) Institute's climate change projects: Climate Vulnerability, Infrastructure, Finance and Governance in CAREC and the Water–Agriculture–Energy Nexus in Central Asia through the lens of climate change. The report utilizes the two projects' findings and conducts an analysis across water, agriculture, and energy sectors in Central Asian countries. The framework, depicted in Figure 2, uses the two-scenario approach of the two CAREC projects to guide the analytical work in each section.

In the analysis and to recommend necessary actions against climate change, the author relied on two future projections: shared Socioeconomic pathways (SSPs) and representative concentration pathways (RCPs). SSPs consider socioeconomic factors such as population, economic growth, education, urbanization, and the rate of technological development. RCPs describe the concentration of different levels of greenhouse gases (GHGs). The two projects are complementary and interchangeably referenced throughout the study. The study is based on the two pathways: the highest emissions pathway (SSP5-8.5/RCP8.5) and the lowest emissions pathway (SSP1-2.6/RCP2.6) (Box1).

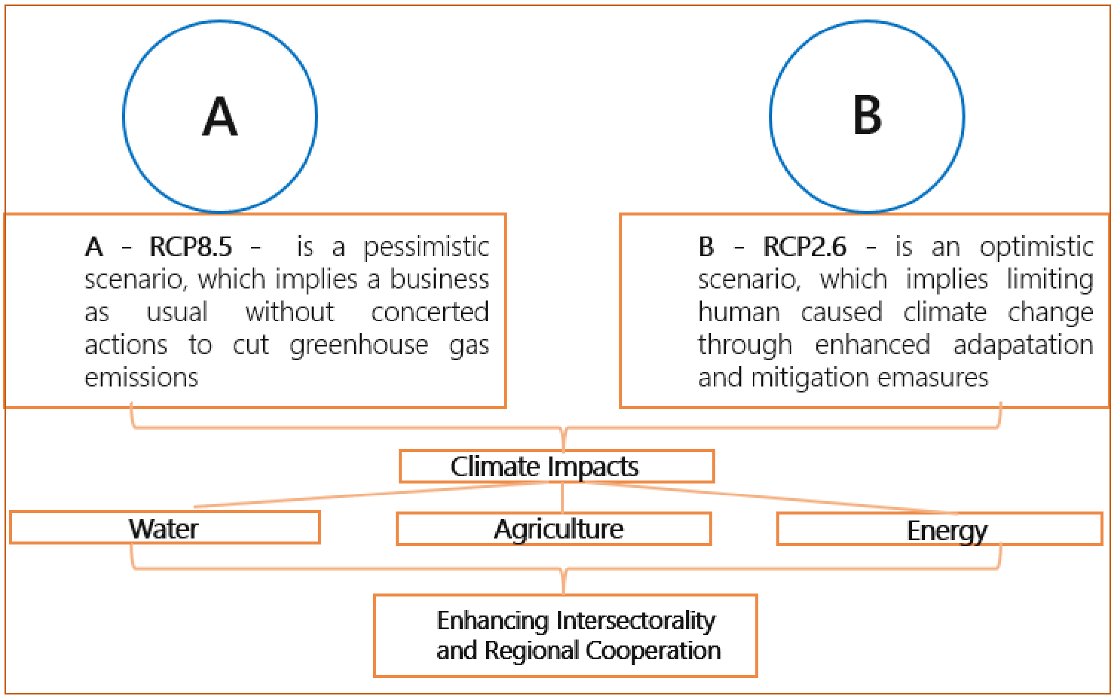
Box 1: Notes on Mean Temperature Projections

SSP1-2.6: In the next-best scenario, global CO2 emissions are cut severely, but not as fast, reaching net-zero after 2050. The scenario imagines the same socioeconomic shifts toward sustainability as SSP1-1.9, but temperatures stabilize around 1.8 °C higher by the end of the century.

SSP5-8.5: In this scenario, current CO2 emissions levels roughly double by 2050. The global economy grows quickly, but this growth is fueled by the exploitation of fossil fuels and energy-intensive lifestyles. By 2100, the average global temperature is a scorching 4.4 °C higher.

Source: https://www.carbonbrief.org/explainer-how-shared-socioeconomic-pathways-explore-future-climate-change/

Figure 2: The Analysis Framework



Based on this framework and information from diverse sources, the study intends to analyze and identify the implications (financial and non-financial) of climate inaction. As no economic modeling was done, the study relies on existing data and information and conducts thorough desk reviews to gather, organize, and analyze country-specific data with the requisite depth to yield informed recommendations. The study comprises several interconnected components based on the following actions and data availability:

First, for our secondary research, the author conducted a comprehensive review of reliable, publicly available information on the Internet, government sources, NGOs, donor institutions, and libraries to identify key issues, challenges, and opportunities related to climate change and their impacts on the water, agriculture, and energy sectors in Central Asia. This review included academic research, project reports, policy documents, and other relevant sources.

Second, aggregate secondary data on the economic and environmental implications of climate inaction for the water, agriculture, and energy sectors in Central Asia were collected from diverse sources, including government reports, international organizations, and academic publications.

Third, primary information and data were collected through interviews with five or more regional experts in each country working in the water, agriculture, and energy sectors. The interview questions (Appendix 1) were designed according to the initial findings of the study and used to verify some of the study's conclusions. The interviews also provided additional information to strengthen the findings.

Fourth, the collected data were analyzed to identify the implications of climate change on the water, agriculture, and energy sectors in Central Asia. The analysis identified the benefits of various adaptation and mitigation measures, including intersectoral and regional cooperation. The analysis also identified patterns, themes, and trends in the data.

Last, policy recommendations were based on the findings of the study and provide actionable steps to address climate inaction in the water, agriculture, and energy sectors in Central Asia. They also provided insights on ways to improve intersectoral and regional cooperation.

Regional Context: Climate Change Trends

With rising temperatures and more frequent and severe climatic hazards, Central Asia has become particularly vulnerable to climate change. Droughts have become more frequent, which will increase aridity and threaten water, food, and energy security. Most climate impacts are concentrated in sensitive sectors such as water, agriculture, and energy. The impact of climate change on the region will continue to expand—causing further ecological, economic, and social disruptions—**unless there are strong global adaptation and mitigation policies backed by concrete regional, national, and local actions**.

Climate change is exerting profound impacts on global water resources in terms of the quantity and quality of available water. Alterations in terrestrial water storage (TWS) serve as a visible outcome of this evolving climate (Deng & Chen, 2017). Despite the fact that only 0.5% of the water on Earth is available as useable freshwater, **terrestrial water storage, the summation of all water on the land surface and in the subsurface, including soil moisture, snow and ice, has been diminishing at a rate of 1 cm per year throughout the past two decades** (World Meteorological Organization [WMO], 2021). Similarly, water-related risks have surged in frequency during the same period. **Since 2000, water-related risks have increased by 134%, in contrast to two previous decades** (United Nations Office for Disaster Risk Reduction [UNDRR], 2020).

Fluctuations in temperature and wind velocity lead to shifts in evapotranspiration and alterations in TWS. This dynamic state is intricately tied to the interplay of various factors such as precipitation, runoff, evapotranspiration, and human water utilization (Deng & Chen, 2017). These impacts are driven by rising temperatures, changing precipitation patterns, and melting ice.

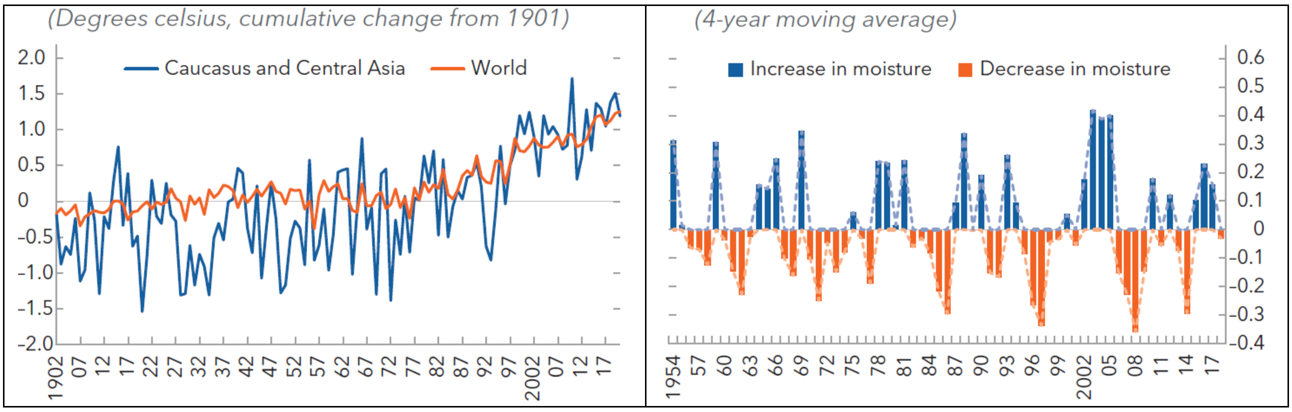
Rising temperatures can lead to increased evaporation, which reduces water availability in many regions. This can exacerbate water scarcity, particularly in arid areas such as Central Asia. **Changes in precipitation patterns also contribute to water scarcity, as some regions experience more frequent and intense droughts, while others face increased flooding**. In addition, **climate change can alter the timing and amount of snowfall in mountainous regions**, which affects the availability of freshwater during the dry season. **Melting glaciers and ice caps further contribute to water scarcity** as they are important sources of freshwater for the whole region.

One of the primary impacts of climate change on water resources is the **alteration of water availability.** Increasing temperatures lead to higher evaporation rates, thereby reducing the amount of water in rivers, lakes, and reservoirs. This worsens water scarcity, particularly in arid and semi-arid regions. According to the Intergovernmental Panel on Climate Change (IPCC), by the end of the century, **water availability in some regions may decline by up to 30%.**

Mountainous regions that rely on snowpack for freshwater face additional challenges. As temperatures rise, snowfall patterns are changing, with more precipitation falling as rain instead of snow. This reduces snow accumulation, which impacts the availability of freshwater during the dry season. The loss of snowpack also affects downstream communities and ecosystems that depend on meltwater for their water supply.

Climate change also affects water quality. Higher temperatures can lead to a proliferation of harmful algal blooms in lakes and coastal areas. These blooms produce toxins that harm aquatic life and pose a risk to human health. Additionally, **changes in precipitation patterns can increase runoff, which carries pollutants from agriculture, industry, and urban areas into water bodies. In turn, this can lead to the contamination of drinking water sources and the degradation of aquatic ecosystems.**

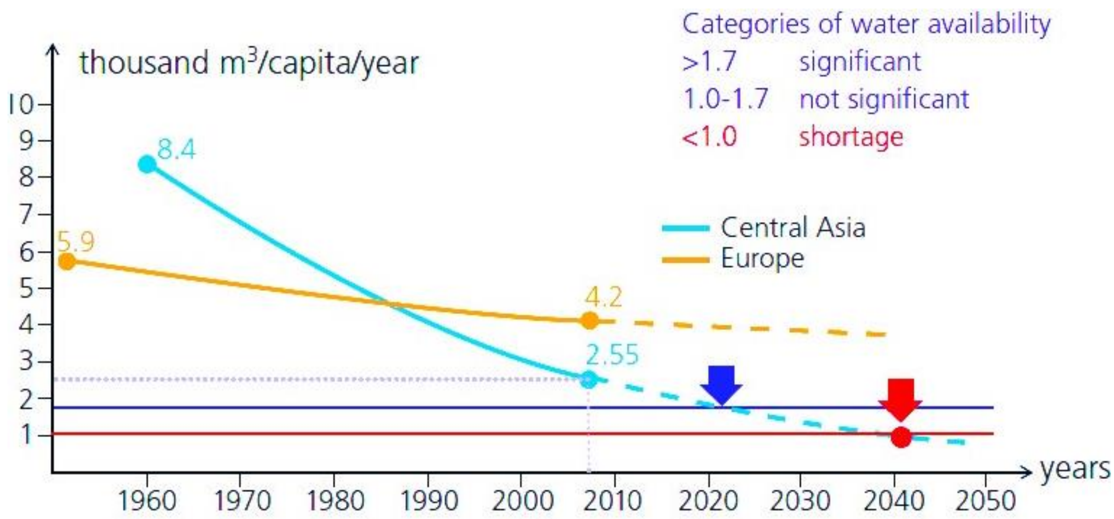
Figure 3: Average Temperature Index and Drought Index



Source: IMF (2023a)

The implications of augmenting climate change are of increasing concern in Central Asia, which has an arid and semi-arid climate (Figure 3). Estimates show that approximately 70% of the region's developmental problems are caused by a shortage of freshwater (Berndtsson & Tussupova. 2020). The region's water is sourced mainly from snowcaps and melting glaciers from the **Tien Shan, the Hindu Kush, the Wakhan, and the Pamirs mountains** that feed into the main regional rivers Amudarya and Syrdarya, which traverse the whole region toward the Aral Sea. The two major rivers provide water that is essential for human health, economic activity, ecosystems, agriculture, hydropower, and inland fisheries (Sara & Proskuryakova, 2022).

Figure 4: Changes in Water Availability in Central Asia



Source: World Bank (2019)

Between 1960 and 2010, the region's water supply decreased from 8,400 m^3 to 2,500 m^3 per person a year (Figure 4). This reduction will reach a critical value of less than 1,700 m^3 per year by 2030 based on the exponential growth rate of Central Asia's population, which necessitates the annual provision of an additional 500-700 million m^3 of water to sustain the population of the region, even at very low levels of consumption (World Bank, 2019).

While river discharge is diminishing due to vanishing glaciers, water resource use in a region with a population of almost 80 million population is set to increase substantially due to demographic factors, industrial and agricultural development, and irrigation (Narbayep & Pavlova, 2022). Currently, **almost a third or as many as 22 million people living in the region lack access to safe water, particularly in the rural areas** (Sara & Proskuryakova, 2022). The Kyrgyz Republic and Tajikistan are relatively water secure. Water stress is highest in Turkmenistan, and Uzbekistan is strongly dependent on transboundary water sources (Figure 4).

Table 1: Water Sector Climate Change Vulnerability Index Scores for Central Asian Countries

Country	Exposure	Sensitivity	Adaptive capacity	Index
Kazakhstan	1,00	0,21	1,31	0,16
Kyrgyz Republic	1,00	0,22	0,87	0,25
Tajikistan	1,00	0,31	0,67	0,47
Turkmenistan	1,20	0,90	0,31	3,52
Uzbekistan	1,20	0,87	0,28	3,71

Source: Author's compilation from Umirbekov et al. (2020)

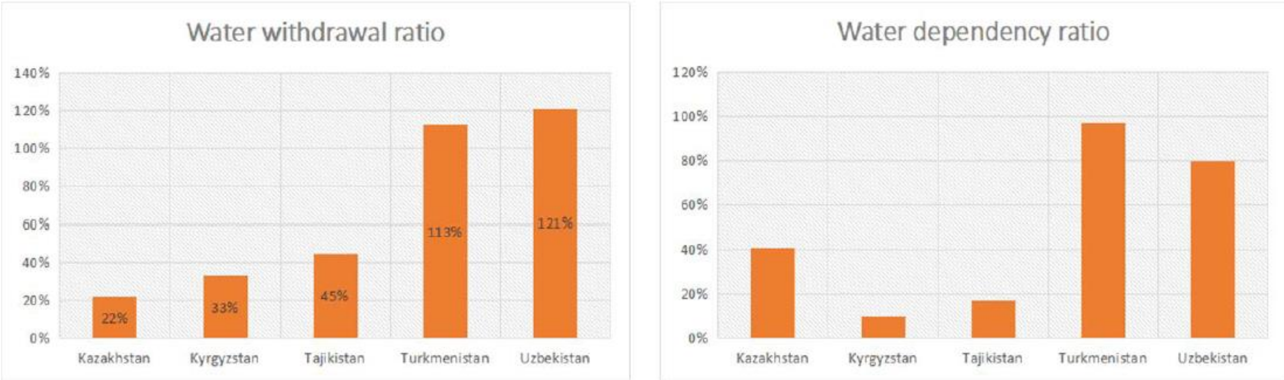
The levels of vulnerability and associated challenges differ in intensity across the countries (Table 1). Turkmenistan and Uzbekistan are exposed to the severe impacts of climate change on water resources, with all three indicators — exposure, sensitivity, and adaptive capacity[1] —highlighted in red (high risk). In contrast, the sensitivity and adaptive capacities of Kazakhstan and the Kyrgyz Republic are highlighted in green (low risk), although their exposure is highlighted in yellow (moderate risk). Tajikistan's exposure and adaptive capacity present moderate risk but low risk to sensitivity.

In The ramifications of climate change in Central Asia's water sector exhibit an uneven distribution; however, the amplified climate impact on one country inevitably spills over and affects other nations in the region. This interconnectedness arises from these countries' mutual reliance on each other for the provision of water, food, and energy resources (Akhmedov, 2022). It is also important to emphasize that countries in Central Asia are exposed to diverse climate-driven natural hazards.

Over the past 70 years, temperatures have already increased by 0.6–0.8 °C in Turkmenistan, by 0.8–1.3 °C in Kazakhstan and Uzbekistan, and 0.3–1.2 °C in the Kyrgyz Republic and Tajikistan (Chikalova, 2016). Projected increases in temperature, rapid glacial melting, decreased winter snow cover, and subsequent alterations in river flows, along with an increase in the frequency and intensity of droughts and floods pose significant threats to the reliability and availability of water resources for crucial sectors such as agriculture, hydropower generation, and human consumption.

[1]Note: Exposure: the nature and degree to which a system is exposed to significant climatic variations. Sensitivity: the degree to which a system is impacted adversely or beneficially by climate-related stimuli. Adaptive capacity: a system's ability to adjust to climate change (including climate variability and extremes) and moderate potential damages, to take advantage of opportunities, or to cope with the consequences (Umirbekov et al., 2020).

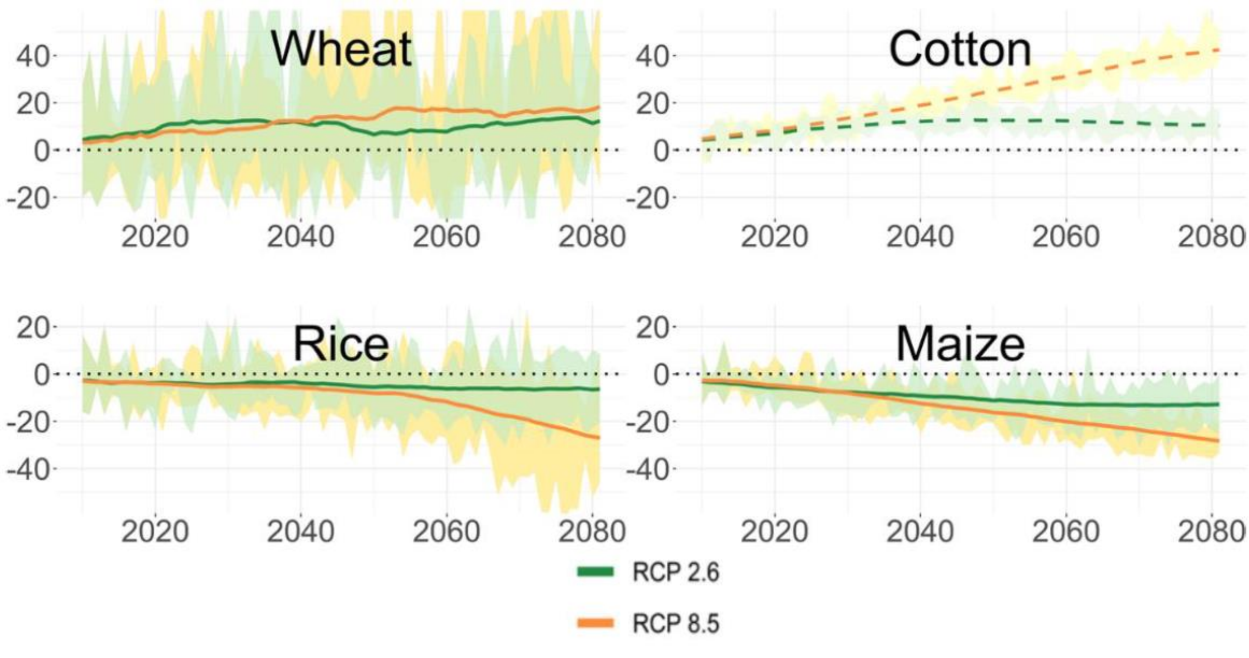
Figure 5: Intensity of Water Use Among the Central Asian States



Source: Umirbekov et al. (2022)

The countries' water consumption patterns of are also misaligned. Kazakhstan has the least water-intensive economy and the region's lowest water-withdrawal ratio. Turkmenistan and Uzbekistan's consumption levels are higher than total annual renewable surface water available due to the scale of their irrigated lands (Figure 5). As most their water resources (above 80%) originate outside their territory, water stress is more intense (Umirbekov et al., 2022); moreover, due to the old infrastructure, nearly 50% of the water resources for irrigation is lost before reaching the fields (Abdullaev & Akhmedov, 2022).

Figure 6: Projected Change in Crop Productivity in Central Asia under RCP 2.6 and RCP

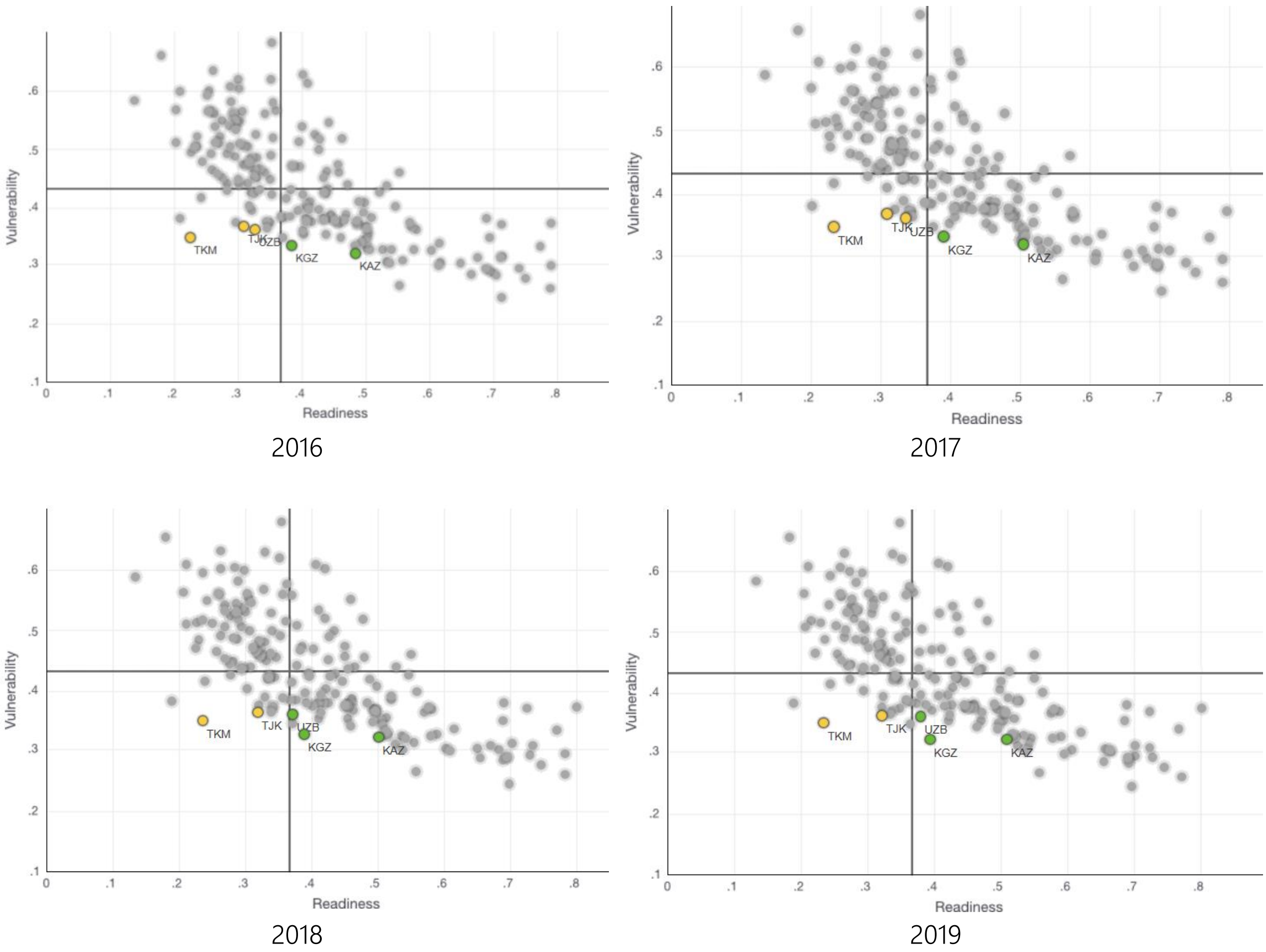


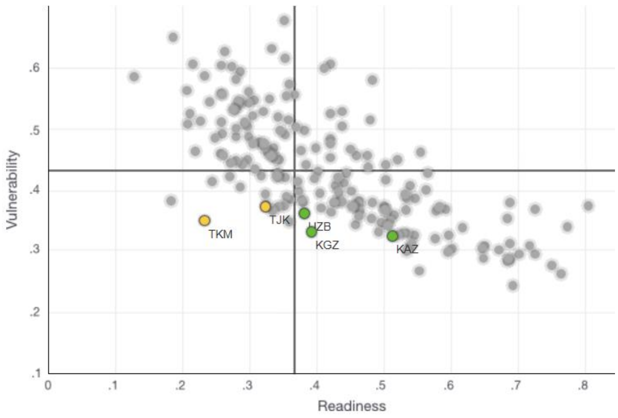
Changes in water flow also affects energy security, because water resources are available for hydropower generation and for the cooling of fossil-based power plants, and risks of natural disasters (Botta et al., 2022). For instance, the flood in Almaty in 2015 caused severe damage to the power network (United Nations Economic Commission for Europe [UNECE], 2015), and a drought in 2008 costed $130 million for Kazakhstan (Botta et al., 2022). Similarly, extreme temperatures in 2008 generated economic losses equal to around 10% of GDP in Tajikistan, while the economic damages of a flood in 2010 were estimated at around 2.5% of the country's GDP (Botta et al., 2022). Overall, the World Bank estimates that floods annually affect nearly 1 million people and cause $4.7 billion of economic losses in the region (World Bank, 2019).

The effects of climate change on agriculture in Central Asia are evident in the increased water scarcity, crop losses due to extreme weather events, and decreased crop productivity (Figure 6). Agricultural activities in the region are rain fed and irrigated and account for approximately 90% of total water withdrawals. Water scarcity due to reduced river flows and increased evaporation rates has led to reduced irrigation water availability, which has affected crop yield and food security. Extreme weather events, such as droughts and floods, cause crop losses that impact the livelihoods of smallholder farmers. The higher prevalence of pests and disease, such as in locusts, cause further crop damage that affect the region's food security.

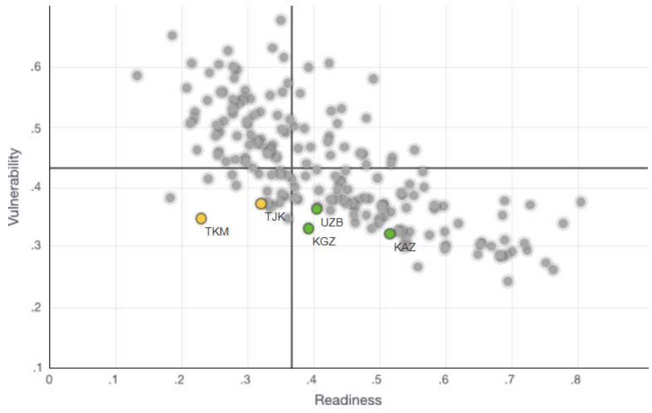
To address these impacts, adaptation and mitigation strategies are crucial. These strategies include improving water management practices, enhancing water storage capacity, promoting water conservation, reducing reliance on monocropping, crop structure optimization, investing in alternative water sources like desalination and wastewater recycling, and prioritizing the development of economic sectors that are less energy intensive. Mitigation efforts to reduce GHG emissions are equally important to slow down the rate of climate change and minimizing its impact on water resources and other sectors.

Figure 7: The Notre Dame Global Adaptation Initiative (ND-GAIN) Country Index Matrix Illustrating the Resilience of Central Asian Countries Between 2016 and 2021





2020



2021

Overall, climate change poses significant challenges to water resources, agricultural production, and energy infrastructure in Central Asia. Even though Kazakhstan, the Kyrgyz Republic and Uzbekistan, joining recently, are in the lower right quadrant, (figure 7), they still face some adaptation challenges. Being in the lower left quadrant, Tajikistan and Turkmenistan face relatively fewer climate issues, they have lesser ability to attract investment. The impacts of climate change are complex and varied. Adaptation and mitigation strategies are necessary to address these challenges to ensure sustainable development and economic growth.

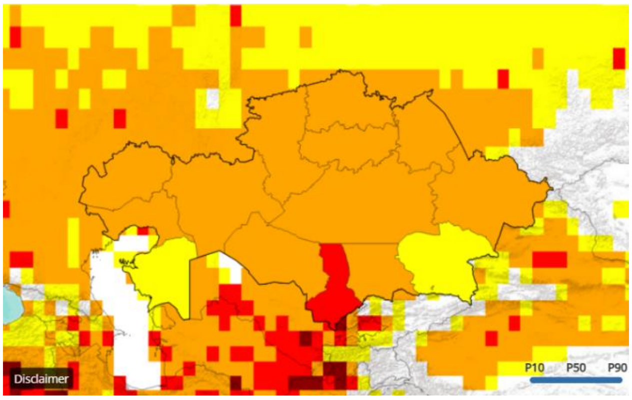
Country Overviews: Impacts and Consequences

Kazakhstan

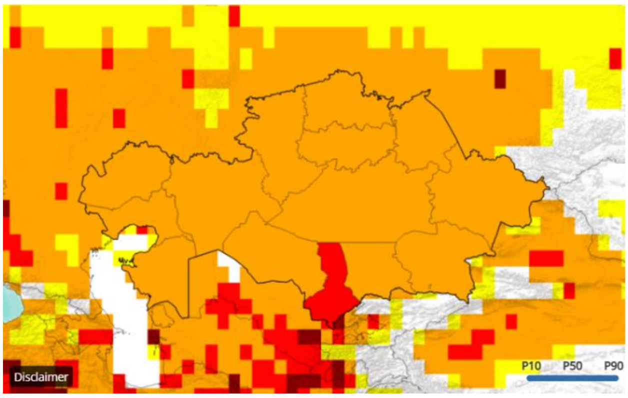
In Kazakhstan, there is a significant acceleration of the average annual increase in air temperature: 0.32 °C for every 10 years (Nurakynov et al., 2023). In the SSP5-8.5 scenario, the average temperature is expected to increase by 2.4–3.1 °C by 2050 and by 3.2–6.0 °C by 2100 compared with the average for 1980–1999 (International Energy Agency [IEA], 2022a). Similarly, the projected average annual precipitation varies from 225–500 mm in RCP2.6 scenario to 275–550 mm in the RCP8.5 scenario (ADB, 2023b). These changes will particularly affect Kazakhstan's northern and central regions (Kostanay and Karaganda), eastern and southeastern parts (East Kazakhstan and Almaty), and the southern region (South Kazakhstan) (Figure 8).

Kazakhstan faces heightened susceptibility to climate-related disasters, with approximately 75% of its landscape at significant risk from hazards such as floods, earthquakes, landslides, mudflows, droughts, heatwaves, snowstorms, avalanches, sand and dust storms, hurricanes, and wildfires, all of which may intensify due to the influence of climate change (ADB, 2023b).

Figure 8: Compound Heat Risks Under the SSP5-8.5 Scenario in Kazakhstan Between 2020–2099[2]



Temperature-based Heat + Population for 2020-2039;



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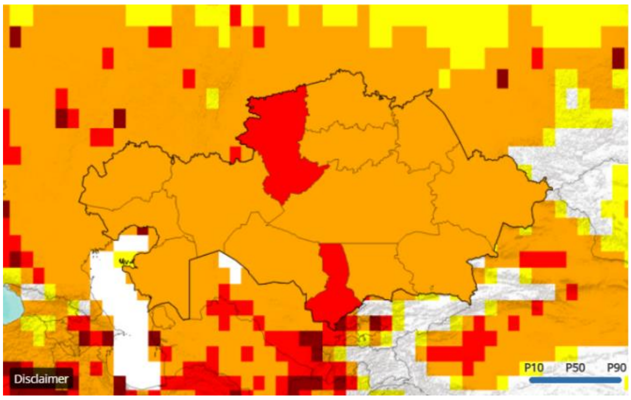
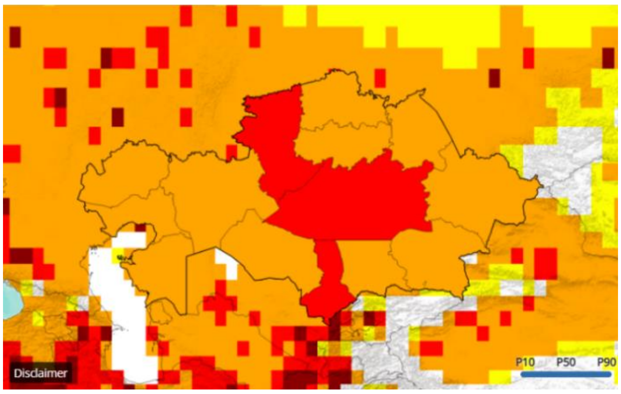


Temperature-Based Heat + Population for 2060-2079;



Temperature-Based Heat + Population for 2080-2099

Source: Climate Change Knowledge Portal of the World Bank

Under current climate conditions, southern Kazakhstan is the region most affected by climate change. In the SSP5-8.5 scenario this impact extends to other regions, including Almaty, Kostanay, and Karaganda (Figure 8). Since Almaty contributes 20%, Astana 18%, and South Kazakhstan 8% of national GDP, the

[2] **Explainer**: The compounded risk categorization of temperature-based heat risk allows users to understand where and when risks may occur under the **SSP5-8.5 (high emissions) scenario** in four periods: 2020–2039, 2040–2059, 2060–2079, 2080–2099. Red and darker areas are most impacted, orange areas moderately impacted, and yellow areas least impacted by climate change.

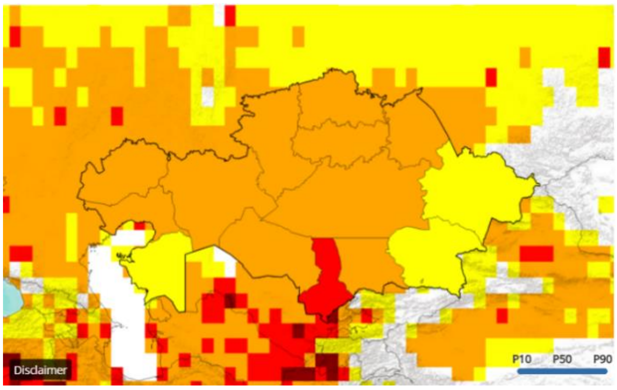
financial ramifications of climate change for the national economy will be substantial unless proper adaptation and mitigation measures are in place.

Another growing concern that impacts Kazakhstan's vulnerability to climate change is the shrinking Caspian Sea; with an average annual decline of 6.7 cm between 1996 and 2015, the northern part of the sea is projected to vanish by the end of the century (ADB & World Bank, 2021a). Coupled with other factors, this trend poses significant adverse consequences for Kazakhstan's ecosystem and economy, particularly in the western region of the country.

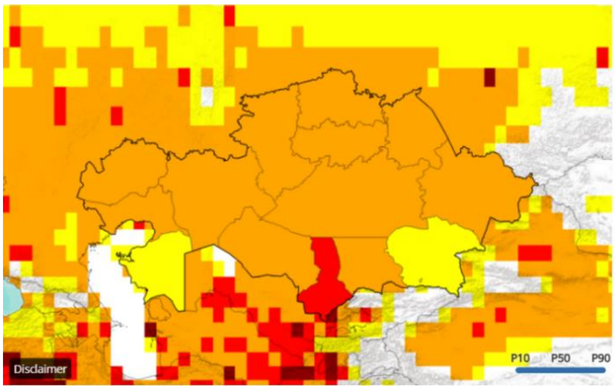
According to 2021 data, the country ranks 36th in climate change adaptation out of 192 countries with an ND-GAIN value of 59.8; its vulnerability ranking is 22 with a score of 0.322; and its readiness rating is 51 with a score of 0.518[3]. Kazakhstan, positioned in the lower-right quadrant of the ND-GAIN matrix due to its low vulnerability and high readiness scores, faces many adaptation challenges. Despite being the 164th most vulnerable country, it ranks 51st in readiness. The recently enacted environmental code includes a chapter on climate change, which outlines priority adaptation areas such as water management, agriculture, forestry, and civil protection.

Under the SSP1-2.6 Scenario, Almaty and East Kazakhstan regions will be impacted more than other regions of the country (Figure 9).

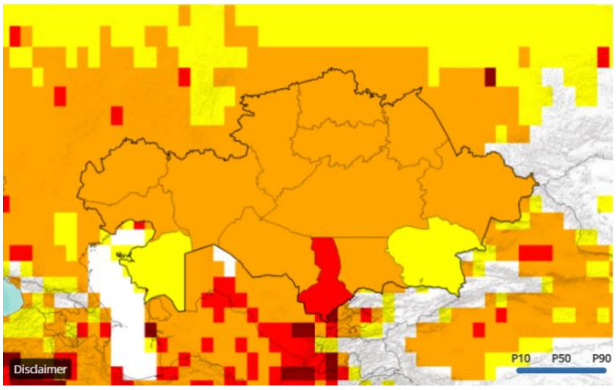
Figure 9: Compound Heat Risks Under the SSP1-2.6 Scenario in Kazakhstan[4]



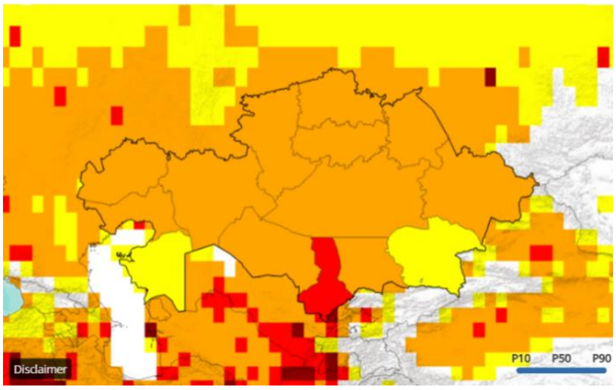
Temperature-Based Heat + Population for 2020-2039



Temperature-Based Heat + Population for 2040-2059;



Temperature-Based Heat + Population for 2060-2079



Temperature-Based Heat + Population for 2080-2099

Source: Climate Change Knowledge Portal of the World Bank

[3] Kazakhstan ND-GAIN index. https://gain-new.crc.nd.edu/country/kazakhstan#readiness

[4] **Explainer**: The compounded risk categorization of temperature-based heat risk allows users to understand where and when risks may occur under the **SSP1-2.6 (low emissions)** scenario in four periods: 2020–2039, 2040–2059, 2060–2079, 2080–2099. Red and darker areas are most impacted, orange areas are moderately impacted, and yellow areas are least impacted by climate change.

Climate inaction in Kazakhstan has the potential to reduce its economy by 1.6% by 2050, increase poverty rates by 3%, and cause real wages to decline by 2.1% (Bjerde & Proskuryakova, 2022). If Kazakhstan fails to decarbonize its economy based on its strategy to achieve carbon neutrality by 2060, the country could experience a persistent long-term contraction in economic growth ranging from 2% to 2.5% annually. The manifestation of these changes is exposed across the water, agriculture, and energy sectors of the Kazakh economy.

Climate Change's Impact on Water Resources

The data points to climate change as the primary factor in decreasing TWS levels in eastern, southern, and central Kazakhstan (ADB & World Ban, 2021 b). An analysis covering 2000 to 2013 reveals that climate-induced soil moisture loss is prevalent in these regions (Deng & Chen, 2017). In the RCP8.5 scenario, this trend will significantly impact Kazakhstan's agriculture sector in the upcoming decades. Anticipated repercussions include substantial water shortfalls, potentially reaching 50% of requirements by 2040. Given the economy's reliance on water across all sectors, this deficiency may lead to a projected 6% decrease in GDP by 2050 (United Nations Development Programme [UNDP], 2021).

Likewise, rising temperatures are expected to hasten the desiccation of major lakes, including Lake Balkhash in southeastern Kazakhstan. The lake's basin is home to around one-fifth of the population and is prone to desertification, soil salinization, and dust storms as it continues to dry out (ADB & World Bank, 2021a). Projections suggest that an increased water in the east and south due to accelerated glacier melting, with simultaneous aridification in the west, will result in a substantial decline in nationwide water availability by the end of the century (World Bank, 2021). These shifts will significantly impact crucial water-dependent sectors such as agriculture, water supply, industry, the environment, and energy by diminishing sector productivity.

Glacier shrinkage currently compensates for the lack of water in rivers, but by 2030–2050 the volume of ice is expected to decrease which will lead to runoff deficits. Over the last 60 years, the glaciers of Ile-Alatau and other mountain ranges in Central Asia have declined at an average annual rate of around 0.73%–0.76% of their area and approximately 1% of their ice volume (UNDP, 2021). According to the Eighth National Communication and Fifth Biennial Report of the Republic of Kazakhstan (United Nations Framework Convention on Climate Change [UNFCCC], 2022), flow changes are typical in the Aral-Syrdarya, Ertis, and Shu-Talas water-related basins (UNFCCC, 2022). Due to nature of the rivers that cross borders, such as the Syradarya and Irtish, a decrease in water supply caused by glacier melting could potentially lead to strained relations between Kazakhstan and its neighboring countries, including the Kyrgyz Republic, Uzbekistan, and China (ADB & World Bank, 2021a).

Over the past five years, Kazakhstan's total annual water consumption across all sectors of the economy averaged 25.7 km^3. Of this volume, about 95% of the water intake is derived from surface water sources. The distribution of annual water use is as follows: more than 60% of water consumption falls on agriculture, more than 20% on industry, and about 4%–5% is used for household needs.

The Eighth National Communication and Fifth Biennial Report of the Republic of Kazakhstan (UNFCCC, 2022) expects the following to happen due to climate change:

- Water consumption will increase as a result of the expansion of irrigated lands from 1.8 to 3 million ha by 2030; water consumption per unit area will also increase.
- The melting glaciers will increase runoff into mountain rivers until the middle of the century.

Climate Change's Impact on Agriculture

Kazakhstan's current temperature and precipitation changes are causing desertification and degradation of its croplands and pastures, with an estimated **66% of land already subject to some form of degradation**

(World Bank, 2022a). This impact is manifested mainly in crop production and productivity. Climate-driven desertification, soil salinization, and land degradation affect these processes and influence the long-term viability of Kazakhstan's agriculture sector. W**heat yields in some regions are expected to decline by 30%–50% by 2050. As the world's ninth-largest wheat exporter (13.9 million tons in 2013) this decline represents over $1 billion of exports per annum** (ADB & World Bank, 2021a). As the world's fifteenth-largest wheat producer, wheat is Kazakhstan's main crop with almost half of cultivated land is under wheat (Islyami et al., 2020).

According to the UNDP[5], climate forecasts under the RCP8.5 scenario show that the yield of spring wheat in some regions of Kazakhstan will decrease 13%–37% by 2030 and 20%–49% by 2050. **This will lead to a reduction in harvested areas and economic losses in the agriculture sector in the amount of up to 608.19 billion tenge at 2019 prices** (Table 2), or approximately $1.3 billion. It is evident that the regions of Kostanay, Akmola, North Kazakhstan, Karaganda, and Aktobe are significant players in wheat production; however, these regions are expected to experience substantial economic losses due to climate change. Economic losses in these regions range from 86.4% to 95.9% of their respective wheat production. Thus, the cost of losses in wheat production alone might be close to $1 billion by 2030 and 1,3 billion by 2050 under a SSP5-8.5 scenario. This will impact not only the economic and food security of Kazakhstan, but also the entire Central Asian region, with implications for global food security.

Table 2: Economic Losses on Wheat Production by 2030 and 2050 Under the Impact of Climate Change

Region	Year	Thousand tons	%	Billion tenge
Kostanay	2030	2827,6	70,8	166,9
	2050	3 578,1	89,5	211,2
Akmola	2030	2285,1	65,7	129,5
	2050	3111,5	89.5	176,3
North Kazakhstan	2030	2064,7	58,2	111,9
	2050	3068,9	86,4	166,3
Karaganda	2030	369	79,7	18,2
	2050	443,7	95,9	21,9
Aktobe	2030	224,1	88,1	12,1
	2050	231	90,8	12,5
Pavlodar	2030	201,1	62,1	9,9
	2050	232,1	71,6	11,4
East Kazakhstan	2030	165,7	91,6	8,5
	2050	168,6	93,2	8,6
Kazakhstan	2030	8137,3	66,46	**456,93**
	2050	10833,9	88,48	**608,19**

Source: https://www.undp.org/ /stories/kazakhstan-may-suffer-economic-losses-wheat-production-due-climate-change

Climate change will also diminish the health and productivity of the labor force in the agriculture sector. In 2020, **27.7% of the population was employed in the agriculture, forestry and fisheries sector.**[6] Thus, climate change's impact on agricultural output may have indirect effects on employment and living standards in small cities or rural areas that are economically dependent on agricultural production (ADB & World Bank, 2021a).

[5] https://www.undp.org/kazakhstan/stories/kazakhstan-may-suffer-economic-losses-wheat-production-due-climate-change

[6] Eighth National Communication and Fifth Biennial Report of the Republic of Kazakhstan to the UN Framework Convention on Climate Change (Astana, 2022).

As one of the main subsectors, livestock production will also be impacted. Climate change can diminish the stocking capacity of pastures, which is crucial for livestock production. UNDP experts expect[7] **climate change to decrease Kazakhstan's pasture lands by 9.8% by 2030, with potential economic losses of over $220 million; by 2050, this will increase to 15.2% with economic losses amounting to over $350 million.**

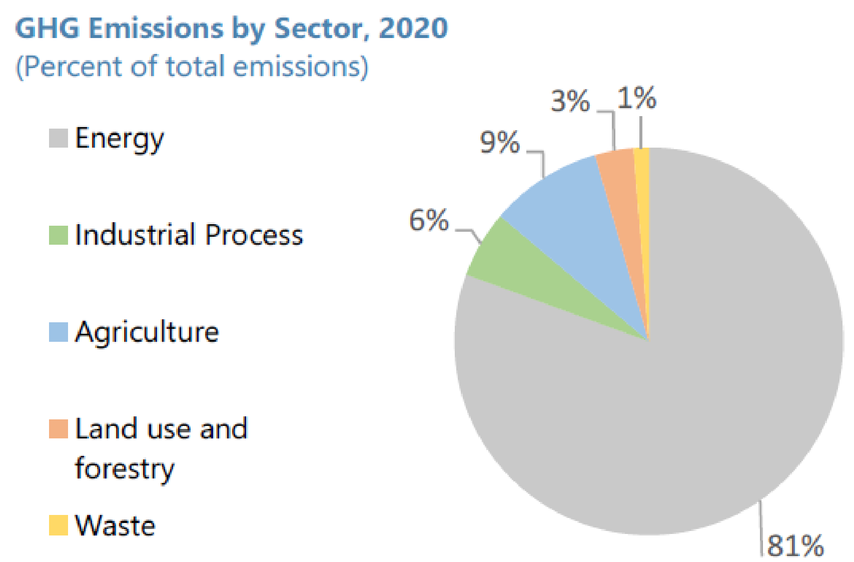
Irrigated farming in southern Kazakhstan will also suffer from climate change. **higher temperatures and changes in rainfall are expected to increase the demand for water by 10%–14% by 2050** (World Bank, 2022a). This substantial increase for a region that is already water-stressed is exacerbated by a growing population and rising food demand, which will have regional ramifications.

Climate Change's Impact on Energy

Kazakhstan is one of Central Asia's most energy-intensive economies due to the predominance of extractive economic activities. Since the early 2000s, the country achieved remarkable economic development through which it reduced poverty, raised living standards, and became a leading economy in Central Asia and joined the group of upper middle-income economies. This growth also made it the regional leader in GHG emissions, which was underpinned mainly by the development of hydrocarbon resources and accelerated by a boom in oil prices over the years. **The energy sector accounts for 81% of Kazakhstan's emissions (Figure 10.) Oil contributes to 50% of the country's energy requirements.**

One of the main impacts of climate change on the energy sector is an increase in the frequency and intensity of extreme weather events that can damage energy infrastructure, disrupt power supply, and result in outages that affect the reliability and stability of energy systems.

Figure 10: Greenhouse Gas (GHG) Emissions by Sector



Source: IMF (2022)

[7] https://www.undp.org/kazakhstan/stories/kazakhstan-may-suffer-economic-losses-wheat-production-due-climate-change

Climate change can also have a negative impact on energy infrastructure. Boilers and generators in coal-fired power plants are less efficient, whereas gas turbines produce less energy. For instance, **a 5.5 °C increase in temperature of can reduce power output by almost 3%.** This has significant implications for an electricity sector that relies heavily on coal and gas generation. In addition, a 1° C increase in temperature can cause transmission lines to sag by up to 4.5 cm, further reducing the reliability of the power system (Chepelianskaia O., & Sarkar-Swaisgood, M, 2022a).

UNESCAP reported that fluctuations in the annual average temperature can affect the energy sector. Elevated air temperatures diminish the temperature gap between the environment and burning temperature in coal-fired power plants and reduce the efficiency of boilers and generators and, consequently, lower the generating capacity of these plants (Table 4). In gas-fired power plants, rising temperatures directly influence output power. The Information and Communications Technology (ICT) sector might experience reduced conductivity and performance in underground cables, along with a decrease in signal range and quality in wireless transmissions. In addition, the transport sector could contend with road surface deterioration, joint expansion, and railway track deflection.

Table 4: Potential Impacts on Kazakhstan's Energy Sector

Climate change pattern	**Potential** impact **on** Kazakhstan's energy sector
Increased average and extreme temperatures	Decreased thermal power generation capacity
	Reduced efficiency of transmission lines
	Reduced hydro power generation capacity
Change in precipitation patterns	Associated increased frequency and intensity of extreme weather events damaging the physical infrastructure
Climate related natural disaster	Floods
	Damage to physical infrastructure such as transmission lines, coal extraction mines, and power plants
	Landslides and mudslides
	Damage to physical infrastructure causing failure of transmission networks and loss of power supply
	Droughts
	Water scarcity may affect hydro power generation capacity and impact thermal power cooling systems

Source: UNESCAP (2022)[8]

Kazakhstan could incur substantial costs related to climate change inaction in its energy sector. If there is a decline in oil and gas demand over time—driven by buyers aiming to meet climate targets—and if goods produced with fossil fuel-intensive energy face risks from global climate policies like the European Union's (EU) Carbon Border Adjustment Mechanism (CBAM), **Kazakhstan could incur a potential annual loss of $1.5 billion in the future** (Bjerde & Proskuryakova, 2022).

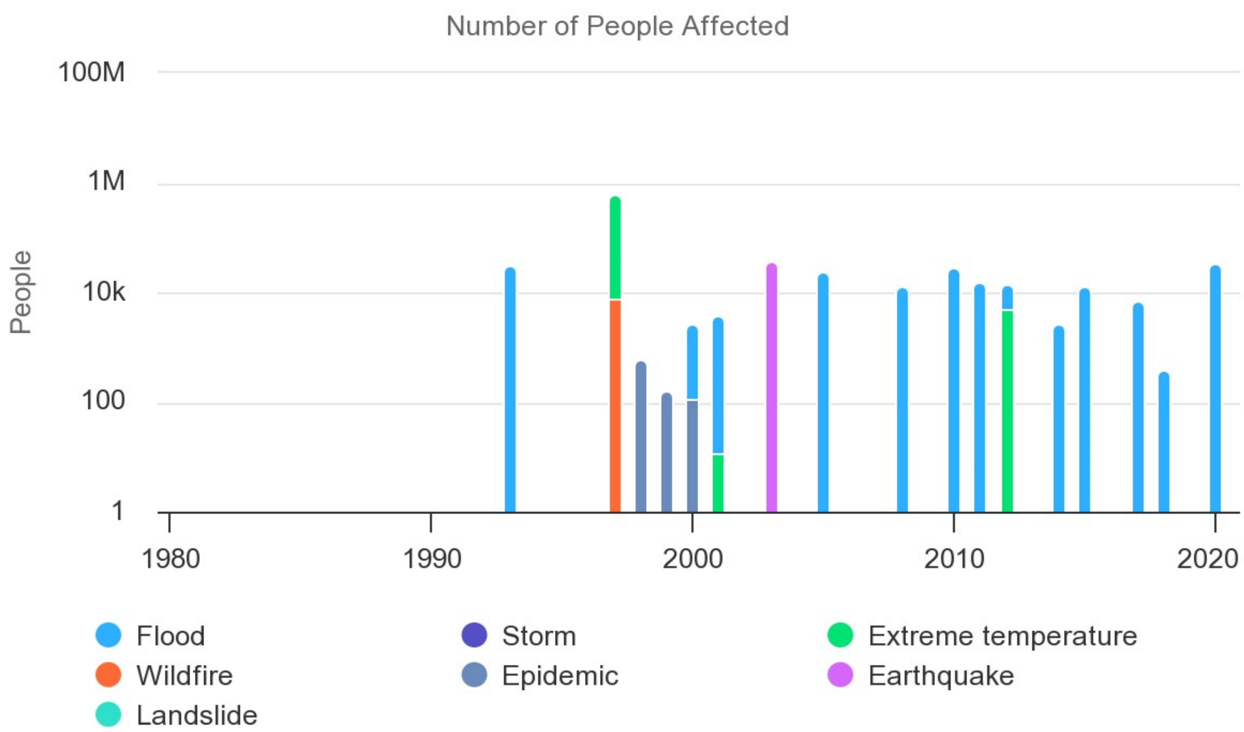
[8] Kazakhstan - Climate Change and Disaster Risk Profile Available at: https://www.unescap.org/sites/default/d8files/event-documents/Kazakhstan%20-%20Climate%20Change%20and%20Disaster%20Risk%20Profile.pdf

Vulnerability to Climate-Related Disasters

Kazakhstan is highly exposed to earthquakes, floods, mudflows, landslides, droughts, and other disasters (Figure 11) due to its geographic location. These natural disasters threaten human lives, livelihoods, and the country's water, energy, and agriculture infrastructure.

Kazakhstan experienced a 150% increase in the frequency of heavy snowfalls and a 170% increase in heavy showers between 1990 and 2002. During the same period, river floods in mountainous areas increased by 100% and mudslides doubled (UNESCAP, 2022). The impact of climate change on temperature and precipitation is expected to increase the intensity and frequency of natural disasters. **The average annual loss (AAL) from flooding is estimated at $419 million, with earthquakes contributing $58 million** (Central Asia Regional Economic Cooperation Program [CAREC], 2022a). The most significant damage from flooding occurs in the northern, central, and southern regions of Kazakhstan, which are particularly vulnerable to the escalating effects of climate change.

Figure 11: Key Climate-Related Natural Hazards in Kazakhstan Between 1980–2020

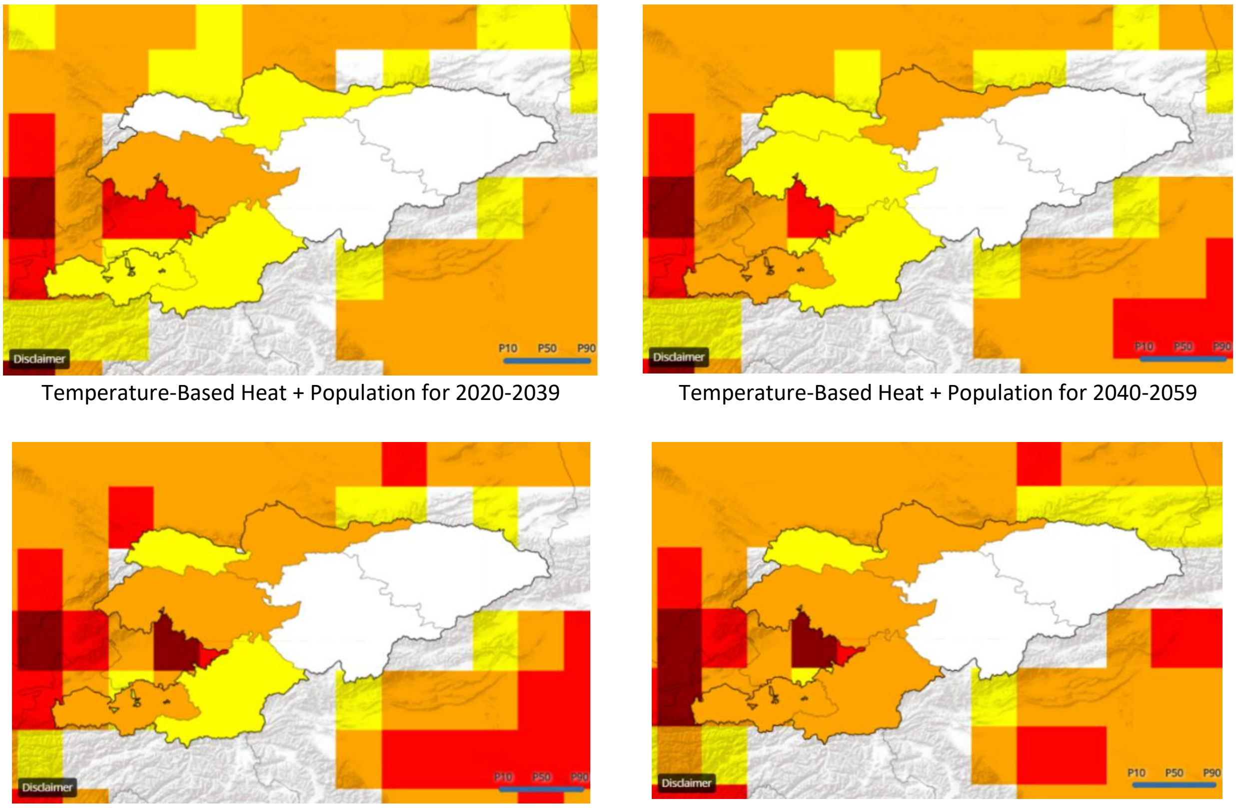


Source: World Bank Group Climate Change Knowledge Portal

Kyrgyz Republic

The Kyrgyz Republic is a landlocked country in Central Asia characterized by diverse landscapes, including mountains, valleys, and rivers. Despite its relatively small size, the country has a wide range of climatic zones owing to its mountainous topography. The Kyrgyz Republic is an agrarian state in which water resources are the main driver of many economic sectors. Rural livelihoods are almost entirely based on irrigated lands, the cultivation of land, and animal husbandry. Thus, the well-being of its people is closely linked to the rivers originating in the high mountains, and the well-being of the rivers depends entirely on the preservation of natural ecosystems in the zone where their runoff is formed. Around 30% of Kyrgyz Republic's GDP is derived from worker remittances and 10% from a single gold mine (United States Agency for International Development [USAID], 2021). As the country has limited hydrocarbon reserves, 90% of its electricity is generated from water resources.

Figure 12: Compound Heat Risks Under the SSP5-8.5 Scenario in the Kyrgyz Republic



Temperature-Based Heat + Population for 2020-2039

Temperature-Based Heat + Population for 2040-2059

Temperature-Based Heat + Population for 2060-2079

Temperature-Based Heat + Population for 2080-2099

Source: Climate Change Knowledge Portal of the World Bank

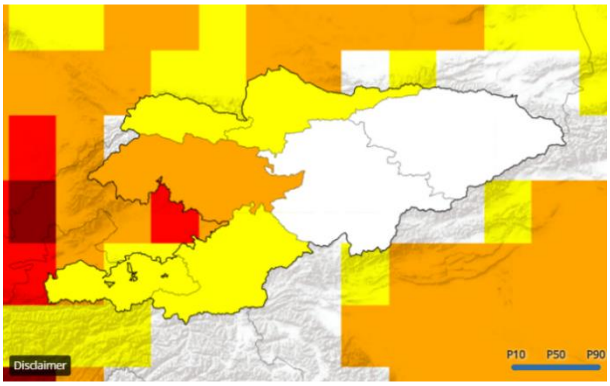
Climate change also has a significant effect on the Kyrgyz Republic. The country has experienced various climate-related phenomena, including rising temperatures, changes in precipitation patterns, and melting glaciers. These changes pose substantial challenges to the country's ecosystems, water resources, and vulnerable communities. The Chu, Talas, Jalalabad, Batken, and Osh regions, in particular, will experience significant changes under a SSP5-8.5 scenario (Figure 12).

Figure 12 shows that under a RCP8.5 scenario, a warming trend across the country with an annual average temperature rise of 2.0–2.5 °C by mid-century (Chepelianskaia & Sarkar-Swaisgood, 2022) and by 5.3 °C by 2090 (ADB & World Bank, 2021b), increases the risks of heatwaves, melting glaciers and drought. **Increased monthly precipitation, in turn, intensifies the risk of floods, landslides, mudslides, and mudflows.** In comparison, Figure 13 shows that under a RCP2.6, temperature changes between 1.4 °C and 1.6 °C in the period of 2020 and 2099, will have a different impact on the regions (ADB & World Bank, 2021b).

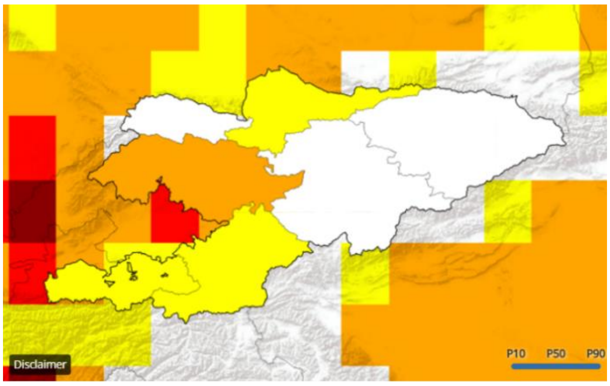
The ND-GAIN ranks the Kyrgyz Republic in 65th place with an index score of 53.3, 28th in vulnerability with a score of 0.331, and 100th in readiness with a score of 0.396. Even though Kyrgyz Republic’s place in the adaptation rankings is relatively positive, its readiness score needs to improve to make effective use of investments in adaptation actions to meet development goals.

Kyrgyz Republic’s unique ecosystems include alpine meadows, forests, and biodiversity hotspots, which are all under threat from climate change. Changes in temperature and precipitation patterns can disrupt ecological processes, affect species distribution, and increase the risk of pest outbreaks and wildfires. Such disruptions can have cascading effects on ecosystem services such as pollination, carbon sequestration, and water regulation.

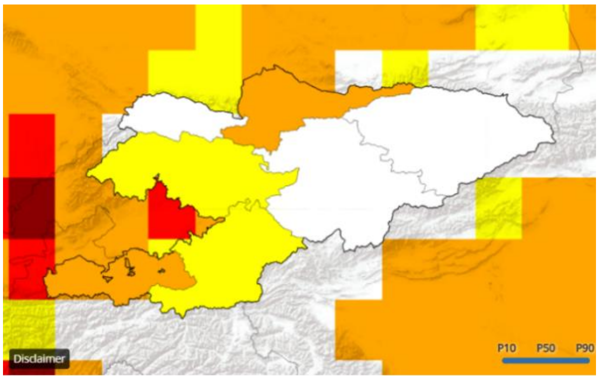
Figure 13: Compound Heat Risks Under the SSP1-2.6 Scenario in the Kyrgyz Republic



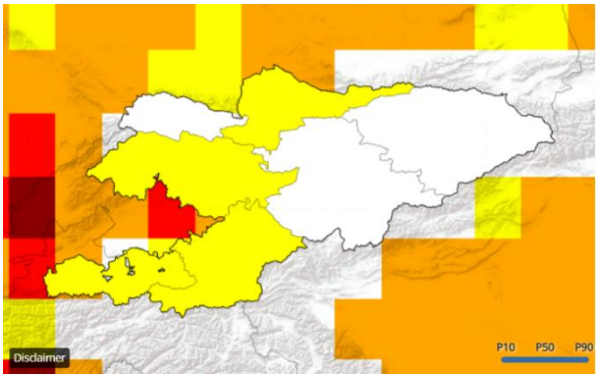
Temperature-Based Heat + Population for 2020-2039



Temperature-Based Heat + Population for 2040-2059



Temperature-Based Heat + Population for 2060-2079



Temperature-Based Heat + Population for 2080-2099

Source: Climate Change Knowledge Portal of the World Bank

Climate Change's Impact on Water Resources

The Kyrgyz Republic is the only country in Central Asia with water resources that originate entirely within its borders. **With a total volume of approximately 2,458 km³, including 650 km³ stored in glaciers, these resources that predominantly support irrigation and agriculture, constituting 94.2% to 95.1% of total water usage** (UN, 2021). While presenting significant potential for diverse crop production, livestock development, and industrial growth, the country's water resources face heightened vulnerability due to the increasing impacts of climate change.

A consistent rise in air temperature triggers glacier melt, which causes an imminent increase in river runoff. This trend is expected to lead to a long-term decline in water availability and poses a significant threat to the agriculture sector and hydropower generation—both integral components of the country's economy. Diminishing glaciers also increase the risk of GLOFs, which present a potential hazard to downstream communities.

From 1961 to 2012, the ice melt from the region's glaciers tripled compared to 1950 levels—an overall decrease of about 27%, which is four times the global average (Farinotti et al., 2015). **Under the SSP5-8.5 scenario, the Tien Shan is expected to lose half of its current glacier volume by 2050. Similarly, under the most severe climate change scenario, runoff may decrease by around 40%, with a significant impact on agriculture—a sector that utilizes 92%–96% of all water for irrigation purposes.** This reduction poses a threat to various sectors, including public health, food security, and the national economy.

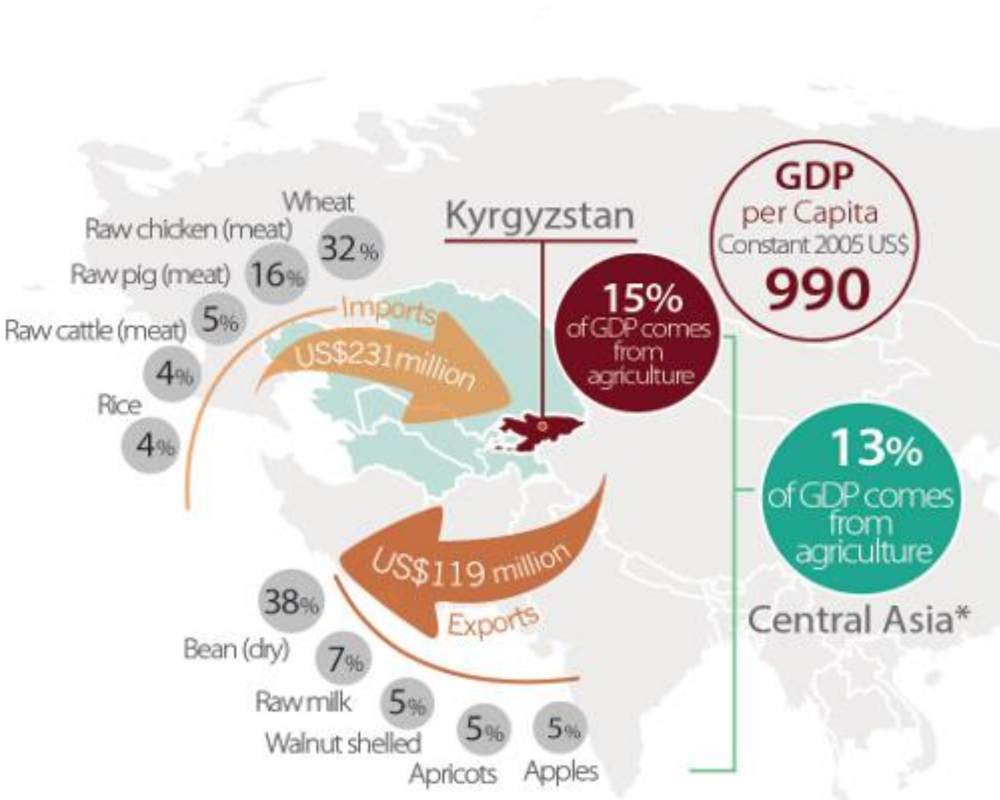
Frequent and persistent droughts and floods coupled with scarce water resources in the well-developed southern region, extensive reliance on international water sources, and inadequate water management infrastructure have contributed to the economy's susceptibility to water shocks. This heightened vulnerability constrains both growth and poverty reduction.

Approximately 40% of the country's total water intake is wasted due to inefficient irrigation systems; annual water loss is estimated at around 2.4 km³/year. Actual total water loss may be even higher as indicated by reports from International Center for Tropical Agriculture (CIAT) and the World Bank (2018).

Climate Change's Impact on Agriculture

Kyrgyz Republic's agriculture sector is among the most vulnerable to climate change. It is subject to an increasing number of natural hazards and phenomena driven by climate change, which increase the risk of geophysical disasters such as landslides, outbursts of mountain lakes, floods, forest and steppe fires, soil erosion, spring and autumn frosts, and heavy snowfalls. Low agricultural productivity and projected population growth also undermine food security. Although half Kyrgyz land is used in agriculture, only 10% is irrigated. The productivity of irrigated land is estimated at only $678 per ha against a regional average of $2,480 per ha (Botta et al., 2022). A**round 45.7% of total agricultural land is exposed to water and/or wind erosion** (CIAT& World Bank, 2018). In the context of a growing population and diminishing freshwater resources, pressure on domestic land is expected to increase in the future under a RCP8.5 climate scenario. **During 2012–2016 agriculture contributed 15% the country's GDP** (Figure 14), and approximately 9.9% of total exports and 14.9% of total imports were related to the agriculture sector (CIAT & World Bank, 2018).

Figure 14: Economic Relevance of Agriculture in the Kyrgyz Republic



Source: CIAT and World Bank (2018)

Even though the sector's contribution to total GDP is declining, it remains important for the rural population, which constitutes 65% of the total population (International Monetary Fund [IMF], 2023b). **The sector employs 60% of the rural population** who mainly work in the production of key crops such as wheat, corn, barley, potatoes, and cotton (ADB & World Bank, 2021b). Agricultural products, including grains, forage crops, meat, and dairy, comprised about 8% of total exports in 2020 (IMF, 2023b).

The current and anticipated adverse effects of climate change in the Kyrgyz Republic jeopardize vital agricultural systems and the livelihoods of those reliant on them. This in turn hampers the country's efforts to eradicate poverty and ensure food security. To address these challenges, nationally determined contributions (NDCs) have highlighted the promotion of sustainable agriculture as a central strategy to mitigate the impacts of climate change.

Climate change also leads to droughts, which can cause a serious degradation of pastures. They significantly reduce yields in rain-fed agriculture, and in some years, intense, prolonged droughts can cause serious damage to perennial plant species, making it difficult to provide animal feed. **Droughts in 2012 and 2014 had devastating consequences. The sharp rise in in the price for dry feed has led to a significant loss of livestock**. Farms in the southern part of the country suffered the most . Extreme conditions have left deep marks and inflicted huge losses on hundreds of families.

Studies conducted by the Institute of Water Problems and Hydropower of the National Academy of Sciences of the Kyrgyz Republic show that the fertility of arable lands will decline steadily, and **the territories of deserts and semi-deserts will expand from 15% in 2000 to 23.3%–49.7% in 2100**. This will lead to a decrease in the yield of wheat, sugar beet, and fruit crops in the Chui region, wheat and barley in Talas, and a number of crops in the Jalal-Abad and Issyk-Kul regions.

The main economic consequences of desertification and land degradation are a decrease in crop yield and production, a reduction in livestock productivity, a decrease in export potential in agriculture, stagnation in the development of food and light industries, and a sharp decrease in tax revenue from the processing and agriculture sectors.

Climate Change's Impact on Energy

The Kyrgyz economy relies significantly on the energy sector, with hydropower contributing approximately 90% of the country's electricity. This sector plays a crucial role in economic development by supplying energy to enterprises and the population, and contributes to GDP through electricity exports; however, the negative impacts of climate change are expected to lead to a 20% decrease in hydroelectric power generation.9 Shifting rainfall patterns, rising temperatures, and increased drought are likely to reduce the reliability and availability of water for hydropower and thermoelectric cooling. The effects of heightened glacier- and snowmelt are expected to impact hydropower sources in the coming decades, with increases projected for the next five to ten years and significant decreases thereafter (IMF, 2023b).

This substantial decline in energy infrastructure poses a significant impediment to Kyrgyz Republic's efforts to achieve consistent economic growth. The key features of the energy sector include **(i) deterioration of energy assets surpassing their economic lifespan; (ii) notable commercial and technical losses; (iii) electric and thermal energy tariffs below cost and distorted market-based fuel tariffs (coal, gas, and fuel oil); (iv) unsatisfactory financial performance; and (v) operational limitations arising from the interdependence of water release and energy production** (ADB, 2016). These factors collectively contribute to diminished reliability in the supply of energy to consumers.

The third National Communication of the Kyrgyz Republic (2016) estimated the possible decline in hydropower potential associated with climate change under a favorable scenario at up to 51 billion kWh, and in the case of the most unfavorable scenario, up to 36 billion kWh. While it is worth noting that the Kyrgyz Republic has an estimated 142 billion kWh hydropower, potential short-term hydropower resources the Kyrgyz Republic are estimated at 48 billion kWh, of which only about 13 billion kWh is in use.

Despite the promotion of renewable energy, the Kyrgyz Republic continues to rely on and expand its use of coal, natural gas, and oil, with no major phase-out attempts on the horizon. Fossil fuels remain the principal source of energy worldwide and are likely to play a significant role in meeting energy demands for several decades (Government of Kyrgyzstan. 2021. NDC, 2021), approximately 60% of all GHG emissions are

[9] https://cabar.asia/en/climate-change-and-water-resources-in-central-asia-growing-uncertainty#:~:text=In%20general%2C%20according%20to%20the,the%20rest%20of%20the%20region.

concentrated in the energy sector. The Kyrgyz Republic intends to reduce emissions in this sector by 13,38% by 2025 with the help of adaptation measures such as a reduction of GHG emissions (decarbonization of transport and reduction of coal use), an improvement of energy efficiency, and the development of renewable energy sources as the driving force behind its carbon-free policy.

Table 3: Impact of Climate Change on Energy Sector of the Kyrgyz Republic.

<table>
<tr><th>Climate change pattern</th><th>Potential Impact on the Energy Sector in the Kyrgyz Republic</th></tr>
<tr><td>Increased average and extreme temperatures</td><td>▪ Decreased hydropower generation capacity
▪ Reduced efficiency of thermal power plants
▪ Damage to physical infrastructure such as transmission lines</td></tr>
<tr><td>Change in precipitation patterns</td><td>Reduced coal quality and thermal power generation capacity</td></tr>
<tr><td rowspan="6">Climate related natural disaster</td><td>Floods</td></tr>
<tr><td>Damage to physical infrastructure such as transmission lines, coal extraction mines, and power plants</td></tr>
<tr><td>Landslides and mudslides</td></tr>
<tr><td>Damage to physical infrastructure causing failure of transmission networks and loss of power supply</td></tr>
<tr><td>Droughts</td></tr>
<tr><td>Water scarcity may affect hydro power generation capacity and impact thermal power cooling systems</td></tr>
</table>

Source: Chepelianskaia and Sarkar-Swaisgood (2022)

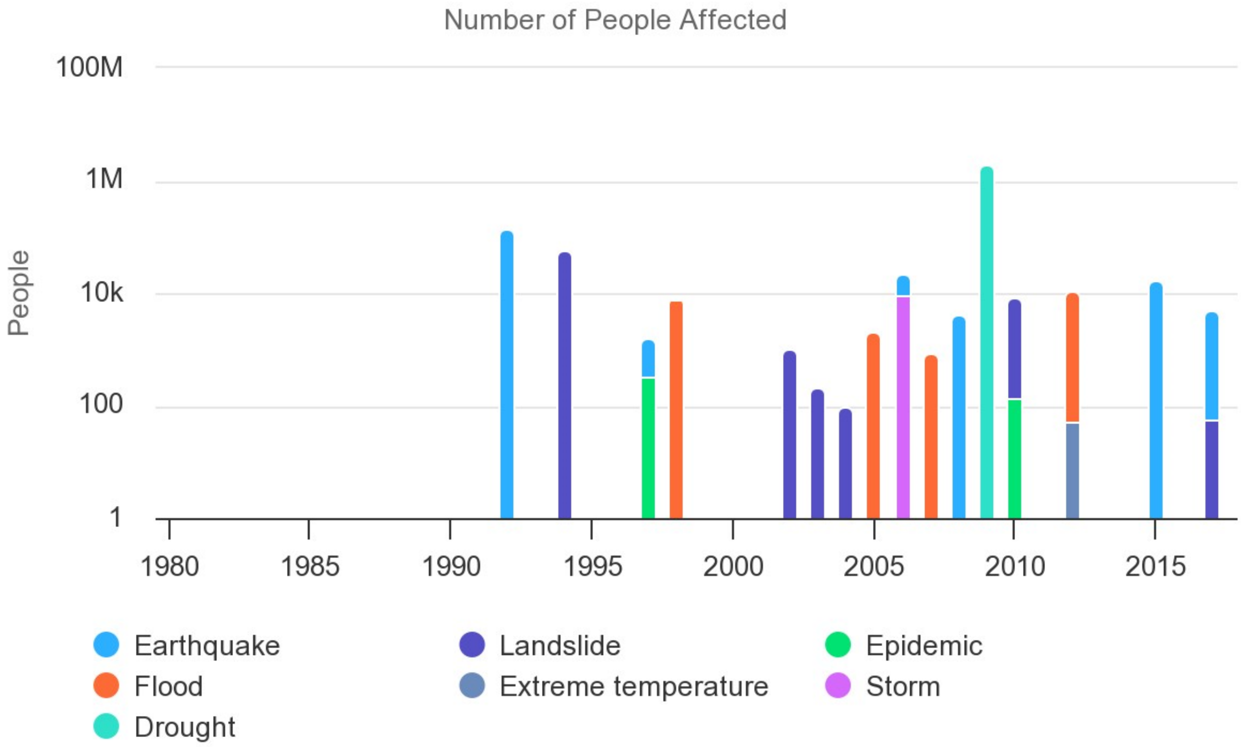
Vulnerability to Climate-Related Disasters

The Kyrgyz Republic is highly susceptible to various natural hazards including mudslides, landslides, avalanches, and earthquakes. **The country incurred substantial damages and losses from climate-related natural disasters—nearly $6.7 million annually—between 2000 and 2011** (Chepelianskaia, O., & Sarkar-Swaisgood, M. (2022b) UNDP, 2013). **According to a World Bank assessment, disasters and climate change stressors are expected to impact environmental, social, and economic sectors, resulting in an annual GDP loss ranging from 0.5% to 1.3%** (World Bank, 2019). **The Kyrgyz Republic has encountered 19 climate-related disasters since independence, which have caused approximately $76 million in damages—equivalent to about 1% of 2020 GDP—and affected over 2 million people** (IMF, 2023b).

The Kyrgyz Republic has a continental climate with distinct wet and dry seasons; however, climate change has disrupted these patterns. Precipitation distribution and intensity have changed: heavy rainfall events and flash floods have increased in some regions, whereas other regions have experienced prolonged droughts. These changes impact agriculture, water availability, and overall ecosystem resilience.

The Kyrgyz Republic's geography and topography make it highly susceptible to natural hazards. Available data indicate significant economic losses due to these hazards, amounting to 0.5-1.3% of the annual GDP (World Bank, CCKP). The country regularly faces droughts, landslides, avalanches, storms, floods, glacial lake outbursts, epidemics, pests, crop diseases, river erosion, and earthquakes (Figure 15).

Figure 15: Climate-Related Key Natural Hazards in the Kyrgyz Republic Between 1980–2016



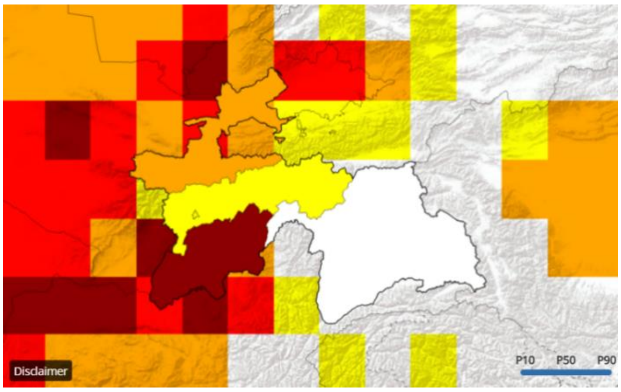
Source: World Bank Group Climate Change Knowledge Portal

Annually, the Kyrgyz Republic contends with significant risks from both earthquakes and floods. The average annual modeled loss attributed to floods surpasses $73 million, while for earthquakes, it stands at $72 million. Combined, these risks result in an aggregate annual average loss approaching $146 million (CAREC, 2022b).

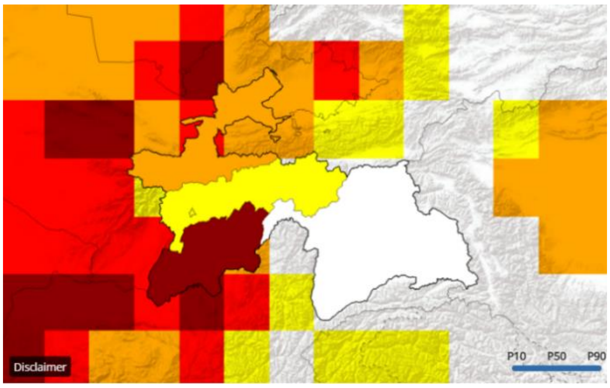
Tajikistan

Tajikistan is also not immune to climate change. Like other countries in the region, Tajikistan has experienced an increase in temperature, changes in precipitation patterns, and other climate-related phenomena in recent decades. This mountainous and land-locked territory has also experienced rising temperatures over the past decade. About **93% of Tajikistan is covered in mountains, with many glaciers primarily in the eastern regions of the country** (German Development Cooperation [GIZ], 2020). **The country provides 60% of Central Asia's water supply and its reliance on water-dependent sectors leaves its economy vulnerable to climate shocks** (IMF, 2023c). Under a RCP8.5 scenario (Figure 16), Tajikistan's temperature is set to rise by 5.5 °C by the 2090s (ADB & World Bank, 2021c).

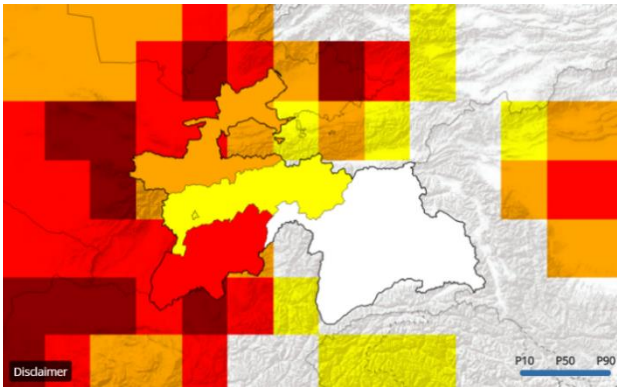
Figure 16: Compound Heat Risks Under the SSP5-8.5 Scenario in Tajikistan



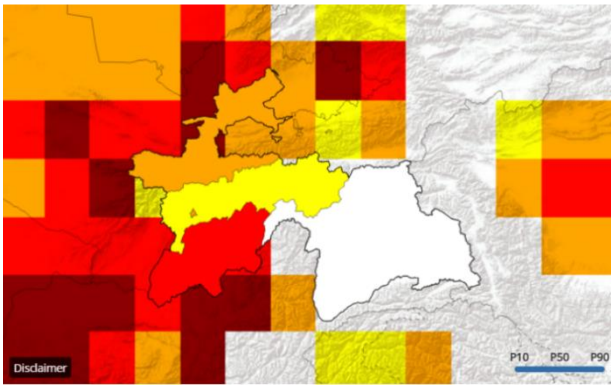
Temperature-Based Heat + Population for 2020-2039



Temperature-Based Heat + Population for 2040-2059



Temperature-Based Heat + Population for 2060-2079



Temperature-Based Heat + Population for 2080-2099

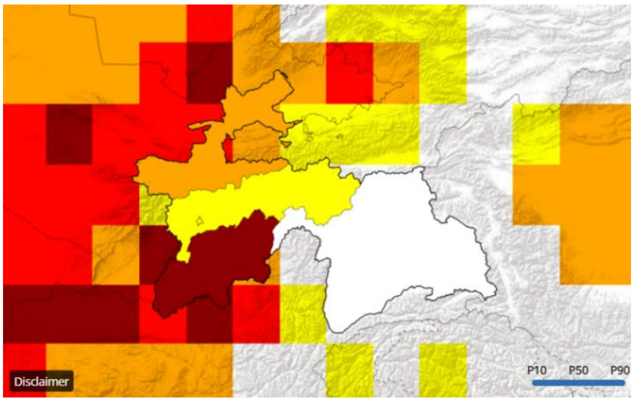
Source: Climate Change Knowledge Portal of the World Bank

Climate-induced natural hazards affect agriculture and can trigger technological accidents that disrupt water, agriculture, and energy infrastructure. In 2010, extreme weather events induced by climate change caused $600 million in losses, equivalent to 4.8% of Tajikistan's GDP. The average annual losses over the period 1996–2015 are estimated at 7.4% of the country's GDP (GIZ, 2020). In 2019, natural disasters triggered the internal displacement of 4,800 people (UN, 2022), which in turn, necessitates rapid adaptation actions for the country. The ND-GAIN ranks Tajikistan in the 98th place with an index score of 47.6. It is ranked 55th in vulnerability with score of −0.372, and 140th in readiness with a score of 0.325. **The annual investment needed to finance climate adaptation by 2030 is estimated at $1 billion** (UNFCCC, 2021).

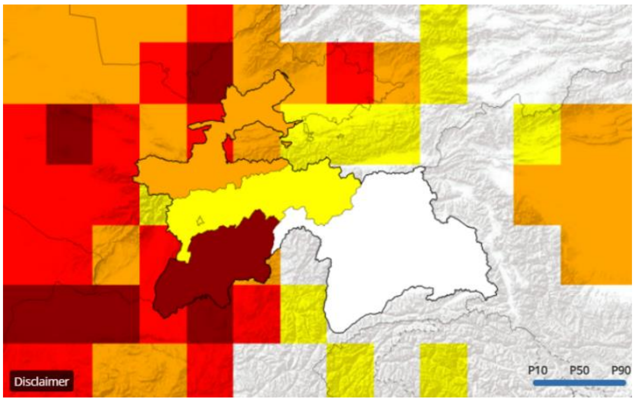
The country is expected to face several significant climatic challenges in coming years. One of the most notable is the melting of glaciers in the Pamir Mountains, which are a crucial source of freshwater. Glacial retreat has already produced new lakes and increased the risk of GLOFs. These events threaten local communities and infrastructure as well as water availability for agriculture and hydropower generation.

Changes in precipitation patterns have led to an increased frequency of extreme weather events such as droughts and heavy rainfall, which can have detrimental effects on agriculture and food security. The country relies heavily on its agriculture sector and any disruptions caused by climate change can have severe socioeconomic consequences.

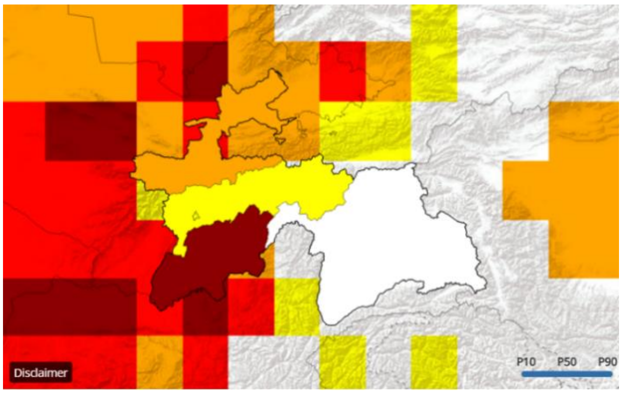
Figure 17: Compound Heat Risks Under the SSP1-2.6 Scenario in Tajikistan



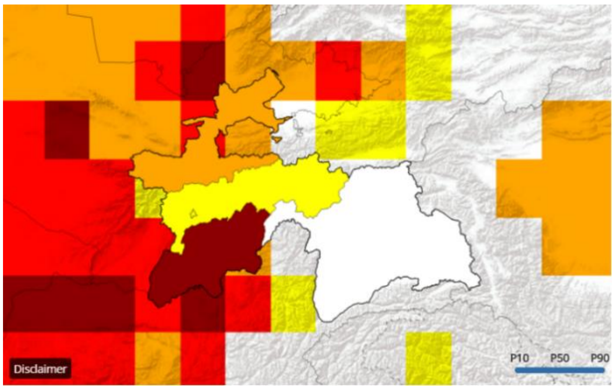
Temperature-Based Heat + Population for 2020-2039



Temperature-Based Heat + Population for 2040-2059



Temperature-Based Heat + Population for 2060-2079



Temperature-Based Heat + Population for 2080-2099

Source: Climate Change Knowledge Portal of the World Bank

Tajikistan is vulnerable to the impacts of climate change on its water resources. The country's rivers are primarily fed by snow and glacial melt, making them highly sensitive to shifts in temperature and precipitation. Changes in water availability can affect energy production because Tajikistan relies heavily on hydropower. Additionally, alterations in river flow patterns can affect downstream countries, which may lead to conflicts over water resources.

The Tajik government has recognized the importance of addressing climate change and has taken steps to mitigate its impact. The country has developed a national climate change strategy and action plan that focuses on adaptation and mitigation measures. These initiatives aim to build resilience in sectors such as agriculture, water management, and energy and promote sustainable development practices.

Climate Change's Impact on Water Resources

Like other nations in the region, Tajikistan's water sector is highly susceptible to climate change. Over 95% of the country's terrain is mountainous, and the water resources derived from these mountains play a crucial role in irrigating agriculture, meeting industrial and domestic demands, and generating approximately 95% of the country's electricity. **About 20% of Tajikistan's glaciers have already retreated, and some have disappeared.** Diminishing glaciers may lead to more intense flooding in certain areas and increased water scarcity in others. **Projections for the year 2050 suggest a 25%–30% reduction in glacier ice volume and a 6 to 15% increase in river runoff** (Green Climate Fund, 2020).

This trend may elevate the threat of sudden floods triggered by GLOF. In the long term, the retreat of glaciers and the intensification of droughts are likely to result in severe water shortages, posing risks to both food security and the environment (World Bank Group, CCKP). Under the RCP8.5 emissions scenario, the projected loss in glacier mass in the region is anticipated to reach 70% by the end of the century (Reyer, et al., 2017). The impact of melting glaciers is expected to be particularly significant in the primary river basins that encompass most of Tajikistan, including the Amudarya and Syrdarya. Approximately 50% of runoff from the Amudarya is sourced from glacial meltwater (Sorg et al., 2012).

Given the interdependence of water resources among Central Asian countries, climate change is likely to exacerbate conflict over water. Downstream countries such as Kazakhstan, Turkmenistan, and Uzbekistan, which have growing populations and substantial water consumption for cotton production, may clash with upstream countries such as the Kyrgyz Republic and Tajikistan, which aim to use more water for electricity generation and farming. The degradation of irrigation and sanitation infrastructure, along with inadequate administrative water allocation systems, has contributed to the region's increasing water scarcity.

The Fergana basin, which spans the Kyrgyz Republic, Tajikistan, and Uzbekistan, is particularly vulnerable to climate change and prone to conflict. As the primary area for agricultural cultivation and the most densely populated part of the region, it faces heightened risks of soil degradation and salinization owing to poorly managed agricultural practices, deforestation, overgrazing, and unsustainable agricultural practices.

Additionally, the anticipated increase in extreme rainfall intensity and frequency demands attention for disaster risk reduction. **Persistent flash floods, and land- and mudslides have affected Tajikistan in recent years, causing loss of life and substantial damage to infrastructure and livelihood damage, and they have occurred almost annually from 2000 to 2018.**[10] Reports suggest that up to 36% of Tajikistan's land area may be at risk of landslides, and this risk will increase with climate change.[11] A similar proportion of the nation faces a high risk of mudflow and the majority of the country faces some level of exposure.[12] Research on the Central Asian region highlights the likely increase in the erosive capacity of rainfall under all emission pathways, potentially elevating the risk of landslides and worsening soil erosion.[13]

While melting glaciers and snow traditionally regulate flows and ensure year-round water availability, the ongoing melting of glaciers is already causing a slight increase in runoff (typically less than 10%) in many rivers (ADB & World Bank, 2021c). The Naryn basin is also expected to experience an increase in runoff by 2040 due to the rapid melting of ice caps (Gan et al., 2015).

The disappearance of smaller glaciers can lead to a significant decline in the runoff of smaller tributary rivers. The cumulative impact of glacier loss is expected to increase in the long term, contingent on global emission reductions, potentially resulting in substantial decreases in runoff. As these processes unfold, a shift in the runoff regime is expected with increased variability in flows. This includes an amplification of the April–June peak and a reduction in the late summer and autumn flows.[14]

Climate change is expected to heighten adverse weather patterns, with temperatures expected to increase by 1.8–2.9 °C by 2050 (UNFCCC, 2014), coupled with substantial variations in precipitation (CAREC, 2020). Climate-related disasters, including winter avalanches, spring floods, and summer dust storms are expected to become more frequent and severe. **Without adaptation measures, their economic cost could potentially reach 20% of GDP** (World Food Programme [WFP], 2017).

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[10] Reliefweb (2018). Tajikistan country profile. https://reliefweb.int/country/tjk

[11] World Bank (2017). A rocky future? Ensuring Central Asia's mountains are climate and disaster resilient. https://www.worldbank.org/en/news/feature/2017/12/11/ensuring-central-asias-mountains-are-climate-and-disaster-resilient

[12] Asian Disaster Reduction Center (2006). Tajikistan: Country Report for Asian Disaster Reduction Center. https://www.adrc.asia/countryreport/TJK/2005/english2.pdf

[13] Duulatov, E., Chen, X., Amanambu, A.C., Ochege, F.U., Orozbaev, R., Issanova, G., & Omurakunova, G. (2019). Projected Rainfall Erosivity Over Central Asia Based on CMIP5 Climate Models. https://doi.org/10.3390/w11050897

[14] Hydrologic impact of regional climate change for the snowfed and glacierfed river basins in the Republic of Tajikistan: Hydrological Response of Flow to Climate Change. https://doi.org/10.1002/hyp.9535

Climate Change's Impact on Agriculture

Tajik farmers are negatively impacted by climate change-induced droughts, shrinking rain-fed lands, reduced crop yields and production and crop failures, and losses in livestock production. Rising temperatures and changes in rainfall patterns may force farmers to leave their land and search for more suitable agricultural areas. Higher evaporation rates may force farmers to use more water to grow the same variety and crop volume in new cultivation areas. They may need to change their traditional growing methods and yields to accommodate longer growing seasons. Reduced water supplies in drylands have the potential to cause significant economic losses for farmers, particularly small farmers who are already facing the impacts of climate change and extreme climate events.

Tajikistan's rain-fed agriculture sector contributes nearly 25% of GDP and employs over 60% of the total workforce (IMF, 2023c). Production is focused on water-intensive crops, such as cotton and wheat, which are highly vulnerable to droughts and unpredictable precipitation. The anticipated drier climatic conditions in the coming decades are expected to exert pressure on crop yields, heighten food insecurity, and increase dependence on food imports.

Climate change can directly and indirectly affect food production by influencing crop growth. Direct effects include changes in carbon dioxide availability, precipitation patterns, and temperature. Indirect effects manifest through alterations in water resource availability and seasonality, soil organic matter transformation, soil erosion, shifts in pest and disease profiles, the introduction of invasive species, and a decrease in arable areas due to desertification.

The overall outlook for agricultural production in Tajikistan leans toward the negative. Studies suggest likely yield declines for key crops, such as wheat, barley, maize, vegetables, and fruits, will typically range between 5% to 10% by 2050. Conversely, rice, potato, and cotton yields are projected to experience modest gains (< 5%) during the same period.[15] The collective impact of these changes poses a potential threat to national food security and community wellbeing.

However, there are some discrepancies in the outlook for wheat, a vital staple crop. While some studies have proposed that rising temperatures may, in the long term, create more favorable conditions for wheat growth, potentially increasing achievable yields by up to 12%, caution is advised.[16] Such projections should be treated carefully because models often evaluate the compatibility of average climatic conditions with plant physiology and may not adequately capture the impact of climate extremes. Additionally, there is a concern that over the long term, the loss of glaciers and snow cover could significantly diminish available water resources, potentially leading to major water shortages for irrigation purposes.[17]

With the increased probability of droughts and heat waves, the stability of agricultural production is likely to diminish and potentially impact net production. Studies have indicated that household income security in Tajikistan's arid regions may decline but increase for households in more humid regions.[18] However, considering the country's diverse ecological zones and their respective farming communities, the overall

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[15] Agricultural production, welfare and food security under climate change in Tajikistan. Institute of Agricultural Development in Transition Economies (IAMO) Samarkand Conference 2016. https://ideas.repec.org/p/ags/iamc16/250089.html

[16] Sommer, R., Glazirina, M., Yuldashev, T., & Otarov, (2013). Impact of climate change on wheat productivity in Central Asia. Agriculture, Ecosystems & Environment, https://geoagro.icarda.org/downloads/publications/papers/Sommer_et_al_2013_Impact_of_climate_change_on_wheat_productivity_in_Central_AsiaR.pdf

[17] Reyer, C. P. O., Otto, I. M., Adams, S., & Albrecht, T. (2017). Climate change impacts in Central Asia and their implications for development. Regional Environmental Change. https://doi.org/10.1007/s10113-015-0893-z

[18] Bobojonov, I., & Aw-hassan, A. (2014). Impacts of climate change on farm income security in Central Asia: An integrated modeling approach. Agriculture, Ecosystems and Environment, https://www.sciencedirect.com/science/article/pii/S0167880914001170

change in net revenue due to climate change is expected to be negative.[19] This shift may disproportionately affect the poorest groups, who characterized by limited access to agricultural technologies, infrastructure, and lower adaptive capacity. Barriers to adoption include a lack of access to credit and agricultural inputs.[20]

Climate Change's Impact on Energy Resources

Tajikistan's energy sector, which relies predominantly on water resources, is vulnerable to climate change. Heavy dependence on hydropower generation leads to a power surplus in summer and a deficit in winter. Despite being the eighth-ranked country globally for hydropower potential, estimated at 527 TWh, Tajikistan currently exploits only 4% of its hydropower potential (IEA, 2022b). The country's high vulnerability to climate change-related disasters and proneness to natural hazards make it difficult to fully exploit its hydropower potential. The cost of natural and climate-related disasters between 1992 and 2016 amounted to $1.8 billion (IEA, 2022b).

An increase in summer temperatures increases electricity consumption, leading to higher summer peak loads that exacerbate energy shortages. Changes in water availability, both random and long-term, can alter hydropower potential. Despite continuous progress toward expanding energy sources, **Tajikistan experiences a significant electricity shortage of 2.2–2.5 billion kWh in winter**. The shortage of electricity in the winter months is 15.5% of the annual energy production (Government of Tajikistan, 2021a). A climate change-driven decline in energy production in the hydropower sector could negatively impact both access to and use of already scarce energy.

The diversification of energy sources would reduce Tajikistan's heavy dependence on hydropower. The diffusion of renewable energy, which occurs at a relatively slow pace, is important for climate change adaptation. Tajikistan climate is favorable for solar energy use with an average of 280–330 sunny days per year. The total intensity of solar radiation varies between 280–925 MJ/m2 in the foothills and 360–1120 MJ/m2 in the mountains (Government of Tajikistan, 2021a).

Vulnerability to Climate-Related Disasters

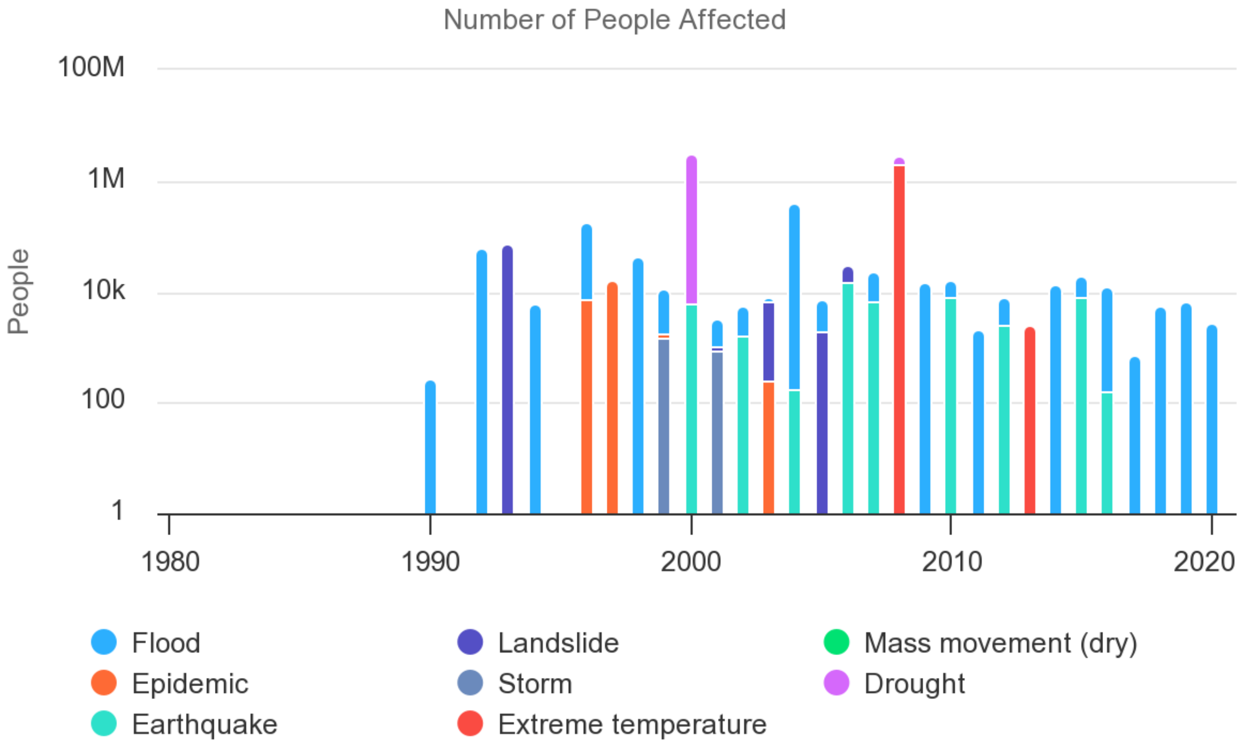
With 95% of its land covered by mountains, Tajikistan is exposed to climate hazards. Vulnerable regions include glacier-dependent river basins that provide hydropower and water for irrigation, fragile mountain ecosystems, and isolated forests in mountainous and riverine terrain that are susceptible to landslides and land degradation (World Bank Group, CCKP).

Under an RCP8.5, **the country is projected to face 7%–23% more heatwaves by the 2090s, droughts will increase by 3% to over 25%, and their impact on GDP by $30 million by 2050s** (ADB & World Bank, 2021c). Other risks and their impacts on the population are highlighted in Figure 18. The United Nations Office for Disaster Risk Reduction estimated the average annual losses to all types of flood at $48 million (UNISDR, 2014). Intensified adverse weather patterns will make climate disasters more frequent and severe, particularly winter avalanches, spring floods, and summer dust storms, whose economic costs could reach 20% of GDP of the country under an RCP8.5 emissions scenario (WFP, 2017).

[19] Closset, M., Dhehibi, B.B.B. and Aw-Hassan, A. (2015). Measuring the economic impact of climate change on agriculture: a Ricardian analysis of farmlands in Tajikistan. https://ccafs.cgiar.org/resources/publications/ measuring-economic-impact-climate-change-agriculture-ricardian-analysis

[20] Food and Agriculture Organization (n. d.). Improving the Resilience of Central Asian Agriculture to Weather Variability and Climate Change. http://www.fao.org/3/a-i7931e.pdf

Figure 2Climate-Related Key Natural Hazards in Tajikistan Between 1980–2020

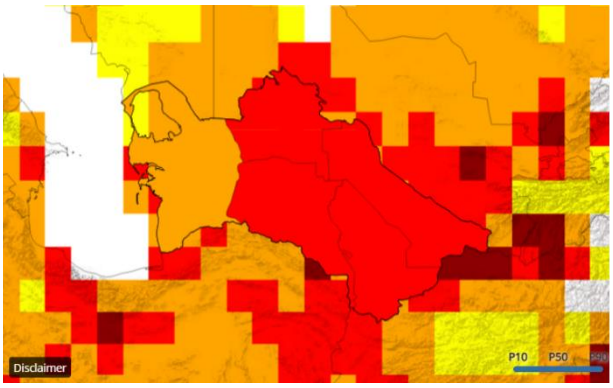


Source: World Bank Group Climate Change Knowledge Portal

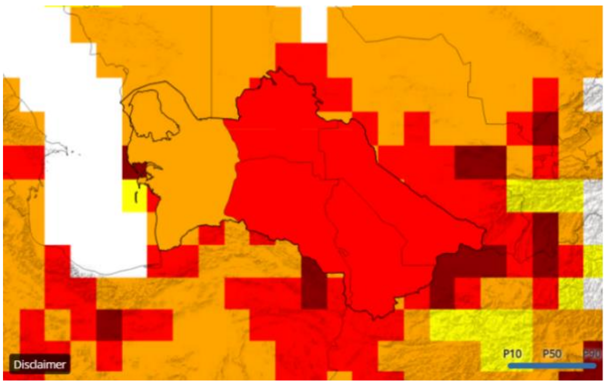
Turkmenistan

Turkmenistan stands out among the Central Asian countries with approximately 80% of its terrain characterized by a flat relief, primarily consisting of deserts and semi-deserts. The remaining 20% comprises mountains, foothill plains, and uplands (Government of Turkmenistan. 2022. NDC-TKM, 2022). The country is experiencing a noticeable intensification of its hot climate, with primary climate change trends marked by rising air temperatures, reduced precipitation, and shifts in seasonal boundaries. According to projections under the RCP8.5 emissions pathway, **Turkmenistan is expected to witness an average temperature increase of 5.1 °C by the 2090s.** This warming pace significantly exceeds the global average and is 3.3 °C higher than projections under the RCP2.6 for the same period (ADB & World Bank, 2021d). The specific impacts of these changes across different regions of the country are illustrated in Figures 19 and 20.

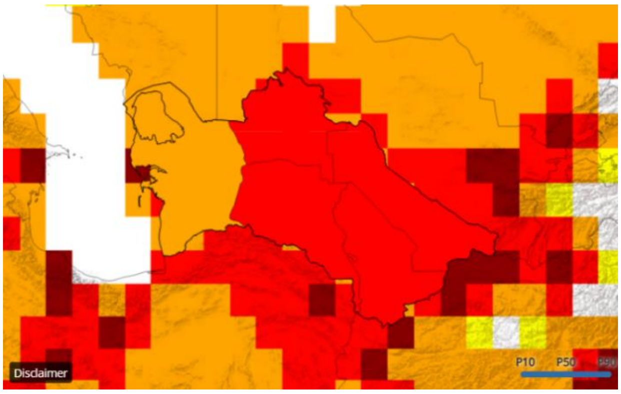
Figure 19: Compound Heat Risks Under the SSP5-8.5 Scenario in Turkmenistan



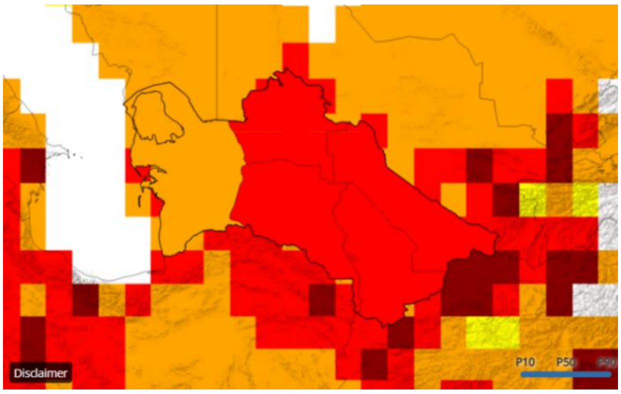
Temperature-Based Heat + Population for 2020-2039



Temperature-Based Heat + Population for 2040-2059



Temperature-Based Heat + Population for 2060-2079



Temperature-Based Heat + Population for 2080-2099

Source: Climate Change Knowledge Portal of the World Bank

Turkmenistan's economy exhibited remarkable growth—12.3% between 1998 and 2016—largely propelled by a substantial expansion in exports of natural gas, oil, and related products. Cotton stands as the country's second-largest export and comprised 6.2% of total exports in 2017 (ADB & World Bank, 2021d).

Under the RCP8.5 scenario, climate change projections are poised to impact critical facets of the country's socioeconomic development, particularly in the realms of water management, agriculture, and healthcare, as well as flora, fauna, forests, water, soil, and land resources (Government of Turkmenistan, 2022). These changes are expected to escalate the frequencies of natural disasters. For example, Mary, historically categorized as a 1-in-70 years event may transition to a 1-in-20 years event, whereas in the Balkan and Dashoguz, an event that was previously considered 1-in-200 years event could a 1-in-20 years event (CAREC, 2022d).

Model evaluations of climate change in Turkmenistan predict an increase in temperature by about 2 °C by 2040 and a decrease in precipitation in all agro-climatic zones from 8 to 17 percent by 2100. The consequences of these processes are inevitably reflected in a country’s socioeconomic development.

ND-GAIN ranks Turkmenistan 117th with an index score of 44.2, 36th in the vulnerability rankings with a score of 0.349, and 183rd in the readiness rankings with a score of 0.234. Turkmenistan has a predominantly arid climate that is experiencing the impacts of climate change and increasingly needs adaptation measures. Although specific data on climate change in Turkmenistan are limited, several key aspects need to be considered.

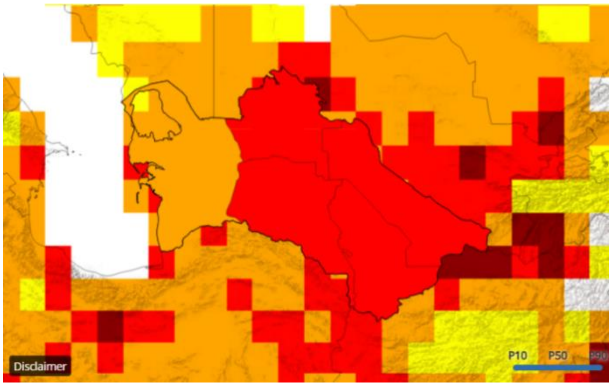
According to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), Turkmenistan is expected to experience higher temperatures and changes in precipitation patterns in the coming decades. Rising temperatures can increase evaporation, water scarcity, and reduced agricultural productivity.

The country's agriculture sector, which relies heavily on irrigation, is particularly vulnerable to climate change. Changes in precipitation patterns and higher temperatures can affect water availability, crop yields, and food security, which can have significant socioeconomic implications, as agriculture plays a vital role in Turkmenistan's economy and livelihoods. Turkmenistan is susceptible to desertification and land degradation, both of which are exacerbated by climate change. The country is already at risk of desert encroachment due to its arid climate and limited vegetation cover. Climate change can exacerbate this process, leading to a loss of fertile land and ecosystem degradation.

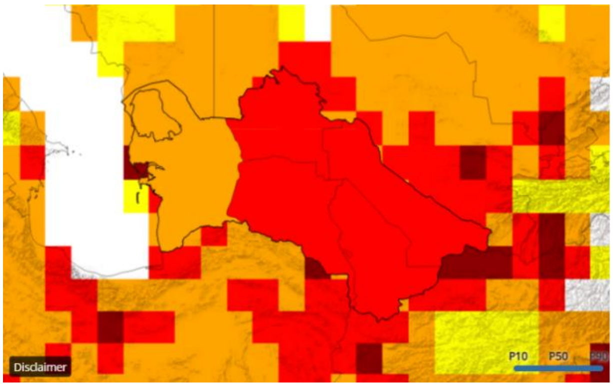
Water resources are a concern in Turkmenistan. The country relies heavily on rivers and underground aquifers for irrigation and drinking water. Climate change can impact water availability by changes in precipitation patterns and higher evaporation rates. This could further strain already limited water resources, affect various sectors, such as agriculture and energy production, and potentially lead to conflict over water. Moreover, the diminishing Caspian Sea, which constitutes 1,748 km of the country's coastline, is set to heighten Turkmenistan's susceptibility to climate change. Although the Caspian Sea is project to experience a less intense increase in temperature, the long-term implications will introduce additional socioeconomic challenges (ADB & World Bank, 2021d).

Like other Central Asian countries, Turkmenistan faces challenges in obtaining and sharing accurate and up-to-date climate data. The country has taken steps toward addressing climate change. In 2017, Turkmenistan ratified the Paris Agreement, which demonstrated its commitment to addressing global warming. The government has also implemented measures to promote energy efficiency, renewable energy, and sustainable development. That said, continued efforts to gather data, develop adaptation strategies, and promote sustainable practices are crucial to address climate change in Turkmenistan.

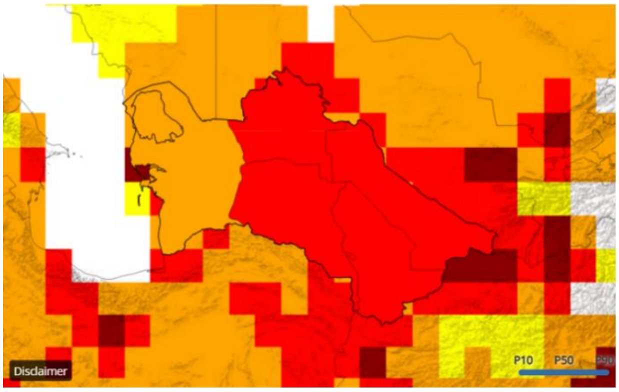
Figure 20: Compound Heat Risk Under the SSP1-2.6 Scenario in Turkmenistan



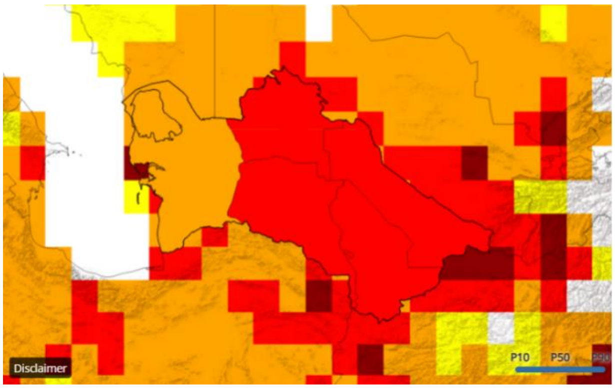
Temperature-Based Heat + Population for 2020-2039



Temperature-Based Heat + Population for 2040-2059



Temperature-Based Heat + Population for 2060-2079



Temperature-Based Heat + Population for 2080-2099

Source: Climate Change Knowledge Portal of the World Bank

Climate Change's Impact on Water Sector

Turkmenistan's geographic location, hot, dry climate and transboundary river flow create sensitive conditions for climate change in the economy's water sector. Water management is the basis of the country's socioeconomic development and provides water for agriculture, social needs, industry, and other priority sectors. **Due to its arid climate, more than 80% of Turkmenistan's territory lacks a constant source of surface water** (Lioubimtseva et al., 2012).

Under the RCP8.5 scenario, the continued impact of climate change will decrease precipitation between 2040 and 2011, combined with a constant increase in temperature, which will lead to a decrease in the total water supply. Consequently, the flow of major rivers, including the **Amudarya (Turkmenistan's main source of surface water), is expected to decrease by 10%–15% by 2050, and the flow of its other rivers**

(Murgab, Tejen, and Etrek) is expected to decrease by 5%–8% by 2030 (Government of Turkmenistan, 2015).

Melting glaciers, evaporation, infiltration, and weather conditions have a significant influence on changes and reductions in river flow. The Turkmenistan's main rivers originate in neighboring countries, are regulated by international agreements on water distribution, and are transboundary in nature. **More than 95% of Turkmenistan's water originates outside the country** (IMF, 2023a), and approximately 90% of this water is derived from the Amudarya, which flows through multiple international boundaries and is set to diminish the scale of available water (Government of Turkmenistan, 2012). **Over 90% of this water is consumed by the agriculture sector. Yet, around 50% of the water is lost between withdrawal and ultimate delivery due to an inefficient water supply chain**.[21]

Therefore, the volume of surface runoff also depends on water consumption in neighboring countries. This makes the country more vulnerable to upstream consumption; moreover, the increased demand for water in Afghanistan is another factor that influences water availability in Turkmenistan. The decline in river runoff has already created water scarcity in Turkmenistan and is expected to worsen. **Increasing hot weather and melting glaciers in the region will reduce the runoff by 25% in July and August,** which would cause major water supply issues for both cotton and wheat cultivation, which are heavily dependent on irrigation (ADB & World Bank, 2021d).

The forecast estimates of the water resource deficit are estimated at 5.5 billion m^3.[22] In addition, a lack of irrigation water will cause land degradation (increased salinization, desertification, weathering of the fertile upper-soil layer, and other types of soil erosion). At the same time, a decrease in precipitation will lead to a reduction in natural pastures and productivity in sheep breeding. Against this backdrop, the implementation of adaptation measures and active international cooperation in the field of water resource sharing are of great importance.

Climate Change's Impact on Agriculture Sector

Turkmenistan's agriculture sector is the main consumer of water resources. As previously mentioned**, 92% of all water consumed in Turkmenistan is used for agriculture.** Therefore, fluctuations in the country's water balance have a negative impact on agriculture. **In 2021, agriculture's share of GDP was almost 12%; in addition, the sector provides employment for over 40% of the population.** As 60% of the country's agricultural land is salinized, crop yields have fallen by 20%–30% in recent years.[23]

As for the structure of agricultural products, crop production surpassed livestock production for the first time in 2021. The agricultural sector is an important dimension of Turkmenistan's economy as it ensures food security.[24] Adaptation measures that boost resilience to climate stress and diversify crops should be an urgent priority for government policies in the agriculture sector.

The greatest threat (risk) to the development of agriculture is drought caused by high air temperatures and a lack of water resources. At present, there is a noticeable increase the frequency of dry years along Turkmenistan's main rivers: the Amu Darya and the Murgab (Government of Turkmenistan, 2022). The lack of river water is aggravated by climate warming and a decrease in precipitation, which increases the risk of a hydrological drought and desertification. This increases the scarcity of water resources and has a negative

[21] https://www.undp.org/turkmenistan/resilience-climate-change-and-energy
[22] Nationally Determined Contribution under the Paris Agreement, Turkmenistan, 2022, p.63.
[23] Impact of climate change on agriculture in Turkmenistan. https://progres.online/society/environment/impact-of-climate-change-on-agriculture-in-turkmenistan/
[24] https://progres.online/en/society/ecology/impact-of-climate-change-on-agriculture-in-turkmenistan/

impact on agriculture. **The loss of crop production alone due to augmenting drought years could cost Turkmenistan $20 billion until 2030**.[25]

Most acute droughts affect livestock grazing. If a strategic water supply is created for crop production, rational irrigation technologies save irrigation water and, despite existing losses, crops can be irrigated. Pasture livestock farming depends on weather conditions and pasture productivity. **During dry years, pasture vegetation experiences earlier burnout compared to the averages recorded in long-term data, resulting in a yield reduction ranging from 50% to 70%. A severe drought in 2000 and 2001 significantly diminished pasture grass yields to 40%–70% and 43%–58% of the long-term norm, respectively.** (Government of Turkmenistan, 2022). The scale of droughts and the damage they cause present the most pertinent and dangerous threat to Turkmenistan's economy and its sustainable development.

Increasing temperatures, decreasing rainfall, and shrinking surface water are likely to increase dry spells, reduce the productive vegetation cover of fragile desert ecosystems, and increase desertification. These processes negatively affect the state of the country's livestock forage base. Natural pastures in deserts as a source of cheap, high-quality natural fodder, play an important role in the development of domestic sheep breeding.

Climate Change's Impact on the Energy Sector

Turkmenistan is the second big emitter of GHG emissions above the global average in the Central Asian region due to its energy-intensive economy, followed by Kazakhstan. Higher temperatures will also affect energy consumption patterns: on average **a one degree increase in ambient temperature can increase electricity demand by up to 8.5% under the RCP.8.5 emissions scenario** (Santamouris et al., 2015).

In line with global trends, Turkmenistan's urban population is increasing, which will eventually put pressure on existing energy, water, transport, and waste management infrastructure. This will increase demand for energy and place more pressure on strained energy systems. Under the RCP8.5 scenario, the median projection could see the number of cooling degree days increase by 84%, causing a sharp decline in electricity demand for air conditioning (ADB & World Bank, 2021d). Combined with potential declines in the productivity of hydropower as an energy source due to rising temperatures, this process will have knock-on effects across many sectors (Reyer et al., 2017).

Vulnerability to Climate-Related Disasters

Turkmenistan is highly vulnerable to climate-related disasters such as recurrent wind, landslides, earthquakes, and droughts. **Climate change can also cause a 10% annual increase in floods and mudflows, a 5% annual increase in heavy rainfall, and gradually augmenting heatwaves** (Government of Turkmenistan, 2012). Under the RCP8.5 scenario, the country's annual losses are estimated at $140 million from floods and $11.3 million from earthquakes (CAREC, 2022d).

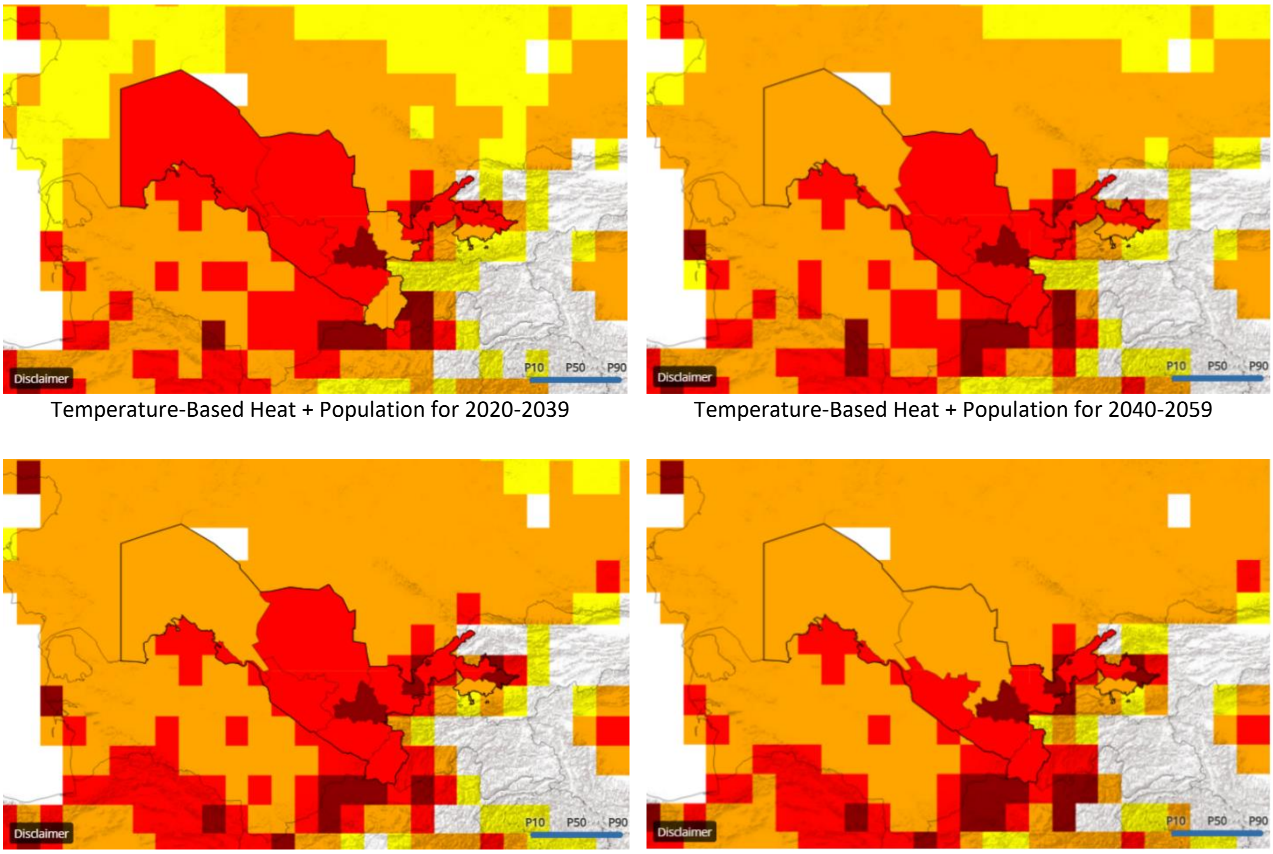
Uzbekistan

Uzbekistan is a double-landlocked country in Central Asia and grapples with the severe impacts of climate change. The country's challenges span desertification, water scarcity, soil salinization, droughts, and the alarming shrinkage of the Aral 1 Sea—acknowledged as the world's most significant anthropogenic disaster. Uzbekistan has a continental and subtropical climate, characterized by daily and seasonal fluctuations, with maximum summer temperatures surpassing 45 °C and minimum winter temperatures plunging below −20 °C. In the desert regions, peak temperatures reach 45–49 °C, while the southern parts of the country

[25] https://reliefweb.int/report/turkmenistan/turkmenistan-begins-developing-national-adaptation-plan-funding-approved-green#:~:text=The%20need%20for%20adaptation%20in,drought%20could%20cost%20US%2420

may experience minimum temperatures as low as −25°C (USAID, 2018c). Figures 21 and 22 offer insights into the impact of these temperature variations on different regions of Uzbekistan under various scenarios.

Figure 21: Compound Heat Risks Under the SSP5-8.5 Scenario in Uzbekistan



Temperature-Based Heat + Population for 2020-2039

Temperature-Based Heat + Population for 2040-2059

Temperature-Based Heat + Population for 2060-2079

Temperature-Based Heat + Population for 2080-2099

Source: Climate Change Knowledge Portal of the World Bank

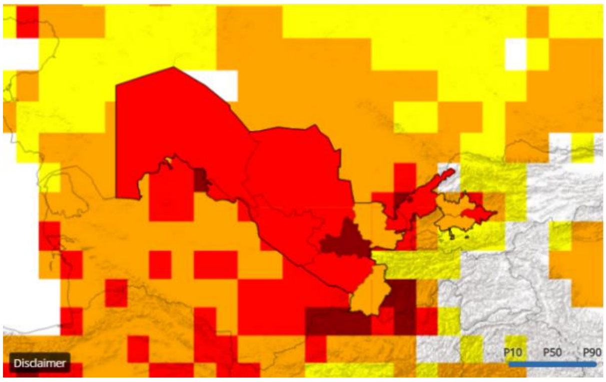
Uzbekistan has one of the world's highest energy intensities. **Inefficiencies in energy use are estimated at around 4.5% of the country's GDP annually**. About 80% of its water is sourced outside the country, which makes it vulnerable to global warming and changes in the consumption patterns of neighboring countries.[26] Uzbekistan relies heavily on its rivers, such as the Amu Darya and Syr Darya, for irrigation, drinking water, and hydropower generation. However, changes in precipitation patterns and increased temperatures can affect water availability, potentially leading to conflict over water resources.

Water availability also affects productivity in the agriculture sector. The country relies heavily on irrigation for crop cultivation; however, changes in precipitation patterns can disrupt water availability and affect yields and food security. Higher temperatures can also increase evaporation rates and exacerbate water scarcity. Poor segments of the population rely on agriculture in arid regions, making this sector important for economic and social stability.

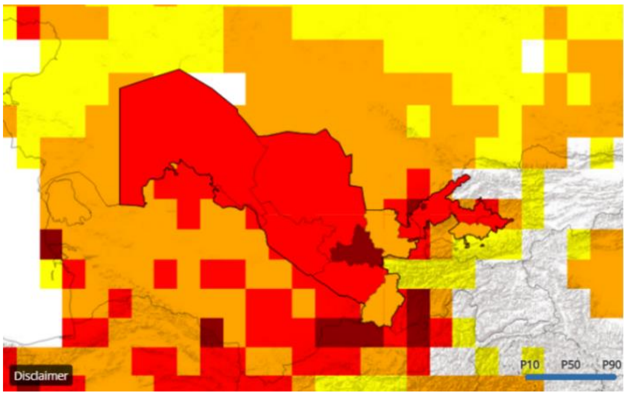
Exceeding the global average, projected average temperatures are set to increase by 4.8 °C by the 2090s under the RCP8.5 scenario or highest-emissions pathway (ADB & World Bank, 2021e). ND-GAIN ranks Uzbekistan 72nd place with an index score of 52.2, 43rd in the vulnerability rankings with a score of 0.364, and 97th in the readiness rankings with a score of 0.408.

[26] https://www.undp.org/uzbekistan/environment-and-climate-action#:~:text=With%2080%20percent%20of%20its,decreased%20productivity%20of%20arable%20land

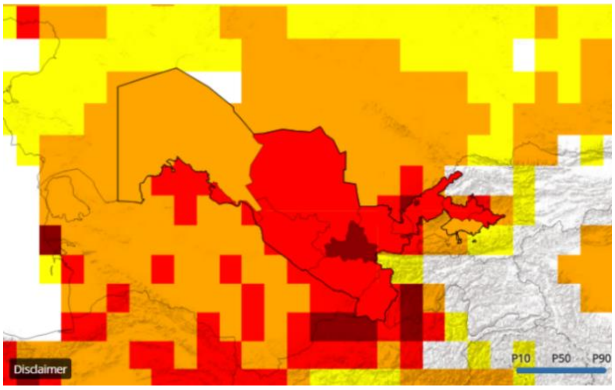
Figure 3: Compound Heat Risk Under the SSP1-2.6 Scenario in Uzbekistan



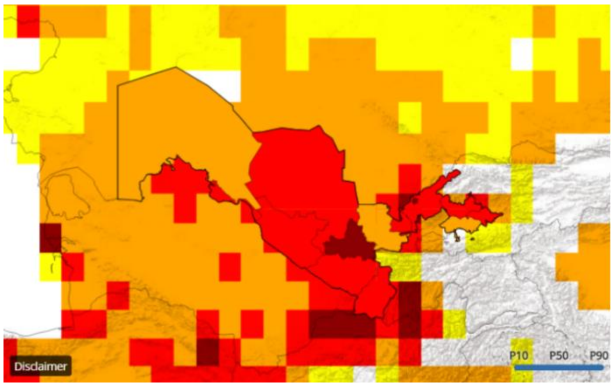
Temperature-Based Heat + Population for 2020-2039



Temperature-Based Heat + Population for 2040-2059



Temperature-Based Heat + Population for 2060-2079



Temperature-Based Heat + Population for 2080-2099

Source: Climate Change Knowledge Portal of the World Bank

Uzbekistan faces a spectrum of extreme weather-related events, which are projected to intensify under the RCP8.5 emissions pathway. Similar to much of Central Asia, Uzbekistan is susceptible to earthquakes, mudslides, glacial lake outburst floods, flash floods, heat waves, droughts, and dust storms.

To address climate change, Uzbekistan has taken steps toward adaptation and mitigation. The country ratified the Paris Agreement in 2017, demonstrating its commitment to combat global warming. Uzbekistan has implemented policies and programs to promote energy efficiency, renewable energy, and sustainable agriculture. Continued efforts to gather data, develop adaptation strategies, and promote sustainable practices are crucial to address climate change in Uzbekistan.

Climate Change's Impact on Water Resources

The desert terrain and arid climate of Uzbekistan make water its most precious resource. The country is highly reliant on water resources for hydropower generation, which **provides 13.6% the country's total electricity production, and for irrigation, which consumes 90% of the country's total water withdrawals** (USAID, 2018c. From 2009 to 2017, **the agriculture sector accounted for 89%–92% of total water use, and nearly one-third of that was lost** (UNECE, 2020). **These inefficiencies in the use of water are estimated to cost about 8% of the country's GDP**,[27] which could worsen under the projected RCP8.5 emissions pathway. Even though it is a cost-intensive measure, by reducing water losses, the country would be able to mitigate water shortages and save enough water to face the anticipated changes in available water driven by variable precipitation due to climate change.

[27] UNDP (n. d.). Environment and Climate Action. https://www.undp.org/uzbekistan/environment-and-climate-action#:~:text=With%2080%20percent%20of%20its,decreased%20productivity%20of%20arable%20land

About 80% of Uzbekistan's water originates outside its territory, which makes it vulnerable to water consumption in neighboring countries (ADB & World Bank, 2021e). Glacial melt dynamics and seasonal snowmelt from the mountains, channeled largely through two main rivers, Amudarya and Syrdarya, and other small rivers of the Aral Sea basin provide most of its freshwater resources (USAID, 2018c). Between 1957 and 2010, the total volume of ice glaciers decreased by 24.3% in the Pskem river basin, by 67.4% in the Kashkadarya river basin, and 40.1% in the Surkandarya river basin. Under the RCP8.5 scenario, all Uzbekistan's glaciers will disappear within the next 50 years (UNECE, 2020). Runoff increases as glaciers melt; however, once they have disappeared, runoff decreases sharply.

Table 4: Effect of Climate Change on Forecast Annual Irrigation Water Shortfall in Uzbekistan by Basin and Climate Scenario

	Under RCP 2.6		Under RCP 8.5	
Basin	m^3 thousands	% shortfall	m^3 thousands	% shortfall
Syrdarya East	615,927	11.6	3,627,991	51.6
Syrdarya West	122,023	1.9	2,817,031	34.4
Amudarya	2,174,069	8.7	8,405,243	28.9
Aral Sea East	0 0	00	0	0
Aral Sea West	0 0	00	0	0
Subtotal	2,912,019	8.0	14,850,265	33.5

Source: Derived from Sutton et al. (2013)

Other projections indicate that by mid-century, inflow into downstream areas could decline by 22%–28% for the Syrdarya and 26%–35% for the Amudarya. By the 2050s, severe water shortages could occur in these river basins, leaving up to 50% of demand levels unmet (ADB & World Bank, 2021e). This will also have a negative impact on water quality. The water quality within the Amudarya basin is already hazardous to health in over 70% of the area, and more than 10% of the water is classified as extremely hazardous[28,29] These trends will further desiccate the Aral Sea and affect the remaining 10% (or less) of levels 60 years ago. It will accelerate the adjoining areas' desertification with winds carrying sand and dust farther afield.

The expanding water deficit, coupled with increasing year-to-year variability, is expected to yield cascading negative impacts on various sectors, notably agriculture, which relies heavily on water for irrigation and human health due to drinking water shortages and increased salinization (UNECE, 2020; USAID, 2018c). **Approximately 20% of the country's population is currently grappling with the effects of water salinization**.[30]

Furthermore, climate change is expected to affect the energy sector by diminishing the productivity of both large and small hydropower stations, primarily because of reduced streamflow, particularly during the summer and autumn months (USAID, 2018c). Although a further decrease in available water is on the cards, current water consumption in Uzbekistan is already at a critical level. **The country's current consumption level is 167% of available water resources due to the intensive nature of its water-intensive economy**.

Addressing the challenges of climate change and water scarcity in Uzbekistan will require a multifaceted approach that includes a combination of conservation measures, technological innovation, and

[28] Chembarisov, E. I., Lesnik, T. V., & Ranneva, I. V. (1998). Contemporary rivers' water quality of Uzbekistan. In T. V. Tuzova (Ed.) Water and Sustainable Development of Central Asia. Materials of the Projects: "Regional Cooperation on the Usage of Water and Power Resources in Central Asia" and "Hydroecological Problems and Sustainable Development of Central Asia," American University in Kyrgyzstan: Bishkek, Kyrgyzstan, 2001; pp. 39–41. (In Russian)
[29] Zharkov, V. V., & Zharkov, D. V. (2002). Hydrochemical composition of waters of the Karakum-river. Problems of Desert Development, 4, 66–71. (In Russian)
[30] https://www.undp.org/uzbekistan/press-releases/uzbekistan-advances-its-climate-change-adaptation-planning

infrastructure improvements. By taking these steps, Uzbekistan will be able to enhance its resilience to climate change, while ensuring sustainable access to water for its people.

Climate Change's Impact on Agriculture

Temperature changes and expected droughts will increase in intensity across Uzbekistan, and the sustainability of agriculture will depend heavily on the availability of water resources and their management. As the main consumer of water resources, the agriculture sector continues to play a vital role in the country's economy, contributing to **27% of total GDP** (Abdullaev & Akhmedov, 2022) **and employing around 24% of the population** (OECD, 2023).

Uzbekistan has 4.3 million ha of irrigated land, which consumes over 90% of available water (UNDP, 2023). **Half of all irrigated land is affected by soil salinity; the irrigated lands located in Karakalpakstan are fully affected by salinization** (ADB & World Bank, 2021e). Under the RCP 8.5 scenario's emissions pathway, the expected increase in temperature will cause further evaporation, increasing the water demand for irrigation.

Sutton et al. (2013) highlighted that if no adaptation measures are taken beyond simply changing planting dates in response to temperature change and reduced water availability, **climate change is likely to reduce yields by up to 50% by 2050 for nearly all crops.** The reduction levels for some of the crops by the 2050s are as follows:

- Spring wheat: Anticipated yield reductions of 41% to 57%
- Winter wheat: Expected yield reductions of 31% to 43%
- Apples: Projected yield reductions of 39% to 63%
- Potatoes: Estimated yield reductions of 37% to 57%
- Tomatoes: Forecasted yield reductions of 29% to 57%
- Cotton: Envisaged yield reductions of 25% to 49%
- Alfalfa: Predicted yield reductions of 27% to 39%.

The warming climate is poised to directly affect crop yields and exacerbate the strain on water supplies, which will be further compounded by reduced precipitation. **Projections indicate that the demand for irrigation water in Uzbekistan will increase by an average of 5% by 2030, 10% by 2050, and potentially 25% by the 2040s under the high-emissions RCP8.5 scenario** (USAID, 2018c). In 2000 and 2001, agricultural yields experienced declines of 14%–17% for cereals and 45%–75% for other crops. The associated losses in agricultural GDP were between $38 million and $130 million, which had severe economic and social consequences for the country (ADB & World Bank, 2021e).

Climate Change's Impact on Energy Resources

Climate change has introduced growing challenges to the production and transmission of energy resources. The escalating impact of climatic phenomena, such as an exponential rise in temperature, an increase in the frequency and severity of extreme weather events, and shifting precipitation patterns has significantly affected energy production and delivery. This impact extends to solar and wind energy parks and is becoming increasingly prominent in Uzbekistan's energy mix.

On the demand side, shifting patterns in heating and cooling demands have emerged due to rising temperatures. On the supply side, these changes encompass alterations in the averages and variability of wind, solar, and hydropower resources, the availability of crops for bioenergy feed stock, costs, and the availability of fossil fuels affected by melting sea ice and permafrost, and the efficiency of PV panels, inverters, and other equipment (Ebinger & Vergara, 2011).

As highlighted previously, climate change is expected to spur an increase in energy demand, a phenomenon pertinent to Uzbekistan. Notably, a significant surge in demand is expected for energy required for cooling.

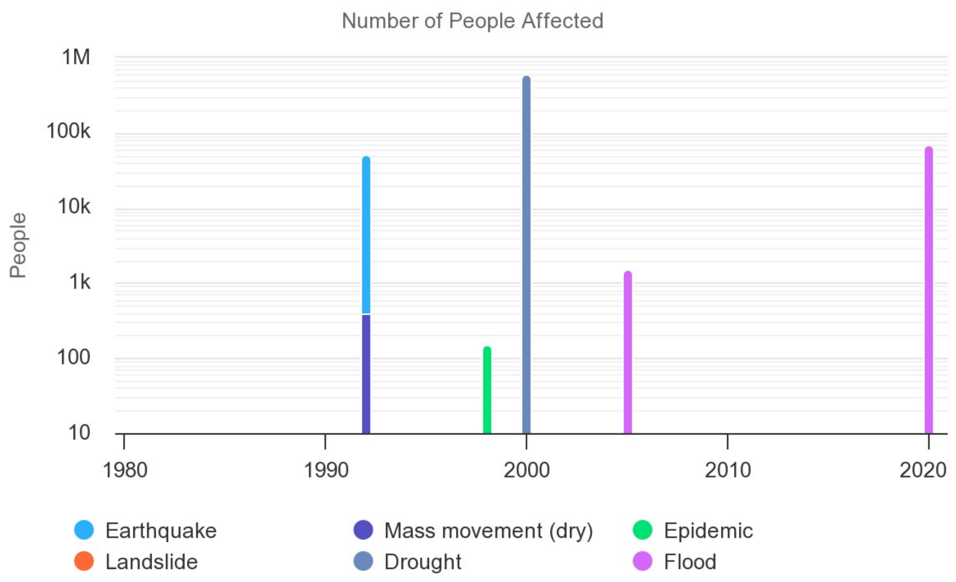
Despite the expected decrease in energy consumption for heating during winter due to climate change, the heightened demand for cooling in summer months will exert a substantial influence on energy demand (UNECE, 2020). **Projections suggest that by 2030, rising temperatures could shorten the average heating season by 9%, while the cooling season's duration might extend by 16% under the high emissions scenario.**[31] This augmented demand poses a risk of power disruptions unless power generation and consumption are effectively balanced, which is contingent on the quality and capacity of the grid.

Furthermore, climate change is expected to impact hydropower production, which accounts for 11% of Uzbekistan's electricity generation (UNECE, 2020). Changing weather patterns adversely affect hydropower production due to changes in water availability. Global warming also adversely affects the production and availability of biomass for energy generation.

Vulnerability to Climate-Related Disasters

Uzbekistan is vulnerable to various climate-related natural hazards, including earthquakes, heatwaves, droughts, and floods (Figure 23). These risks threaten water resources, agricultural productivity, energy generation processes, and the associated infrastructure. While less than 15% of the country's territory is exposed to critically high seismic risk, **over half of the population resides in these areas and contribute approximately 65.5% of the country's GDP**. The vulnerable regions are concentrated in the northeastern Tashkent and southwestern Bukhara regions. Tashkent, ranked first in Central Asia and the Caucasus region in terms of exposure and susceptibility to seismic hazards, accounts for approximately 8% of the country's population. A low-frequency, high-impact earthquake with a 100-year return period could result in a $3.6 billion loss in Uzbekistan, equivalent to approximately 5.96% of the country's nominal GDP (CAREC, 2022e). **Floods impact an average of 1.4 million people annually, causing losses close to $3 billion** (World Bank, 2022b). With the expected accelerated melting of glaciers by the mid-century, these seismically active areas pose a serious threat to Uzbekistan's economic, environmental, and social security.

Figure 23: Key Natural Hazards in Uzbekistan in 1980–2020



Similarly, **extreme floods could incur approximately $2.8 billion in costs at the 100-year return period, nearly equivalent to 2.8% of the country's nominal GDP** (CAREC, 2022e). The escalation of these risks will be contingent on the extent of climate change, intensity of precipitation, and other influencing factors unless adequate adaptation measures are implemented.

[31] Second National Communication of the Republic of Uzbekistan to the UNFCCC.

Benefits of Regional Cooperation and Nexus approach

Despite existing regional institutional structures and general political commitments, regional cooperation in Central Asia was largely driven by uncoordinated and uneven policies before 2017, with water resources being the main hurdle for cooperation. Some argue that comprehensive regional cooperation and integration are still less likely to occur in the wake of diminishing water resources, particularly in the context of Afghanistan's increasingly active engagement in water and agricultural issues under the reign of the Taliban. A tectonic shift toward regional integration started in 2017. Regional cooperation has since improved significantly when Uzbekistan shows its ambitions as an increasingly important variable of regional development in Central Asia. Therefore, unlocking regional cooperation in the battle against climate change presents an opportunity.

Regional Cooperation

As demonstrated in previous sections, most of the impacts and implications of growing climate change have, to a large extent, come from the degree of frequency and exposure to hazards in the past and were reviewed by country. Yet, from now onwards, the intensity and impact of hazards will likely cross the borders of countries, communities, and businesses. Therefore, integrated efforts on a regional scale are necessary to enhance adaptation to climate change and build a collective resilience. Witnessed during the COVID-19 pandemic, regional cooperation and intersectoral approach are the most productive way in dealing with challenges that do not respect boundaries. Fragmented national policies no longer fit for the expected scale of climate challenges. Reviving enhanced regional collaboration can help to address cross-border climate challenges.

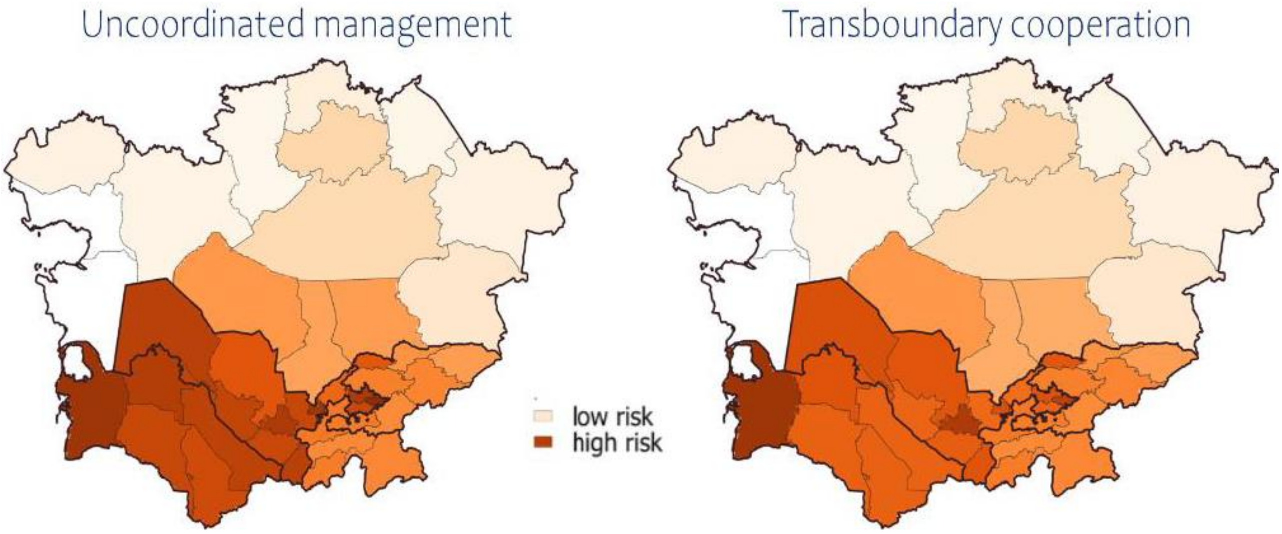
Regional cooperation[32] is crucial for several reasons, including the potential for cost reduction and resource efficiency and offers compensation for resource shortages. Leveraging fewer resources allows for more impactful operations, and the replication and rescaling of best practices becomes more feasible and efficient. Additionally, regional collaboration fosters the exchange of knowledge and technology, thereby providing opportunities for capacity development. These spillover effects collectively strengthen resilience by mitigating the risks of climate change. Moreover, regional cooperation unlocks the region's potential for accelerated integration and fosters sustainable economic growth through the establishment of regional value chains. This becomes particularly valuable during times of high uncertainty, such as global pandemics. Specifically, Central Asia's agricultural trade and exchanges can be further fortified given its status as the most regionally oriented value chain (Akhmedov, 2022). Regional cooperation offers novel opportunities for progress. Some samples across relevant sectors are highlighted below.

Water

Central Asia's water resources are highly transboundary. The majority of the water forms upstream in the Kyrgyz Republic and Tajikistan and flows downstream through Kazakhstan, Uzbekistan, and Turkmenistan toward the desiccating Aral Sea. The upstream and downstream states use water resources for electricity generation and agricultural irrigation, respectively. Diverging interests in the use of water resources necessitate regional collaboration.

[32] The author defines the regional climate cooperation as follows: Joint action of neighboring countries at a regional level to make progress in terms of climate change mitigation and adaptation by deploying necessary financial and technical resources.

Figure 24: 4Magnitude of Climate-Induced Water Stress Threat Under Two Cooperative Performance Scenarios.



Source: Umirbekov et al.(2022)

According to the foundational assumptions of Umirbekov et al. (2022), downstream states exhibit heightened sensitivity to changes in water discharge from upstream sources due to climate change due to their strong reliance on inflowing water resources. Nevertheless, effective regional cooperation among governments in implementing integrated water resource management has the potential to significantly reduce the impact of transboundary water dependency (Figure 21). Table 5 summarizes the potential benefits of regional water cooperation. Additionally, **improved regional water cooperation can save at least $4.5 billion for the region** (Adelphi & CAREC, 2017).

Table 5: Potential Benefits of Regional Water Cooperation

	On Economic Activities	**Beyond Economic Activities**
From Improved Water Management	Economic Benefits	Social & Environmental Benefits
	▪ Increased activity and productivity in economic sectors (irrigated agriculture, energy generation, industrial production, nature-based tourism) ▪ Reduced cost of carrying out productive activities ▪ Reduced economic impacts of water-related hazards (floods, droughts)	▪ Health impacts from improved water quality and reduced risk of water-related disasters. ▪ Employment and reduced poverty impacts ▪ Improved access to services (such as electricity and water supply) ▪ Avoided habitat degradation and biodiversity loss
From Enhanced Trust	Regional Economic Integration Benefits	Peace and Security Benefits
	▪ Development of regional markets for goods, services, and labor ▪ Increase in cross-border investments ▪ Development of transnational infrastructure networks	▪ Ability to avoid costs of military conflicts ▪ Savings from reduced military spending ▪ Other geo-political benefits

Source: Fisher (2014) and UNECE (2015)

As a precious resource, water remains at the core of regional cooperation in Central Asia**. In the wake of the growing potential consequences of climate change, the countries of the region should design a regional cooperation framework that keeps water as a central component and the mainstay of the countries' agriculture and energy sectors**. This process must be undertaken considering the projected climate hazards, previous failures, and lessons of regional cooperation models from the past and contemporary eras involving Afghanistan as a key stakeholder. The framework must be strategic and should bring value to a shared resources approach centered on regional water. Cooperation gatherings to discuss regional frameworks should not turn into conferences, reports, or strategies that can never be accomplished.

Numerous cases have demonstrated that establishing robust institutions for collaborative governance of transboundary water resources is an effective strategy for managing natural disasters and preventing conflicts. Notable historical examples include the Congress of Vienna's regime for the Rhine, the establishment of the Central Commission for the Navigation of the Rhine in 1815, and the Paris Agreement of 1856, which formed the European Commission for the Navigation of the Danube. These commissions, now modernized, continue to serve as key pillars of contemporary European stability (Kibaroglu, 2016). Another pertinent example is the Senegal River Basin Organization, which brings together and oversees the water assets of four African states (Mali, Senegal, Mauritania, and Guinea) and manages them as regional resources. Delegations from Central Asia can learned from their success stories.[33]

Agriculture

The improved management of water resources in the region is poised to have significant positive effects on the agriculture sector of downstream countries, given the sector's reliance on timely water releases from upstream systems. Mitigating the risks associated with reduced water availability, particularly in affected provinces, could partially alleviate constraints on agricultural productivity. This is especially pertinent for crops like wheat and cotton, which, as previously highlighted, may potentially produce higher yields with increased CO_2 fertilization and a sufficient supply of irrigation water. In addition, for crops that are negatively impacted by rising temperatures, such as rice, maize, and soybeans, collaboration on water resources could mitigate the added risks associated with irrigation deficits (Umirbekov et al., 2022).

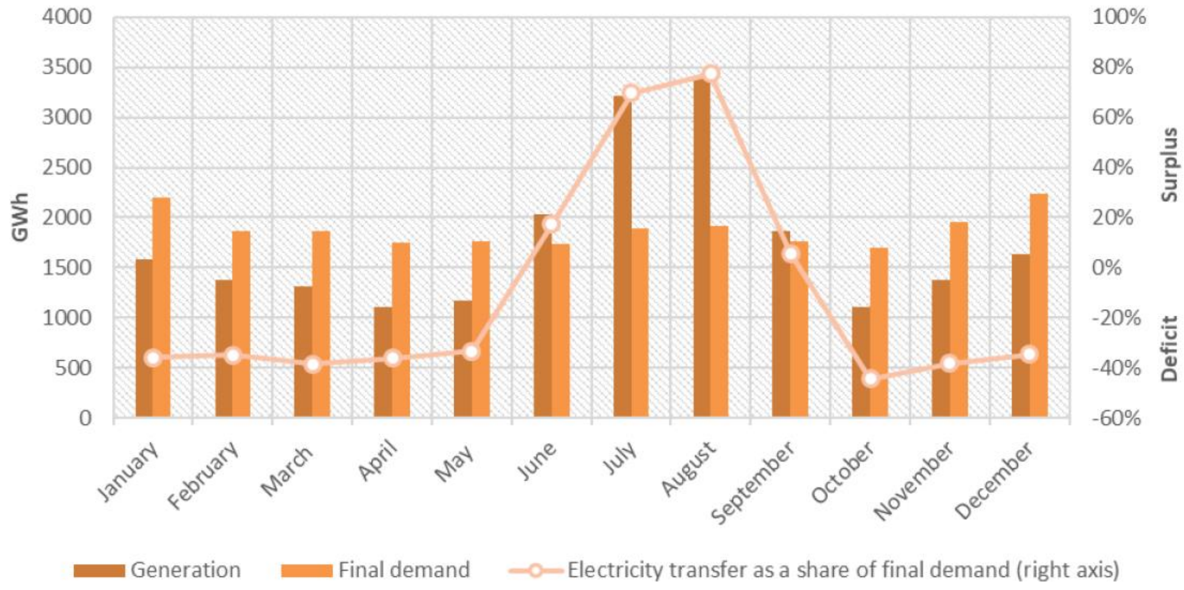
Energy

Cooperative management of transboundary water resources is also linked to the energy sector. Regional cooperation can allow for the exchange of electricity between countries. As depicted in Figure 25, the monthly variations between electricity demand and supply in Tajikistan can be mitigated when hydroelectric facilities operate in a manner that ensures timely water availability for downstream states. Enhanced regional cooperation among upstream countries could provide more flexible options to balance seasonal shortages and surpluses through the transboundary trade of electricity (Umirbekov et al., 2022). Thus, both upstream and downstream countries can compensate for shortages in electricity and water for irrigation.

Improved regional cooperation in the energy sector could bring an additional benefit of up to $6.4 billion per year to Kazakhstan, the Kyrgyz Republic, Tajikistan, and Uzbekistan (Botta et al., 2022). Unrealized benefits from regional power trade in Central Asia were estimated at around $5.2 billion for 2010-2014 (World Bank, 2019). Similarly, comprehensive energy efficiency in a Central Asian country could reduce energy costs by $12.3 billion by 2030, avoiding investment in new generating plants and reducing fuel consumption (World Bank, 2019).

[33] https://carececo.org/en/main/news/news/obuchayushchiy-vizit-delegatsii-iz-tsentralnoy-azii-v-basseyn-reki-senegal-/

Figure 25: 5Monthly Electricity Balance in Tajikistan



Source: Umirbekov et al. (2022)

Nexus approach in Central Asia

The preceding sections highlighted the adverse impacts of climate change on the water, agriculture, and energy sectors in Central Asian economies. These sectors are intricately connected and amplify the repercussions of climate change by triggering additional economic, social, and environmental spillover effects. The effects on water resources may pose health risks to the population through heightened water contamination. Reduced productivity in the agriculture sector could lead to economic hardships in rural communities and spur outmigration. Disruptions in energy infrastructure due to increased natural hazards may contribute to biodiversity degradation and heightened financial challenges for the economies. The consequences of climate change on energy, water, and agriculture are becoming increasingly intertwined, fueled by population growth, economic expansion, industrialization, and a rising demand for resources.

The nexus between water, agriculture, and energy is therefore a crucial aspect of sustainable development in Central Asia. As the region is highly dependent on agriculture, water resources, and energy, the nexus between these sectors is critical to ensure sustainable development. As climate challenges threaten the sustainability of the nexus, the climate actions of the Central Asian countries need to be designed in an interlinked way.

This approach can help governments identify inclusive cost-effective solutions for the low-carbon transition of the regional energy system while also mitigating water stress. Botta et al. (2022) showed that a larger uptake of wind and solar energy in the Syr Darya basin would lower dependency on the basin’s water resources for electricity generation by 25% by 2030. Increased efficiency in the use of water and energy resources substantially reduces stress on water resources and enhances regional resilience to climate risk. The application of the nexus could, in fact, help all Central Asian countries understand the potential trade-offs between planned sectoral measures and roll out the best strategy to deal with the negative impacts of climate change.

Similarly, enhancements in irrigation efficiency can generate positive spillover effects across all sectors. Given the region's population growth, the imperative for heightened agricultural production persists, placing continued strain on the area's water resources. Therefore, the implementation of intelligent water management practices at both national and regional levels is crucial for the well-being of farmers and the agriculture sector. **As an illustration, in Uzbekistan, a 1% improvement in water pumping efficiency would**

yield annual savings of $10 million, while a 10% increase in efficiency would result in regional savings of $188 million per year (World Bank, 2019).

Robust economic and financial assessments must be undertaken to better understand the optimum benefits of a nexus approach at both regional and national scales. This will help to mobilize greater political support for the widespread application of a nexus approach when designing effective financing and policy frameworks to enable enhanced regional cooperation and national coordination across sectors. Yet, to achieve optimum benefits from both regional and intersectoral cooperation, there should be solid interagency collaboration in each country. Limited cooperation and information sharing between government agencies significantly increases administrative and information processing costs and the probability of errors of exclusion and inclusion (IMF, 2023a).

Recommendations and Roadmap for Future Actions

Climate change has far-reaching implications for Central Asian economies. Changing temperatures might maintain the sufficiency of water for all key sectors in the medium term; however, in the long term, countries will face a fierce water shortage that will impact agriculture, energy generation, and other sectors. Based on available data, Table 6 presents the estimates of potential losses from climate inaction in Central Asia. Overall, the cost of inaction in the short and medium term amount to $76 billion. The estimation is based on the data highlighted throughout this report on the potential economic losses in each country and the unrealized potential benefits of regional cooperation until 2050 (mid-term). However, the amounts cannot be considered comprehensive because of the lack of data.

Table 6: Costs of Climate Inaction in Central Asia

Risk Countries	Water		Agriculture		Energy		Natural hazards		Total	
	$	% of current GDP	$	% of GDP	$	% of GDP	$	% of GDP	$	% of GDP
Kazakhstan	13.2 bn	6%	3 bn	1.5%	1,5 bn	0.7	480 mil	0.2%	18.2 bn	8
Kyrgyz Republic							146 mil	2%		
Tajikistan							1.5 bn	20%		
Turkmenistan			20 bn	45%			140 mil	0.3%		
Uzbekistan	6.4 bn	8%					7.2 bn	9%		
	Unutilized benefits of concerted regional actions									
	4.5 bn				18 bn					
Total	24.1 bn		23 bn		19.5 bn		9.4 bn			
Grand Total					**$76 billion**					

Source: Author's Calculations Based on Previous Sections)

The appropriate response to climate change in Central Asia depends on the degree to which decision-makers understand the risk management approach across sectors and how effectively it is executed. The expected consequences of climate inaction in the region and the highlighted cost of inaction do not include the potential spillover effects of these risks, such as climate migration and health impacts. While this study offers an overview of the impacts of climate change on the water, agriculture, and energy sectors of Central Asian countries, future in-depth research with detailed macroeconomic considerations is necessary to devise and enable full-fledged responses to climate change consequences in the region. The suggested response measures of this paper are divided into two categories: sectoral interventions on a national and regional scale and capacity building interventions.

Recommended Sectoral Interventions

The country overview sections illustrate which regions are the most vulnerable to the consequences of climate change. Given the magnitude and far-reaching impacts, countries should first catalyze climate actions in those identified areas. As depicted in Figures 8 and 9, the northern, southern, and central regions of Kazakhstan will be highly impacted by climate change in the coming decades compared to other parts of the country. These regions include Karaganda, Kostanay, and South Kazakhstani.

Figures 12 and 13 show the most-affected regions in the Kyrgyz Republic, including Chuy, Talas, Jalalabad, Osh, and Batken. Figures 16 and 17 show that almost the entire Tajikistan territory is vulnerable to climate change. The same vulnerability applies to regions in Turkmenistan, as shown in Figures 19 and 20, where all regions, except the Balkan region, are subject to substantial climate change. Figures 21 and 22 indicate that almost all regions of Uzbekistan are highly affected, with Samarkand, Syrdarya, and Andijon being the most vulnerable. To minimize the potential socioeconomic vulnerabilities driven by increasing temperatures with maximum impacts, comprehensive climate measures must be prioritized in these regions.

Addressing the root causes of climate problems, which involve the burning and financing of fossil fuels, should be the primary focus. Given the region's vulnerability to resource depletion and climate-induced hazards and considering the relatively low emissions rate, Central Asian countries should prioritize extensive adaptation actions while committing to transitioning from dirty energy to clean energy. To assist decision makers in Central Asia in assessing, adapting to, and mitigating the potential risks of climate change, the following recommendations are provided across the water, agriculture, and energy sectors and presented on national and regional scales.

National Scale

Water Sector. Water has always been the crux that couples or decouples countries in a region, affecting cooperation across many sectors. The climate-induced challenges that countries will face in the next decades should encourage countries to join forces to manage an important resource such as water, a central part of the economies of the region's countries.

***Modernize Infrastructure, Improve Maintenance and Monitoring of Water Facilities*.** Because water demand is poised to rise across all Central Asian countries, it is crucial to revitalize and modernize aging water supply and irrigation infrastructure to enhance water efficiency. **The upgrading of irrigation systems and promotion of efficient techniques, such as drip or sprinkler irrigation, could minimize water losses and optimize water-use efficiency. Over the long term, where feasible, investments in water recycling, desalination, and resource recovery from wastewater could further boost water use efficiency by expanding and optimizing multipurpose water storage capacity.** Establishing a conducive environment that encompasses policies, regulations, norms, and process transparency would lay the foundation for effective climate action in the sector.

Enhance Climate Risk-Related Decision-Making and Preparedness. Climate change is a risk multiplier, and scientific models cannot simulate climate change and its impact precisely, although models provide good approximations. Local climate is influenced by many different factors, including ice cover, resource consumption levels, technology availability, to name just a few. Therefore, it is important for countries to establish a monitoring system to gain a holistic understanding of the issue. It is essential to **enforce mandatory and automated water accounting, coupled with regular accuracy checks in fulfilling water delivery plans and minimizing losses at key junctions within the water hierarchy. Implementing mandatory charges for water use, with a progressive scale, serves as a valuable measure to incentivize water conservation.**

Enhance Research and Digitalization of the Water Sector. Research and data collection should be improved through collaboration with universities and research institutes. Data and analyses should be a crucial part of decision-making and better preparation. The creation of a digital water cadaster/register is another approach for improving the monitoring of the current situation and could help in the effective management of water resources. The digitization of water systems would make it possible to monitor the condition of waterways, the level of storage capacity, and the efficiency of water resource distribution in real time.

Improve Planning. Strategic planning is necessary to ensure that climate adaptation is a core part of water management plans and legislation. Strengthening the understanding and assessment of how climate change may impact the spatial and temporal mismatch between water resources availability and increasing demand are crucial to ensure better sector planning in the five countries. Similarly, **strengthening the**

understanding and management of trade-offs among key water-using sectors to improve the allocation and utilization of water resources, improved through better inter-agency collaboration, plays a substantial role in effective planning.

Take Flood Control Measures. Flooding is a significant natural hazard in all five Central Asian countries and causes extensive damage to infrastructure, agriculture, and human settlements. In the medium term, from the 2040s to the 2060s, when accelerated ice melting in the mountains is expected, the region will be poised to increased risk of flooding, particularly Kazakhstan, the Kyrgyz Republic and Tajikistan. The prioritization of risk reduction measures in budget allocations is an important action to respond to the risk. **In areas with high exposure to flooding, land use and economic activities should be restricted to avoid the potential impact of floods on the crops.** Also, investments should be made to modernize and expand early flood warning systems. This involves the installation of flood monitoring stations, weather forecasting technologies, and communication networks. These systems could provide timely alerts to at-risk communities and authorities, allowing for timely evacuations and emergency response planning.

Agriculture Sector. The agriculture sector dominates the economies of all five countries with strong social dimensions as the sector employs the majority of the rural population. However, limited access to modern farming techniques and equipment, outdated irrigation systems, and insufficient market opportunities have hindered agricultural development.

New Approaches in Wheat Cultivation. Kazakhstan is one of the major wheat suppliers worldwide. And, a reduction in wheat yields in some regions by 30%–50% by 2050, driven by land degradation, will have a substantial impact on global and regional food security. As wheat yields are negatively correlated with rising temperature and positively correlated with precipitation, shifting planting to earlier months when temperatures are lower and increasing the planting of winter wheat can be an appropriate strategy. The execution of these approaches must be accompanied by the necessary technical training for farmers.

Crop Diversification. Improving agricultural practices by supporting the diversification of crop choices to higher-value, drought-resistant, heat-tolerant, and water-wise crops across all five countries in the region is useful on multiple levels. It would help to provide food security, water efficiency, and create job opportunities for the regional population. Encouraging farmers to diversify their crop portfolios and adopt resilient crop varieties that can better withstand climate extremes should be supported by the state. Similarly, investment in R&D to develop crop varieties that are more resilient to climate change impacts, such as drought- and heat-tolerant varieties, should be encouraged.

Promotion of Climate-Smart Agricultural Practices. Implementing climate-smart agricultural practices involves the introduction of targeted incentive schemes that are linked to existing subsidies to encourage the adoption of resource-efficient farming practices. Capacity-building programs for farmers play a crucial role in this endeavor. Overall, agricultural land management must move from an expansion- to an efficiency-based approach. This can be supported through research and extension services that provide farmers with knowledge for selecting appropriate crops and adopting climate-smart agricultural practices. Establishing systems that provide farmers with timely and accurate climate information, weather forecasts, and advisory services are fundamentally important. In addition, conducting training programs and workshops to build the capacity of farmers, extension workers, and policymakers for climate-smart agricultural practices would also be helpful.

Improve Pasture Management. Climate change is also a principal cause of pastureland degradation. Improved pastureland management to increase climate resiliency is key to maintaining the productivity of the remaining sustainable pasturelands, particularly in Kazakhstan and the Kyrgyz Republic. Rotational grazing and the application of management technologies are advantageous strategies.

Agroforestry and Soil Conservation. Encouraging agroforestry practices and soil conservation measures, such as terracing, contour plowing, and cover cropping to prevent erosion, maintain soil moisture, and enhance soil fertility, will have a significant positive impact on agricultural production.

Energy sector

Capitalize on Solar and Wind Opportunities. Central Asian countries, particularly Kazakhstan, Turkmenistan, and Uzbekistan, have tremendous potential for solar and wind resources. Their vast lands with suitable geological formations enable abundant solar and wind resource generation. With proactive policies and investments in this sector, countries can accelerate their transition to clean energy while continuing to grow their economies.

Energy Conservation and Raising Awareness. Promoting energy conservation practices and raising awareness among individuals and businesses about the importance of reducing energy consumption and making sustainable energy choices are critical for the better management of existing energy resources.

Climate Resilient Energy Infrastructure. Protective infrastructures, such as dams and the improvement of power line design standards by expanding underground or insulated power lines, can improve their physical protection from augmenting climate impact. However, substantial investment is required in this sector. It is equally important to upgrade and expand the electricity grid infrastructure to accommodate the integration of renewable energy sources, enhance grid resilience, and optimize energy distribution.

Regional Scale

Regional Climate Change Framework. The creation of a policy and economic basis for sustainable and mutually beneficial water use, considering climate risks, and promoting the intraregional trade of resources could enhance regional-scale responses to augmenting climate impacts. Lowering barriers to agri-food and power-product trading in the region by improving and connecting infrastructure can increase resource-use efficiency.

Upscale Joint Investment in Transboundary Infrastructure. Upscaling investment in transboundary water infrastructure should continue. The modernization of existing reservoirs and the construction of new reservoirs in regional or bilateral partnerships could improve the management of transboundary water resources. The operations and maintenance (O&M) costs of the facilities should be part of the partnership agreements.

Regional Data-Sharing Practices. The availability, quality, and appropriate use of data are important building blocks for enhancing regional collaboration. This helps not only to better deploy the available water resources by increasing efficiency but also to improve the preparedness of countries for potential natural hazards, including floods and droughts. Regional data-sharing can be realized through the harmonization of approaches to data collection, management, and dissemination.

The realization of elaborate national- and regional-scale climate actions can be performed best through the analysis of each national context and sectoral risk assessment. This, in turn, requires national and regional capacity-building workshops to understand the contextualized climate change measures.

Climate related Capacity Building

This study shows that Central Asia faces severe challenges related to climate change: longer, hotter, drier weather conditions; reduced water availability for economies; and higher risks of natural disasters. The cost of extreme weather is already high, and its frequency and intensity are increasing, bearing more costs to the life and infrastructure of water, agriculture, and energy resources.

Increased climate risks require both sweeping and holistic solutions to help prevent further climate impacts and reduce the negative impacts on a region's sustainable development (ADB, 2023a). The region's economic development will be impacted by a multitude of deep structural changes, of which global warming and decarbonization are among the most fundamental. Climate change is augmenting in volume and impact on the region's economies, and the same is true for countermeasures implemented by the respective countries. However, these balanced actions cannot ensure sustainability, because the implementation of net-zero commitments is lagging globally. **Bolder measures with strengthened and targeted investments should be deployed**.

In this context, the development of **adaptation measures, climate-proof policies and growth strategies becomes crucial for these countries.** Successful adaptation requires planning based on risk and vulnerability assessments and on how well they are understood by stakeholders. For instance, stakeholders in Kazakhstan face three important challenges when planning climate action (Government of Kazakhstan, 2019): the collection of information related to climate trends and future climate change scenarios; the development of capacities for conducting a comprehensive risk and vulnerability assessment, and elaboration and prioritization of adaptation measures; and accessing budgets for implementing adaptation measures.

Similarly, responses to climate challenges in the Kyrgyz Republic are complicated because of the low level of awareness of climate risks, both in the public administration and among the population (Government of Kyrgyzstan, 2021). Therefore, building a public understanding of the seriousness of climate threats is a key challenge for the future. The country requires comprehensive capacity building and awareness-raising measures in all relevant sectors.

In Tajikistan, Government of Tajikistan (2021b) identified key capacity-building needs in various sectors. The energy sector involves training energy company officials to conduct climate risk assessments and vulnerability methodologies. In the water sector, there's a focus on enhancing the capacity of water users' associations (WUAs). In agriculture, priorities include imparting knowledge about crop diversity, plant breeding, improving farmers' access to information, promoting new technologies, advocating the use of drought-resistant seeds, and educating farmers on methods to protect plants from frost. The NDC underscores the current lack of a comprehensive database of traditional climate change adaptation methods in Tajikistan.

Government of Turkmenistan (2022) underscores the necessity of substantial financial and technical resources, along with an increase in the capacity of government decision-makers, to effectively implement climate change adaptation and mitigation measures. Similarly, Government of Uzbekistan (2021) emphasizes that meeting enhanced commitments requires extensive effort, encompassing capacity building at all levels, allocation of technical and financial resources, establishment of effective incentive mechanisms, and enhancement and efficient implementation of national and sectoral strategies and plans. It introduces an indicator focused on enhancing awareness and capacity regarding climate change mitigation, adaptation, and early warning of risks and climate hazards for individuals, institutions, organizations, and businesses.

Considering this and the high uncertainty associated with climate change, capacity-building activities at national and regional levels would be instrumental in facing the upcoming climate-related challenges. This exercise would help countries better understand existing and emerging climate-induced challenges and enhance the capacity of stakeholders to identify and deploy sector-specific and regional climate measures. Therefore, a set of capacity-building interventions (Table 7) could support the process of coping with climate change and increase the efficiency of climate financing in the Central Asian region.

Table 7: Typologies of Proposed Capacity-Building Interventions

Typology	Descriptions	Indicative Time frame
Short-term interventions	**Short-term, demand-based interventions include training, access to knowledge platforms, learning from best practices, on-the-job training, peer-to-peer mentorship**, and others. These could be ADB or CAREC Institute's training series, based on the requests from the region's country representatives during the country missions, and from private sector stakeholders. The number and frequency of such training series would depend on the financial and human capacities of both the countries in focus and financing parties. Short-term training can be of individual interventions/activities focusing on creating sufficient critical mass at countries' critical sectors.	1–3 years
Medium-term interventions	The **mid-term interventions include demonstration projects on supporting existing capacity building(CB) efforts, supporting knowledge-sharing platforms, and triggering and leveraging partnerships**. The midterm plan includes partnerships with regional, and national level training centers, civil societies, international partners, and other knowledge owners and holders to build knowledge alliances and partnerships to support the process of capacity building. Midterm CB interventions also depend on funding availability, and capacity to coordinate and implement. The midterm training/interventions will be more of a cascading or training of trainers (ToT) mode that will also target effective dissemination and continuity issues.	5–10 years
Long-term interventions	The **longer-term CB interventions target support to build institutional capacities and instruments** for successfully cascading capacities-building during the short and mid-term interventions. The long-term interventions are primarily of a strategic nature and focus on building a framework for the capacities built by short and midterm interventions and creating a framework for furthering the countries' capacities on self-training and capacity building of national experts. The joint climate knowledge centers and information systems are expected to function fully at the regional and sub-regional levels long term. Most long-term capacity building interventions are rather strategic and institutional and require commitment by both countries and financing parties. The long-term intervention will be based on ownership, independent implementation, and support by countries.	10–15 years

While strengthening knowledge stakeholders, these highlighted capacity-building interventions will help identify more details on contextually relevant strategies against climate-posed challenges in countries and the region of Central Asia as a whole.

Conclusion

Central Asia is expected to experience rising temperatures, making climate change a prominent challenge for regional economies. Central Asia is evolving into a potential climate "hotspot" in the broader Asian region, as it grapples with both current and impending climate challenges. The region's constrained water resources, overdependence on traditional fossil fuels, and limited share of renewables in the energy balance highlight the need for resilient climate-change strategies. While certain countries in the region may benefit agriculturally from climate change with increased yields, overall volatility, influenced by climatic factors, tends to produce negative outcomes that affect various key sectors of the economy.

The water, agriculture, and energy sectors have been key pillars of economic development in Central Asia, and their effective management has been a crucial factor in interstate relations in the region since independence. The uneven endowments of energy, water, and land resources generate strong interdependencies, tensions, and divergent interests between the upstream and downstream countries of the region. The consequences of climate change worsen these circumstances and have the potential to heighten tensions within the region. However, there are ways to translate this into opportunities for collaboration. Concerted climate action could be instrumental in unlocking these opportunities.

In all five countries, prioritizing adaptation measures for climate change remains essential. Although mitigation measures align with economic growth and sustainable development needs, they do not overshadow the significance of adaptation. Given the region's vulnerability to climate hazards, prioritizing adaptation is crucial for addressing the direct and cascading effects of climate change. Considering the region's emission levels and vulnerability, prioritizing adaptation activities is imperative in the face of the projected climate change impacts on economies.

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