Republic of Kazakhstan



TECHNOLOGY NEEDS ASSESSMENT FOR ADAPTATION TO CLIMATE CHANGE

REPORT I
TECHNOLOGY PRIORITISATION

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TNA TECHNOLOGY NEEDS ASSESSMENT

AIIB ASIAN INFRASTRUCTURE INVESTMENT BANK

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Abbreviations

Abbreviation	Full Form
AIIB	Asian Infrastructure Investment Bank
BAEF	Barrier Analysis and Enabling Framework
CCC	Climate Change Centre
CTCN	Climate Technology Centre and Network
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
GCF	Green Climate Fund
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
GPS	Global Positioning System
IPCC	Intergovernmental Panel on Climate Change
MCA	Multi-Criteria Analysis
MENR	Ministry of Ecology and Natural Resources
NAP	National Adaptation Plan
NDC	Nationally Determined Contribution
NGO	Non-Governmental Organization
NSC	National Steering Committee
OECD	Organisation for Economic Co-operation and Development
RCP	Representative Concentration Pathway
SDG	Sustainable Development Goal
SPI	Standardized Precipitation Index
SSP	Shared Socioeconomic Pathway
SWG	Sectoral Working Group
TAP	Technology Action Plan
TFS	Technology Fact Sheet
TNA	Technology Needs Assessment
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
USD	United States Dollar

Executive summary

This Technology Needs Assessment Report presents Kazakhstan's systematic evaluation and prioritization of climate adaptation technologies for the agriculture sector, conducted with support from the Asian Infrastructure Investment Bank and UNEP Copenhagen Climate Centre following the TNA step-by-step guidance (UNEP CCC, 2024). The assessment engaged diverse stakeholders through a structured participatory process to identify technologies best suited to address the country's agricultural climate vulnerabilities.

Climate Context and Agricultural Vulnerability

Kazakhstan's agricultural sector operates under increasingly challenging climatic conditions that threaten both productivity and rural livelihoods. Observed temperature trends across all regions show warming rates that substantially exceed global averages: the national average warming rate is +0.36°C per decade (Kazhydromet, 2024; Salnikov et al., 2023), compared to the global average of approximately +0.20°C per decade (NOAA, 2024). Under the SSP5-8.5 scenario, projections indicate temperature increases of +4.0 to +8.5°C, with central regions potentially exceeding +6°C by century's end (Climate Change Coordination Centre, 2025; World Bank Climate Portal, 2024) that could fundamentally alter agricultural production patterns. Central and southern regions face particularly pronounced warming, with southwestern areas recording rates of 0.32°C to 0.50°C per decade, affecting crop calendars, water availability, and livestock management practices.

Precipitation dynamics present additional complexity for agricultural planning. While annual precipitation shows a slight positive trend of approximately +0.5% of normal per decade (+1.7 mm per decade nationally), the seasonal distribution is shifting unfavourably for agriculture (Kazhydromet, 2024). Under the SSP3-7.0 and SSP5-8.5 long-term scenarios (2081–2100), summer precipitation is projected to decrease while winter precipitation increases, intensifying pressure on agriculture and potentially increasing flood risks (Climate Change Coordination Centre, 2025; World Bank Climate Portal, 2024). This seasonal redistribution compounds the challenges faced by both rainfed and irrigated farming systems across the country's diverse agro-ecological zones.

The agriculture sector's significance extends beyond economic contribution to encompass food security and social stability for approximately 8 million rural residents. Compound vulnerabilities have emerged from the intersection of climate change with existing environmental pressures: extended droughts affecting rainfed crop production across the northern grain belt, heat stress reducing livestock productivity and reproduction rates, accelerating soil degradation diminishing long-term agricultural potential, and water scarcity threatening the viability of irrigated farming in southern regions. The classification of approximately 80% of national territory as arid or semi-arid land underscores the inherent sensitivity of Kazakhstan's agricultural systems to climate variability and change.

Sectoral Impact Assessment

Crop production faces differentiated impacts across regions and commodity types. Human-induced climate change decreased wheat yields in northern Kazakhstan by approximately 6.2–8.2% during 2000–2019, with economic losses estimated at $96–180 million USD annually (Romanovska et al., 2024). In the western cereal belt, wheat and barley yields declined by 1.9% and 4.8% respectively between 1980–2015 (Schierhorn et al., 2020). The primary climate drivers include elevated nighttime temperatures that increase plant respiration and reduce grain filling, extreme heat events during critical growth stages, and altered precipitation timing that disrupts established farming calendars. Future projections suggest continued regional divergence: under high-emission scenarios (RCP 8.5), the arid steppe zone faces potential wheat yield losses exceeding 16% (Teleubay et al., 2023), while spring barley in southeastern Kazakhstan may experience yield increases of 15–33% under various climate scenarios (Sabitova et al., 2024).

The livestock sector confronts multiple interconnected climate stressors affecting the extensive pastoral systems that characterize Kazakh animal husbandry. Approximately 186 million hectares of natural pastures support 8.2 million head of cattle, 20.1 million sheep and goats, and 4.1 million horses, with approximately 70% of animal diets derived from natural pastures. Approximately 27.1 million hectares of pastures show signs of degradation (15% of total pasture area), with the total area at risk reaching 90 million hectares (FAO, 2024). Intensified aridization in southern and southwestern regions has reduced vegetation productivity over 2000–2024, while overgrazing pressures compound climate-driven changes. Heat stress increasingly challenges animal welfare and productivity as temperatures more frequently exceed the 30°C comfort threshold for cattle.

Soil resources—the foundation of agricultural productivity—face accelerating degradation under climate change. Arable soils are losing humus at a rate of approximately 1% per year (National Inventory Report, 2024), representing both immediate productivity constraints and longer-term carbon emission concerns (arable lands remain a net source of GHG emissions at +40,326.7 thousand tonnes CO_2-equivalent in 2022). Wind erosion affects 26 million hectares, water erosion affects 15 million hectares, and salinization affects 3.8 million hectares of irrigated land (World Bank, 2024a). The economic costs are substantial: soil erosion causes damage of approximately $779 million annually, soil salinity accounts for $375 million in losses, and pasture degradation causes an additional $963 million in annual economic damage (World Bank, 2024a). Furthermore, 76.1% of Kazakhstan's land area is considered sensitive to desertification (Hu, Han and Zhang, 2020). These soil impacts threaten the sustainability of agricultural production and require targeted technological interventions.

Technology Prioritization Process

An Agriculture Sectoral Working Group comprising 17 members from government agencies, research institutions, private sector enterprises, and civil society organizations guided the technology assessment. The participatory process ensured that diverse perspectives informed both criteria weighting and technology evaluation, strengthening the legitimacy and practical relevance of outcomes.

Technology identification began with comprehensive review of adaptation options, yielding an initial portfolio of 28 candidate technologies spanning water management, soil conservation, livestock systems, and agroforestry approaches. Systematic screening using feasibility and local relevance criteria reduced this to 12 technologies meriting detailed Multi-Criteria Analysis. The final portfolio demonstrates balanced thematic coverage across water resources and irrigation, soil and land management, and livestock system adaptation.

Stakeholders validated nine evaluation criteria encompassing economic viability considerations, social benefit dimensions, environmental effectiveness measures, and policy alignment factors. The weighting process reflected Kazakhstan's development context. Costs criteria (Capital Expenditure at 19% and Operation and Maintenance at 8%) and Economic criteria (Job Creation at 10% and Farm Income Enhancement at 12%) together received the highest combined weight (49%), followed by Environmental (Soil Fertility Preservation, 15%), Climate (Vulnerability Reduction, 15%), Institutional (Ease of Implementation at 9% and National Priority Alignment at 7%), and Social (Gender and Social Inclusion, 5%). A sensitivity analysis tested three alternative weighting scenarios: an economic focus (increasing combined cost and income weights), an environmental and climate resilience focus (assigning 40% combined weight to climate and environmental criteria), and a balanced distribution across all nine criteria. The analysis confirmed that Conservation Agriculture maintains its first-place ranking across all scenarios, and the top-ranked technology group remains largely unchanged, demonstrating robust prioritisation outcomes.

Priority Technologies

The Multi-Criteria Analysis identified three highest-ranking adaptation technologies that warrant priority attention in Technology Action Plans and investment programming.

Conservation Agriculture achieved the highest overall score, reflecting broad stakeholder consensus on the approach's potential to address soil degradation through integrated practices of minimal tillage, permanent ground cover maintenance, and diversified crop rotations. The technology offers proven pathways to reverse soil fertility decline while maintaining economic viability for farmers across diverse production contexts.

Agroforestry ranked second, valued for its capacity to deliver multiple adaptation benefits simultaneously including erosion control, microclimate moderation, livelihood diversification, and carbon sequestration. Implementation aligns with national reforestation commitments while strengthening agricultural system resilience through landscape-level interventions.

Climate-Smart Soil Management ranked third, encompassing complementary practices including mulching, biochar application, and composting that directly address documented soil organic matter losses. This technology package offers flexible implementation pathways suited to diverse farm contexts and production systems.

Chapter 1. TNA process and the national context

1.1 Introduction

The TNA process is a comprehensive, country-driven, and participatory effort that is critical to implementing both mitigation and adaptation actions under the global climate regime. It is aimed at identifying, selecting, and planning for the effective transfer, adoption, and diffusion of climate technologies to reduce greenhouse gas (GHG) emissions (mitigation) and/or increase resilience to the adverse effects of climate change (adaptation).

The importance of widespread technological change was directly referenced in the Paris Agreement, building on earlier mandates from the United Nations Framework Convention on Climate Change (UNFCCC). The current Technology Needs Assessment (TNA) is provided through the Asian Infrastructure Investment Bank (AIIB), in partnership with UN Environment Programme (UNEP) and UNEP Copenhagen Climate Centre (UNEP-CCC).

The TNA process involves three distinct and sequential steps:

1. Technology Identification and Prioritisation: The focus of this TNA Report.
2. Barrier Analysis and Enabling Framework (BAEF).
3. Technology Action Plan (TAP) Development.

The steps build upon each other, resulting in TAPs that serve as national roadmaps. These roadmaps are designed to be integrated into government planning and to create a pipeline of bankable programmes and projects targeted at specific sources of multilateral (e.g., Green Climate Fund - GCF) and private finance.

The main objectives of the TNA project are:

- To identify and prioritise technologies that contribute to the country's mitigation and adaptation goals, while meeting national sustainable development goals and priorities.
- To identify and analyse barriers hindering the acquisition, deployment, and diffusion of these prioritised technologies.
- To develop Technology Action Plans (TAPs) specifying activities and enabling frameworks to overcome these barriers and facilitate technology transfer.

Ultimately, the TNA process enhances the country's capacity to mainstream climate change and leverages international climate finance to adopt environmentally sound technologies (ESTs) for a low-carbon, climate-resilient development pathway. The process steps, moving from priorities to implementation, are illustrated in Figure 1.1 below.



Figure 0.1 Steps in a TNA process: from priorities to action (UNEP CCC, 2024)

1.2 TNA process in Kazakhstan

This Technology Needs Assessment (TNA) is conducted in the context of the Republic of Kazakhstan's fundamental and long-term commitment to a sustainable, low-carbon, and climate-resilient economy.

Kazakhstan's engagement in the global climate change agenda is demonstrated by its adherence to key international frameworks. Following its independence, the nation became a Party to the United Nations Framework Convention on Climate Change (UNFCCC) in 1995, reinforced by the ratification of the Kyoto Protocol in 2009 and the Paris Agreement in 2016. Recognizing the urgent need for transformative action, the country has adopted the Strategy for Achieving Carbon Neutrality by 2060, which represents the country's decisive long-term climate policy. This strategy integrates comprehensive measures to decarbonize key economic sectors and promotes sustainable development in line with the country's updated Nationally Determined Contribution (NDC).

The foundation for this process was laid by the first TNA project, approved by the Government in late 2010 and carried out in 2014-2017. This initial effort, implemented by the Ministry of Environment Protection and the Climate Change Coordination Centre (CCCC) funded by the GEF through UNEP and the UNEP Risø Centre (URC) – the forerunner of UNEP-CCC with AIT Bangkok providing regional support, focused on technology identification under the framework of the Concept for the Transition to a "Green Economy" (approved May 2013).

The key output of the first TNA was the prioritisation of specific technologies across four critical sectors:

- **Mitigation:** For the Energy (Power Production) and Industry (Cement Production) sectors, priority technologies included Pulverized Coal Combustion with higher efficiency (to address reliance on fossil fuels), Small Hydropower, and measures such as energy efficiency and the change from wet to dry production technology for cement.
- **Adaptation:** For the highly climate-sensitive Agriculture and Water Resources sectors, priority technologies included Drip Irrigation and Water Metering (to improve water use efficiency), Diversification of crop production, and the development of grazing and stabling systems on an industrial basis.

These results led to the development of the first National Technology Action Plans (TAPs), which provided detailed roadmaps designed to inform and support subsequent climate policy and project development.

The current TNA Project, starting in 2025, is designed to build upon this foundational technical work. It updates and refines the country's technological pathways, ensuring they are fully aligned with the 2060 Carbon Neutrality Strategy. The priority sectors selected for this TNA, **Energy** and **Waste** sectors for mitigation and **Agriculture** for adaptation, reflect the current strategic focus on deep decarbonization and investment required to meet the long-term national climate goals.

1.2.1 Sector selection

The selection of agriculture as the priority sector for adaptation TNA was conducted through a comprehensive assessment process, guided by the country's strategic documents and consultation with key stakeholders and relevant national authorities.

The Environmental Code of the Republic of Kazakhstan (2021) identifies four priority sectors for adaptation measures: agriculture, water resources, forestry, and civil protection and security. The Ministry of Ecology and Natural Resources of Kazakhstan determined agriculture to be the highest priority for the current adaptation assessment.

For Adaptation, the Agriculture sector was selected as the highest priority due to:

- Its critical importance for food security and rural livelihoods, employing approximately 13% of the workforce while contributing approximately 5% to GDP (World Bank, 2022).
- Extreme climate vulnerability, with approximately 75% of Kazakhstan's territory classified as arid or semi-arid land (FAO, 2012).
- Significant climate change impacts already observed, including increased drought frequency, pasture degradation affecting 20–60% of pastureland depending on region (with 38% of the 186 million hectares of pastureland degraded nationally), and water stress in irrigated agriculture (Government of Kazakhstan, 2021; FAO, 2022).
- Strong policy drivers, including the Strategy for Achieving Carbon Neutrality by 2060 targeting 75% of arable land to implement sustainable agriculture practices by 2045, and the Concept of Development of the Agro-Industrial Complex for 2021-2030.
- The forthcoming National Adaptation Plan (NAP), which identifies agriculture as one of four priority adaptation sectors.

1.2.2 Organisational structure

Institutional Arrangements for the TNA Project in Kazakhstan

The Technology Needs Assessment (TNA) process in Kazakhstan operates within a robust institutional framework designed to bridge high-level political objectives with operational excellence, ensuring effective coordination between national authorities, sectoral experts, and international partners. This structure establishes clear roles and responsibilities, facilitates broad stakeholder engagement, and ensures technology prioritization aligns with national climate strategies.

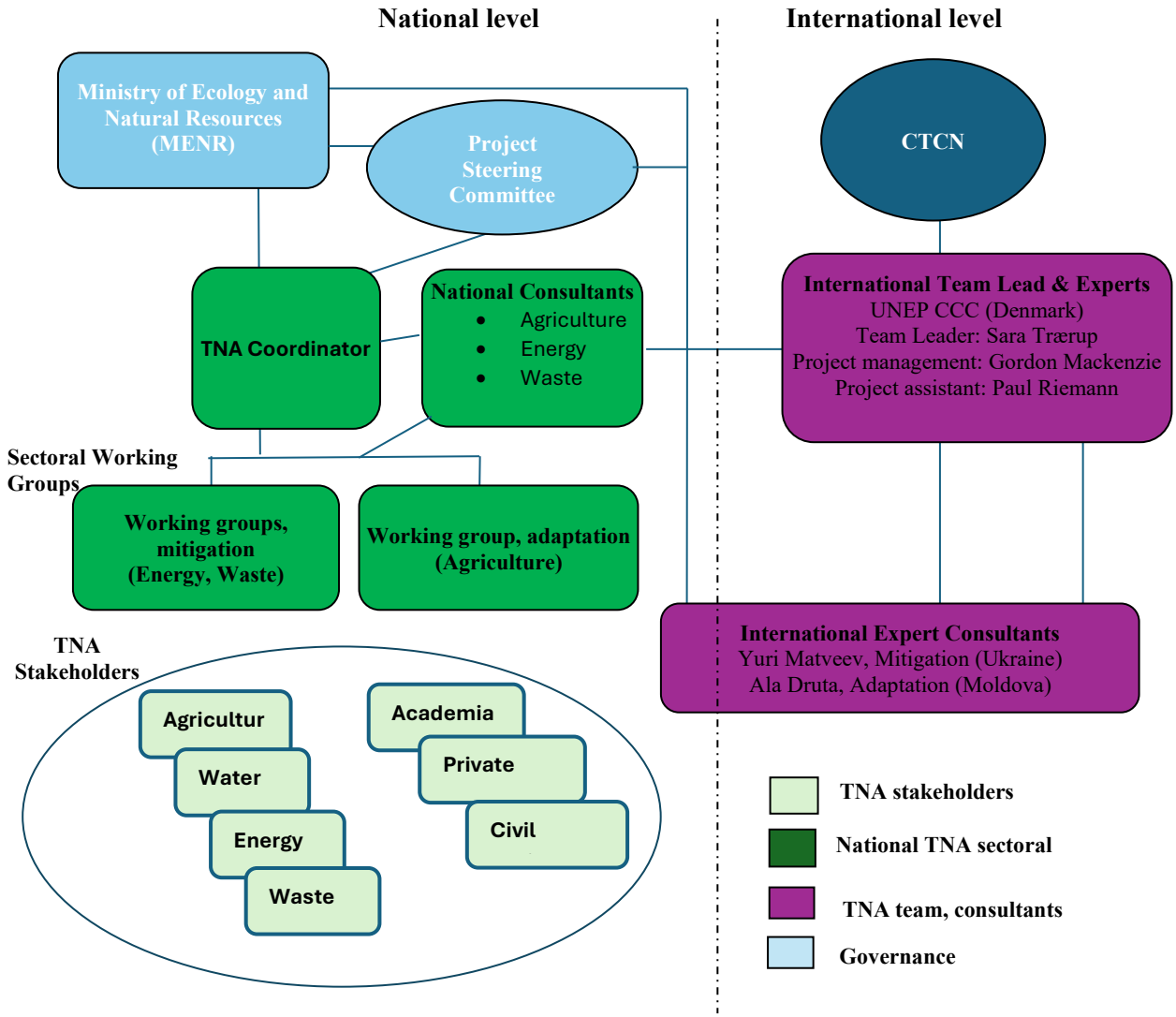


Figure 1.2. Institutional arrangements for the TNA project in Kazakhstan

National Leadership and Oversight

The **Ministry of Ecology and Natural Resources (MENR)** serves as the National Focal Point and host entity, ensuring alignment with Kazakhstan's Strategy on Achieving Carbon Neutrality by 2060 and NDC 3.0. The Ministry also serves as the UNFCCC National Focal Point and National Designated Authority for the Green Climate Fund. The **National TNA Project Steering Committee (PSC)** provides high-level strategic guidance and grants final approval on all reports. Comprising senior representatives from key ministries (Ecology, Energy, Agriculture, National Economy, Education), the PSC ensures cross-sectoral policy coherence, monitors quality control, and provides recommendations to the National Designated Authority.

International Framework and Strategic Finance

UNEP and UNEP Copenhagen Climate Centre (UNEP-CCC) provide the global methodological framework and technical backstopping, ensuring national analysis meets international standards. The project is reinforced by dedicated funding from the **Asian**

Infrastructure Investment Bank (AIIB), ensuring the TNA generates bankable, investment-ready climate projects suitable for infrastructure financing.

National TNA Coordinator

The **International Green Technologies and Investment Projects Center (IGTIPC)**, operating under MENR, serves as the National TNA Coordinator. IGTIPC manages day-to-day operations, stakeholder engagement, and quality assurance. Its divisions—including Best Available Techniques Research and Expert Assessment—contribute analytical capacity for technology evaluation. A Project Implementation Coordination Group comprising sectoral counterparts meets regularly to review progress and address implementation challenges.

Sectoral Working Groups

Sectoral Working Groups (SWGs) constitute the primary mechanism for stakeholder engagement and technical validation. For the Agriculture sector, a dedicated SWG comprising **17 members** was established, representing: government (Ministry of Agriculture, Department of Soil Resources and Climate), research institutions (Kazhydromet, including Climate Research Center directors), private sector (Association of Organic Agriculture Producers, Birch Private Company, Soil Solutions LLP), and civil society organizations. The SWG conducted consultative meetings in September-November 2025, focusing on technology identification, prioritization criteria, and multi-criteria analysis.

National and International Consultants

The consultant team serves as the analytical engine, conducting data collection, technology research, stakeholder consultations, and drafting technical reports under the UNEP-CCC methodological framework.

Stakeholder Engagement Process

The engagement strategy captures perspectives across the agricultural value chain—from producers to policy-makers. The process includes: sector selection consultations guided by GHG inventory and vulnerability assessments; technology identification through long-list development and SWG validation; multi-criteria analysis with stakeholder-defined criteria and weighting; and bilateral consultations with key informants. This multi-modal approach—combining plenary discussions, individual surveys, and expert consultations—ensures comprehensive representation and technology options grounded in local reality.

1.3 Summary of the national context

The foregoing analysis of Kazakhstan's national circumstances, agriculture sector profile, climate trends, and policy framework provides a compelling rationale for conducting a Technology Needs Assessment focused on climate adaptation in the agriculture sector. A consistent increase in mean annual temperature has been observed across all regions of Kazakhstan (Kazhydromet, 2024; Salnikov et al., 2023). The national average trend is +0.36°C per decade, which is statistically significant and substantially higher than the global average. SSP5-8.5 scenario projects temperature increase from +4.0 to +8.5°C with central regions potentially exceeding +6°C by the end of the century (Climate Change Coordination Centre, 2025; World Bank Climate Portal, 2024).

Precipitation trends show high inter-annual variability without a strong uniform trend across the country (Kazhydromet, 2024). Annual precipitation shows a slight positive trend of approximately +0.5% of normal per decade, equivalent to +1.7 mm per decade nationally. In the long-term horizon of 2081-2100, the SSP3-7.0 and SSP5-8.5 scenarios projects slight increase of precipitation. However, summer precipitation will decrease, while winter increase making more pressure on agriculture and potentially increasing floods (Climate Change Coordination Centre, 2025; World Bank Climate Portal, 2024).

The agriculture sector, supporting approximately 13% of the workforce and approximately 8 million rural residents (World Bank, 2022), faces compound vulnerabilities including increased drought frequency and severity, pasture degradation affecting over 27 million hectares, water stress in irrigated zones, and accelerating soil erosion.

According to the National Inventory Report (2024), arable soil loses humus at rate of about 1% per year. The latter leads to economic losses as well as increased GHG emissions. The National Inventory Report 2024 demonstrates that arable lands remain a significant source of greenhouse gas emissions at +40,326.7 thousand tonnes CO_2-equivalent in 2022, while forests and grasslands provide important carbon sinks. This carbon balance underscores the dual adaptation-mitigation potential of sustainable agricultural technologies.

The Technology Needs Assessment directly supports Kazakhstan's NDC 3.0 adaptation commitments, Carbon Neutrality Strategy 2060, Agricultural Development Concept 2021-2030, and the ongoing National Adaptation Plan process. The conditional NDC target of 25% emission reduction and adaptation implementation by 2035 require international technology transfer and finance, which the TNA process is designed to facilitate. The TNA provides a systematic framework to identify, prioritize, and plan for deployment of climate-resilient agricultural technologies aligned with national development priorities.

Key Climate Change Vulnerabilities in Agriculture Sector

Impact on Crop Production

Historical analyses demonstrate that human-induced climate change decreased wheat yields in northern Kazakhstan by approximately 6.2-8.2% during 2000-2019, with economic losses estimated at $96-180 million USD annually (Romanovska et al., 2024). In the western cereal belt, wheat and barley yields declined by 1.9% and 4.8% respectively between 1980-2015 (Schierhorn et al., 2020). The primary climate drivers are increased daily-minimum temperatures, extreme heat events, and shifting precipitation patterns.

Future projections indicate continued divergence by region and crop type. Under high-emission scenarios (RCP 8.5), the arid steppe zone faces potential wheat yield losses exceeding 16%, while the steppe zone demonstrates greater resilience (Teleubay et al., 2023). In contrast, spring barley in southeastern Kazakhstan near Almaty may experience yield increases of 15-33% under various climate scenarios (Sabitova et al., 2024). Winter crop varieties generally show more positive trends than spring varieties.

Impact on Livestock Production

Kazakhstan's livestock sector faces compound vulnerabilities from multiple climate stressors. The country has approximately 186 million hectares of natural pastures (FAO, 2022) supporting 10.3 million head of cattle, 27.4 million sheep and goats, and 4.4 million horses (Bureau of National Statistics, 2023). Livestock production depends heavily on pasture resources, with approximately 86% of animal diets coming from natural pastures (Kerven et al., 2021).

Pasture degradation represents the most significant challenge. According to data from Kazakhstan's Land Resources Management Committee, approximately 27 million hectares of pastures show signs of degradation, while 5 million hectares are prone to water erosion and 24 million hectares are susceptible to wind erosion (Qazinform, 2025). The total area of land at risk of degradation reaches 90 million hectares (CABAR.asia, 2024). Research published in MDPI Sustainability (2024) found that southern and southwestern regions experienced intensified aridization and reduced vegetation productivity over 2000-2024.

Heat stress presents significant challenges for livestock productivity and reproduction, with temperatures frequently exceeding the 30°C comfort threshold for cattle.

Climate Change Impacts on Soils

Soil degradation represents a fundamental challenge for Kazakhstan's agricultural sustainability, with climate change exacerbating existing degradation processes. Wind erosion affects 24 million hectares of agricultural land, water erosion affects 5 million hectares, and salinization affects irrigated land extensively (Land Resources Management Committee, 2025). According to research in the Almaty region, annual soil loss ranges from 0.5 to over 100 tonnes per hectare depending on terrain and land use practices (Kaliyeva et al., 2024).

A World Bank policy analysis (2024) applying economic assessment found that the economic costs of soil degradation are substantial: soil erosion causes damage of approximately $779 million annually, soil salinity accounts for $375 million in losses, and pasture degradation causes an additional $963 million in annual economic damage.

Desertification poses a major threat: 76.1% of Kazakhstan's land area is considered sensitive to desertification, with 3.8% actively undergoing desertification processes (Hu et al., 2020). Climate projections indicate northward migration of humidity zones by up to 450 kilometres, expanding the area susceptible to desertification.

Existing Efforts to Increase Climate Resilience

National Policy Framework

Environmental Code (2021): The foundational legislation for climate policy identifies agriculture as one of four priority adaptation sectors (Chapters 20-21). Requires vulnerability assessments, climate impact information systems, and annual reporting on adaptation measures.

Strategy for Achieving Carbon Neutrality by 2060: Sets target for 75% of arable land to implement sustainable agriculture practices by 2045. Recognizes that over 80% of agricultural infrastructure is outdated and only 1% of agricultural land is used for organic farming. Includes reforestation program to plant 2 billion trees by 2025.

NDC 3.0 (November 2025): Introduces interim target for 2035, with unconditional target of 17% reduction below 1990 levels and conditional target of 25% with international support. Integrates adaptation, loss and damage, and just transition principles for the first time.

Concept of Development of the Agro-Industrial Complex 2021-2030: Comprehensive framework targeting agricultural transformation, including climate adaptation through modernization addressing soil degradation, water scarcity, and reduced yields. Financial support includes 407.8 billion tenge allocated in first half of 2024.

Water Code Reforms (2024): Targets expansion of irrigated land to 2.5 million hectares, reduction of irrigation water loss from 50% to 25% by 2030, and mandatory adoption of water-saving technologies. Currently only 3% of irrigated land uses water-saving technologies.

Law on Pastures (2017, amended 2024): Regulates sustainable pasture management through pasture rotation systems, maximum permissible load standards, and pasture improvement measures including watering infrastructure and drought-tolerant vegetation.

National Adaptation Plan (under development): Being developed with UNDP and Green Climate Fund support, identifies agriculture as one of four priority sectors. Includes crop diversification, drought-resistant practices, water-saving irrigation, sustainable pasture management, and digital early warning systems.

Key Focus Areas of the TNA Analysis

Based on the vulnerability assessment and policy analysis, the TNA for agriculture adaptation focuses on the following key areas:

Soil and Land Management: Given that 76.1% of Kazakhstan's territory shows moderate to high sensitivity to desertification and soil degradation affects agricultural productivity across all farming systems, technologies for soil conservation, erosion control, and fertility restoration represent a critical area for assessment. This includes conservation tillage practices, agroforestry systems, organic soil amendments, and desertification control measures.

Crop Production Adaptation: Technologies for drought-resistant and climate-resilient crop varieties, precision agriculture, improved soil management, conservation tillage, altered planting calendars and crop diversification to reduce climate risks.

Water Resources and Irrigation: Water-saving irrigation technologies (drip systems, sprinkler systems), rainwater harvesting, and snow retention structures, particularly relevant for irrigated agriculture in southern regions.

Livestock and Pasture Management: Drought-resistant fodder production, rotational grazing systems, and heat stress management infrastructure for livestock.

Existing Technologies within Key Focus Areas

Current technology adoption in Kazakhstan's agriculture sector remains limited but provides foundation for scaling:

Crop Production: Domestic breeding programs have registered 38 sunflower varieties, 28 soybean varieties, 6 rapeseed varieties, and drought/salt-tolerant crop varieties. Conservation tillage is practiced on limited area. Precision agriculture tools (GPS, remote sensing) are in early adoption stage.

Water Resources: Only 3% of irrigated land uses water-saving technologies. Drip and sprinkler irrigation systems are available but adoption is limited by cost. Subsidies cover 50-70% of costs for water-saving equipment. Irrigation reached 10.9 km³ in 2024, fulfilling 97% of demand.

Livestock and Pasture: Climate-resilient breeds including Kazakh White-Head cattle are available. Pasture rotation systems are implemented in demonstration projects. Electric fencing and watering infrastructure are being developed under the Law on Pastures.

Soil Management: No-till farming is practiced on limited scale. Agrochemical soil surveying is being improved. Remote sensing for plant species monitoring is under development.

The TNA process will identify priority technologies for scaling and deployment, analyse barriers to adoption, and develop Technology Action Plans to accelerate climate-resilient agricultural transformation in Kazakhstan.

Chapter 2 Technology prioritization for Agriculture Sector

The technology prioritization process follows the standardized Multi-Criteria Analysis (MCA) methodology developed by UNEP Copenhagen Climate Centre for Technology Needs Assessments. This methodology provides a structured, participatory approach to identifying and ranking climate technologies based on country-specific criteria and stakeholder preferences.

The prioritization process consists of seven sequential steps that progressively narrow the technology options from an initial long list to a final shortlist of priority technologies (Figure 2.1). These steps are outlined in the TNA step-by-step guidance (UNEP CCC, 2024).

The intermediate outputs of this process include the national context analysis, the long list of technologies with Technology Fact Sheets, the description of the technology prioritisation process, and the shortlist of 2-3 priority technologies per sector. The main output is the TNA Report, which documents the entire process and results. A feedback loop allows for adjustment of weights and scores based on stakeholder review, ensuring the final prioritisation reflects consensus among all participants.

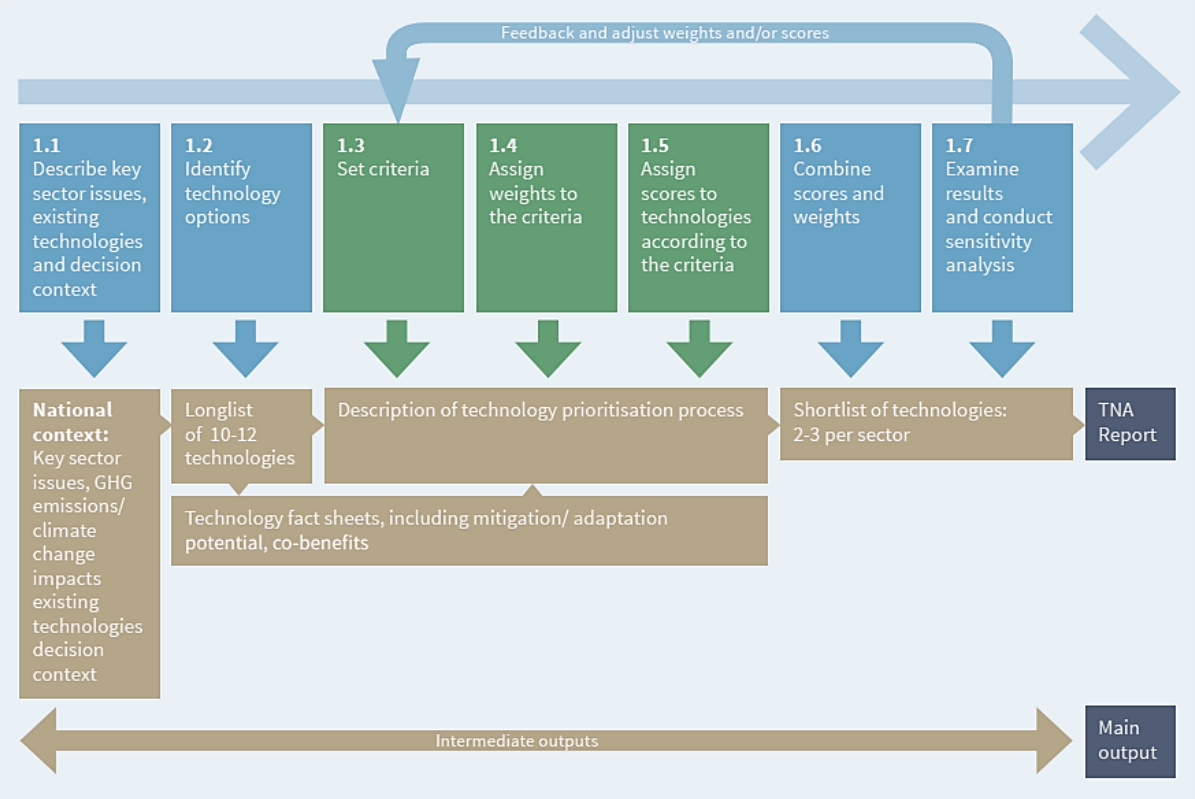


Figure 0.1. Seven steps in the technology prioritization process (UNEP CCC, 2024)

2.1 Technology options in Agriculture

Kazakhstan's agricultural sector operates predominantly through conventional production systems, with technology adoption for climate adaptation remaining limited across all subsectors.

In the northern grain belt, spring wheat and barley production continues under traditional tillage practices on most farms. Conservation agriculture, including no-till and minimum tillage, has been introduced by some large agricultural holdings but covers less than 20% of arable land (World Bank, 2024a). Conventional tillage leaves soils exposed to wind and water erosion—affecting 26 million and 15 million hectares respectively—and reduces the soil's capacity to retain moisture during increasingly frequent drought periods (World Bank, 2024a). Improved crop varieties with drought and heat tolerance show moderate adoption rates of 30–40%, primarily among larger commercial operations with access to certified seed suppliers (OECD, 2024).

Southern Kazakhstan's irrigated farming systems rely predominantly on furrow and flood irrigation methods, achieving water-use efficiency of only 40–50% (OECD, 2024). Modern water-saving technologies remain marginal: drip irrigation covers approximately 50,000 hectares, representing less than 5% of the 1.5 million hectares of irrigated land. Sprinkler systems and precision irrigation are even less common. The primary barriers to adoption include high capital costs (drip systems require $1,500–3,000 per hectare initial investment), limited access to

agricultural financing, and insufficient technical support services for installation and maintenance (OECD, 2024; World Bank, 2024a).

The livestock sector comprises extensive pastoral systems on natural rangelands and semi-intensive operations concentrated near urban centres. Pastoral systems, which account for the majority of cattle, sheep, and goat production, operate with minimal investment in pasture improvement or management infrastructure. Traditional transhumance patterns that historically allowed pasture recovery have weakened significantly since the Soviet era, contributing to overgrazing and degradation of 27 million hectares of pastureland, particularly within 10–15 kilometres of permanent settlements (World Bank, 2024a). Local breeds—including Kazakh Whitehead cattle, Edilbai sheep, and Kazakh horses—predominate due to their resilience to extreme continental climate conditions, though their productivity metrics (milk yield, weight gain, wool production) are typically 30–50% lower than improved breeds. Adoption of improved or crossbred livestock remains limited to 15–20% of commercial farms, constrained by inadequate breeding infrastructure, limited artificial insemination services, and weak performance recording systems (FAO, 2024).

Current adoption rates for key climate adaptation technologies remain low to moderate across the sector. Conservation agriculture covers less than 20% of arable land, constrained by equipment costs, knowledge gaps, and weed management challenges. Improved and drought-tolerant crop varieties show moderate uptake at 30–40%, limited by seed availability and cost premiums. Drip and sprinkler irrigation remain below 5% of irrigated land due to high capital costs of $1,500–3,000 per hectare, limited financing access, and inadequate technical support. Precision agriculture similarly covers less than 5% of farms, constrained by technology costs, digital infrastructure gaps, and limited technical capacity. In the livestock sector, improved breeds are used on approximately 15–20% of farms, with expansion limited by breeding infrastructure and performance recording deficiencies, while rotational grazing is practiced on only 10–15% of pastoral land due to land tenure complexities, water infrastructure requirements, and the need for community coordination (World Bank, 2024a; OECD, 2024; FAO, 2024).

2.1.1 Process of Identifying Technologies

The identification of candidate technologies for climate change adaptation in Kazakhstan's agriculture sector followed a structured, participatory process aligned with the TNA step-by-step guidance (UNEP CCC, 2024). This process combined desk research, expert consultation, and stakeholder engagement to develop an initial Extended list of 28 climate adaptation technologies that reflect both international best practices and national priorities.

The National Expert compiled the Extended list of 28 technologies through a comprehensive review of multiple sources:

- International climate adaptation databases and technical resources from FAO, IPCC, and UNFCCC, which provided evidence-based technologies proven effective in similar agroclimatic conditions

- TNA reports from countries with comparable agricultural systems and climate challenges, particularly Moldova, Ukraine, and Kyrgyzstan, which offered insights into technology applicability for Central Asian and Eastern European contexts
- Kazakhstan's first TNA (2014-2017), which prioritized Drip Irrigation and Water Metering, Diversification of Crop Production, and Grazing Systems on an Industrial Basis for the agriculture and water resources sectors
- National research institutions, including Kazakhstan's Agricultural Institutions, National Meteorological Office "Kazhydromet" and others, which provided local data on climate projections and agricultural vulnerabilities
- National strategic documents, including the NDC 3.0, Carbon Neutrality Strategy 2060, Environmental Code (2021), and the Concept of Development of the Agro-Industrial Complex for 2021-2030
- Input from international consultants (UNEP CCC, CTCN)
- Review of international best practices and climate adaptation technologies

Alignment with National Planning Documents

The technology identification process was guided by key national policy and planning documents. The Environmental Code of the Republic of Kazakhstan (2021) identifies agriculture, water resources, forestry, and civil protection as priority sectors for adaptation measures. The Strategy for Achieving Carbon Neutrality by 2060 targets 75% of arable land to implement sustainable agriculture practices by 2045. The Third Nationally Determined Contribution (NDC 3.0) sets adaptation implementation targets by 2035. The Concept of Development of the Agro-Industrial Complex for 2021-2030 includes provisions for water infrastructure modernization, including construction of 20 new reservoirs, reconstruction of 15 existing ones, and modernization of 14,000 km of irrigation canals. The Law on Pastures (2017, amended 2024) regulates sustainable pasture management through rotation systems and maximum permissible load standards.

Working Group Involvement and Stakeholder Consultation

The Agriculture Sectoral Working Group (SWG) comprising 17 members was established as the primary mechanism for stakeholder engagement and technical validation. The SWG membership represents government agencies (Ministry of Agriculture, Department of Soil Resources and Climate, Ministry of Ecology and Natural Resources), research institutions (Kazhydromet, Climate Research Center, agricultural research institutes), private sector (Association of Organic Agriculture Producers, farming enterprises), civil society (environmental NGOs, farmer associations), and international organizations familiar with FAO, UNDP, and GIZ climate adaptation programmes.

The National Expert prepared descriptions of the identified technologies, aligned them with feedback from the international expert, and presented the Extended list of 28 technologies to the SWG members during online meetings. The technologies were organized into categories covering

Water Resources and Irrigation, Soil and Land Management, Livestock and Pasture Systems, and Crop Production, ensuring comprehensive coverage of Kazakhstan's agricultural adaptation needs.

Technologies were organized into five thematic categories:

Table 1. Technology categories in the Extended List

Category	**Number of Technologies**	**Examples**
Water Resources & On-Farm Irrigation	4	Drip irrigation, rainwater harvesting, snow retention
Soil & Land Management	11	Conservation agriculture, mulching, biochar, saline restoration
Climate-Resilient Crops	1	Winter crop varieties, drought-resistant cultivars
Livestock Systems	8	Rotational grazing, fodder production, cooling systems
Agroforestry & Ecosystem Management	4	Windbreaks, erosion control, riparian buffers

2.1.2 Long list of Technology Options

The National Expert in agriculture prepared descriptions of the identified technologies in section 2.1.1, aligned them with feedback from the international expert, and presented the Extended List of technologies to the SWG members during an online meeting. A structured assessment was conducted using Google Forms, allowing SWG members to evaluate all 28 technologies against the following criteria:

1. Climate Adaptation Potential: Effectiveness in addressing climate vulnerabilities (Scale 1-10)
2. Economic Viability: Cost-effectiveness and return on investment (Scale 1-10)

Each technology was scored on a scale of 1-10 for each criterion, with 14 out of 17 working group members providing independent assessments. The scoring process took place over a two-week period, with members having access to detailed Technology Fact Sheets.

The following formula was used to rank technologies according to adaptation and economic scores:

$$\text{Final score} = \frac{(\sum_1^{14} Adaptation_score_{(i)} + \sum_1^{14} Economic_score_{(i)})}{2},$$

Where *i* is the score of i-th member of working group.

Average scores were calculated for each technology across assessment criteria and all working group members. Technologies were ranked by their composite scores, with the top 12 technologies selected as the priority adaptation portfolio for Kazakhstan's agriculture sector. After reviewing and examining the list of technologies presented it was decided to optimize the list by merging some of the technologies and adjusting the ranking based on adaptation focus. Extended list of 26 technologies is presented in table 2.3.

Table 2.2. Scoring and Ranking of Technologies

Rank	**Technology Name**	**Score**
1	Drip Irrigation Systems	111,5
2	Snow Retention Structures (Barriers, Fences, Windbreaks)	109
3	Conservation Agriculture (Minimum/Zero Tillage, Crop Rotation)	109
4	Climate-Smart Soil Management: Mulch, Biochar, and Compost	107,5
5	Saline Soil Reclamation (Gypsum Application, Halophyte Crop Rotation)	106
6	Rainwater Harvesting (Farm Ponds, Reservoirs)	105
7	Production and conservation of drought-resistant feed	105
8	GPS-Based Rotational Grazing Systems	104
9	Livestock Watering Infrastructure and Mobile Shade Structures and Integrated Livestock Hydration, Shade, and Water Harvesting Systems for Transhumance Corridors	102,5
10	Agroforestry Systems for Erosion Control and Soil Protection	101,5
11	Transition to Winter Crops (Autumn Sowing, Early Harvest)	100,5
12	Livestock Cooling Systems and Heat Stress Reduction (Sprayers, Fans, Shade Nets)	98
13	Precision Fertilizer Application Equipment (Variable Rate Spreaders, Soil Test Kits)	98
14	Biogas Production from Livestock Waste	98
15	Mechanized Forest Planting with Drip Irrigation	97,5
16	Cold-Press and Refining for Special Oil Crops (Flax, Camelina, Rapeseed)	97,5
17	Modern Forest Nurseries (Automated Seedling Production Systems)	96,5
18	Straw Processing for Building Materials (Wheat and Barley Straw Panels)	96,5
19	Flax Straw Processing for Bioproducts (Insulation Panels, Geotextiles)	96
20	Canal Lining and SCADA-Based Automated Water Management Systems	95

21	Marginal Land Restoration (Terracing, Contour Plowing, Soil Amendments)	95
22	Tele-Veterinary Diagnostic Systems and Mobile Vaccination Units	93,5
23	Riparian Buffer Zone (Tree Planting, Bioengineering for Bank Stabilization)	91,5
24	Plantation Forestry and Fast-Growing Tree Cultivation	91
25	Precision Land Levelling Equipment (Laser and GPS Systems)	87,5
26	Remote Sensing Based Livestock Monitoring Systems for Index Insurance	86

Adaptation Focus Selection

It was found that 3 technologies Precision Fertilizer Application, Livestock Cooling Systems and Heat Stress Reduction, and Biogas Production ranked 12-14 had the same score of 98 points. Among the three top-ranked technologies with a similar score Livestock Cooling Systems and Heat Stress Reduction was selected for inclusion in the long list of top 12. The rationale was that:

- Biogas production has primarily a mitigation effect rather than adaptation
- Precision fertilizer application is mainly about efficiency rather than climate adaptation
- Livestock cooling directly addresses the climate vulnerability of heat stress on animals.

Table 2.3. Long list of 12 Priority Technologies

Rank	**Technology Name**	**Score**	**Category**
1	Drip Irrigation Systems	111.5	Water
2	Snow Retention Structures	109	Water
3	Conservation Agriculture (No-Till/Crop Rotation)	109	Soil
4	Climate-Smart Soil Management (Mulch/Biochar/Compost)	107.5	Soil
5	Saline Soil Reclamation	106	Soil
6	Rainwater Harvesting	105	Water
7	Drought-resistant Feed Production/Conservation	105	Livestock
8	GPS-Based Rotational Grazing Systems	104	Livestock
9	Integrated Livestock Hydration and Shade Systems	102.5	Livestock
10	Agroforestry for Erosion Control and Soil Protection	101.5	Agroforestry

11	Transition to Winter Crops	100.5	Crops
12	Livestock Cooling and Heat Stress Reduction	98	Livestock

The final portfolio of 12 technologies demonstrates balanced coverage across three key adaptation themes: Water Resources & Irrigation (4 technologies), Soil & Land Management (3 technologies), and Livestock Systems (4 technologies), plus Agroforestry (1 technology).

Technology Fact sheets were developed for the final top 12 technologies listed in table 2.4 and distributed among working group members (see appendix 1).

2.2 Technology prioritisation process

2.2.1 Setting Criteria

Following the initial prioritization by the SWG, a comprehensive Multi-Criteria Analysis (MCA) was conducted to provide a more detailed evaluation of the Long List of 12 priority technologies. The MCA follows the UNFCCC TNA methodology developed by UNEP Copenhagen Climate Centre.

The initial set of criteria reflecting the key considerations for technology adoption in Kazakhstan's context: cost constraints, economic benefits for farmers, social inclusion, environmental sustainability, climate effectiveness, and institutional feasibility was proposed to Agriculture SWG as a starting point for selection and discussion. The feedbacks were collected and the final set of criteria was used for technology prioritization.

COSTS Dimension

Capital Expenditure represents the initial upfront investment required to adopt a technology, measured in dollars per hectare. This includes equipment purchase, infrastructure development, and installation costs. Lower capital expenditure is preferred as high initial costs constitute a major barrier to technology adoption, particularly for smallholder farmers with limited access to credit. Technologies requiring minimal initial investment score higher on this criterion.

Operation and Maintenance Costs capture the annual recurring expenses needed to sustain the technology over time, expressed in dollars per hectare per year. This includes labour, consumable inputs, repairs, energy consumption, and regular maintenance activities. Technologies with lower ongoing operational costs are preferred as they ensure long-term affordability and sustainability of adoption.

ECONOMIC Dimension

Job Creation measures the employment generation potential of each technology, scored on a 1-10 scale. This criterion considers both direct employment opportunities in technology implementation and operation, as well as indirect jobs in related supply chains, input provision, and processing

activities. Technologies that create more employment opportunities contribute to rural economic development and are scored higher.

Potential to increase farm income and investment opportunities represents the expected percentage improvement in farm income resulting from technology adoption, scored on a 1-10 scale. This includes benefits from higher crop yields, reduced production losses, improved product quality and better market access. Technologies that deliver greater income improvements for farming households receive higher scores on this criterion.

SOCIAL Dimension

Gender equality and Social Inclusion assesses how effectively the technology benefits women, youth, and other vulnerable groups in rural communities, scored on a 1-10 scale. This criterion evaluates whether the technology reduces women's workloads, creates economic opportunities for marginalized groups, improves access to resources, and promotes more equitable participation in agricultural decision-making. Technologies that actively address gender disparities and social inequalities score higher.

Women play significant roles in Kazakhstan's agricultural sector, particularly in household-level production, livestock management, and food processing activities. In rural areas, women often bear primary responsibility for household food security, water collection, and care of small livestock. Climate change impacts on water availability, pasture productivity, and crop yields therefore affect women's workloads and economic opportunities in these domains. Technology prioritisation considers the accessibility of proposed technologies to women farmers and rural households, the potential for technologies to reduce labour burdens that disproportionately affect women, and opportunities for women's economic empowerment through technology adoption.

ENVIRONMENTAL Dimension

Preservation and increase of soil fertility measures the contribution of each technology to improving soil health and organic matter content, scored on a 1-10 scale. This criterion evaluates improvements in soil structure, nutrient cycling, carbon sequestration capacity, erosion prevention, and long-term land productivity. Given that Kazakhstan's arable soils are losing humus at approximately 1% per year, technologies that restore and maintain soil fertility are essential for sustainable agricultural development.

CLIMATE Dimension

Contribution to reducing vulnerability to climate change impacts assesses the effectiveness of each technology in reducing climate vulnerabilities, scored on a 1-10 scale. This criterion evaluates the capacity to withstand drought conditions, heat stress, flooding, erratic precipitation, and other climate hazards affecting agricultural production. Technologies that enhance adaptive capacity, reduce climate-related production risks, and maintain productivity under changing climatic conditions receive higher scores.

INSTITUTIONAL Dimension

Ease of Implementation evaluates the technical and institutional feasibility of deploying the technology in Kazakhstan's context, scored on a 1-10 scale. This criterion considers availability of required inputs and equipment, technical skills and training requirements, compatibility with existing farming systems, infrastructure needs, and the capacity of extension services to support adoption. Technologies that can be implemented with existing resources and capabilities score higher.

Alignment with national adaptation and sustainable development priorities measures consistency with Kazakhstan's climate commitments and development goals, scored on a 1-10 scale. This criterion assesses how well each technology contributes to achieving targets set in the NDC 3.0, Carbon Neutrality Strategy by 2060, National Adaptation Plan, Agricultural Development Concept 2021-2030, and related strategic documents. Technologies that directly support national priority areas receive higher scores.

2.2.2 Assigning weights

The national expert developed the proposed distribution of criteria weights and discussed it with the working group members and the international consultant. The assignment of weights to the criteria was adjusted and validated during consultations by SWG members, with specific considerations of climate and sustainable development national priorities (see Table 2.5).

Table 2.4. MCA Criteria, Weights and Descriptions

Dimension	Criterion	Weight	Description
COSTS (27%)	Capital Expenditure	19%	Initial investment cost per hectare ($/ha). Lower costs preferred.
	O&M Costs	8%	Annual operation and maintenance costs ($/ha/year).
ECONOMIC (22%)	Job Creation	10%	Employment generation potential (jobs per 1,000 ha).
	Potential to increase farm income and investment opportunities	12%	Expected increase in farm income (%).
SOCIAL (5%)	Gender & Social Inclusion	5%	Benefits for women and vulnerable groups (1-10 scale).
ENVIRONMENTAL (15%)	Preservation and increase of soil fertility (humus content, %)	15%	Contribution to soil health and organic matter (1-10 scale).

CLIMATE (15%)	Contribution to reducing vulnerability to climate change impacts	15%	Effectiveness in reducing climate vulnerabilities (1-10 scale).
INSTITUTIONAL (16%)	Ease of Implementation	9%	Technical and institutional feasibility (1-10 scale).
	Alignment with national adaptation and sustainable development priorities	7%	Consistency with national climate commitments (1-10 scale).
TOTAL		100%	

2.2.3 Scoring

The scoring of the shortlisted 12 adaptation technologies was carried out through a structured Multi-Criteria Analysis (MCA) process in accordance with the TNA step-by-step guidance (UNEP CCC, 2024) methodology. The objective of the scoring was to generate a comparable assessment of each technology against the agreed nine criteria, reflecting Kazakhstan's national adaptation priorities and implementation conditions.

As a first step, a Performance Matrix was developed (Annex 2), compiling the raw indicator values for each technology across all criteria. Cost-related criteria—Capital Expenditure and Operation & Maintenance (O&M) Costs—were quantified in USD per hectare, based on expert judgment, available benchmarks, and indicative technology cost ranges. All benefit-related criteria (economic, social, environmental, climate and institutional) were assessed using a 1–10 scale, where higher values represent stronger expected contribution to national goals such as resilience building, soil protection, income growth, feasibility of deployment, and alignment with policy commitments.

Raw data was collected for each technology across all evaluation criteria. Data sources included expert assessments from SWG members, literature review, and international benchmarks from similar climate zones.

The Performance Matrix presents raw indicator values for each of the 12 priority technologies across nine evaluation criteria. Cost criteria (Capital Expenditure and Operations & Maintenance) are expressed in USD per hectare. All benefit criteria use a 1-10 point scale. Conservation Agriculture demonstrates the lowest capital costs at 50 USD/ha with operating costs of 15 USD/ha annually, and scores 9 points on soil conservation and 9 points on NDC alignment. Winter Crops Transition has the lowest capital requirement at only 50 USD/ha. Drip Irrigation shows the highest capital investment at 2500 USD/ha but achieves high scores on job creation (8 points) and income enhancement (9 points). Agroforestry exhibits maximum scores on soil conservation (9 points) and climate vulnerability reduction (8 points).

To ensure comparability across criteria with different measurement units, the raw values were converted into a normalized Scoring Matrix (Annex 2) using a 0–100 scale. For criteria where higher values are preferred (e.g., climate vulnerability reduction, soil fertility, job creation), the normalization applied a positive scaling approach. For criteria where lower values are preferred (i.e., capital and O&M costs), an inverse approach was applied so that technologies with lower costs received higher normalized scores (OECD, 2023).

The normalization methodology depended on criterion type:

- For "lower is better" criteria (costs): Score = (Max - Value) / (Max - Min) × 100
- For "higher is better" criteria (benefits): Score = (Value - Min) / (Max - Min) × 100

The normalized scoring results highlight clear differences among technologies in terms of investment needs and expected benefits. For example, Conservation Agriculture performs strongly due to relatively low operating costs compared to conventional tillage, combined with high scores in soil conservation and climate resilience, though it requires significant initial capital investment in specialized equipment such as no-till seeders and direct drilling machinery. Drip Irrigation shows high potential economic and climate benefits but requires substantially higher upfront investment. Drip Irrigation shows high potential economic and climate benefits but requires substantially higher upfront investment. The completed scoring matrices are provided in Annex 2, and these normalized scores form the basis for calculating weighted totals in the subsequent step.

For cost criteria, an inverse scale is applied where lower costs receive higher scores. Conservation Agriculture receives high normalized scores: 98.7 on capital costs (due to low 80 USD/ha investment) and 84.8 on operating costs. Agroforestry and Climate-Smart Soil Management achieve maximum normalized soil conservation scores of 100. Drip Irrigation receives 0 on capital cost normalization due to its high 2500 USD/ha requirement, but achieves 100 on job creation and income enhancement criteria.

2.3 Prioritised technologies for Sector A

The final stage of the technology prioritization process involved combining the normalized performance scores with stakeholder-validated criteria weights to produce an overall ranking of adaptation technologies.

2.3.1 Combining scores and weights

The Decision Matrix shows weighted scores calculated by multiplying normalized scores by the corresponding criterion weights. The final column shows the total weighted score for each technology.

Weighted scores were calculated by multiplying normalized scores by criteria weights: Weighted Score = Normalized Score × Weight / 100

Total scores were computed by summing all weighted scores for each technology. The Decision Matrix presents weighted scores calculated by multiplying normalized values by

stakeholder-validated criterion weights. Weighted scores range from 0 to approximately 1900 points per criterion, and are then summed to produce final rankings. The criterion weights are: Capital Expenditure (19%), O&M (8%), Job Creation (10%), Income Enhancement (12%), Gender Equality (5%), Soil Conservation (15%), Climate Vulnerability (15%), Ease of Implementation (9%), and NDC Alignment (7%).

Table 2.5. Final MCA Ranking of Priority Technologies for Agriculture Sector

Rank	Technology	MCA Score	Category	Key Contributing Factors (weighted points)
1	Conservation Agriculture (No-Till/Crop Rotation)	7,660	Soil	Capital Costs (1,877), Soil Conservation (1,500), O&M Costs (752)
2	Agroforestry Systems for Erosion Control and Soil Protection	7,407	Agroforestry	Capital Costs (1,629), Soil Conservation (1,500), Climate Vulnerability (1,125)
3	Climate-Smart Soil Management	6,336	Soil	Capital Costs (1,784), Soil Conservation (1,500), Climate Vulnerability (750)
4	Drip Irrigation Systems	6,085	Water	Climate Vulnerability (1,500), Income Enhancement (1,200), Job Creation (1,000)
5	Drought-resistant feed production/conservation	6,084	Livestock	Capital Costs (1,846), Ease of Implementation (900), O&M Costs (727)
6	Transition to Winter Crops	5,717	Crops	Capital Costs (1,900), Climate Vulnerability (1,125), Ease of Implementation (900)
7	Rainwater Harvesting	5,229	Water	Job Creation (857), Income Enhancement (800), Climate Vulnerability (750)
8	Snow Retention Structures	4,965	Water	Capital Costs (1,822), Ease of Implementation (900), O&M Costs (800)
9	Saline Soil Reclamation	4,919	Soil	Capital Costs (1,667), Soil Conservation (1,250), O&M Costs (582)
10	GPS-Based Rotational Grazing	4,644	Livestock	Capital Costs (1,590), Soil Conservation (1,000), O&M Costs (606)

Rank	Technology	MCA Score	Category	Key Contributing Factors (weighted points)
11	Livestock Hydration and Mobile Shade Infrastructure	3,299	Livestock	Capital Costs (1,644), O&M Costs (630), Ease of Implementation (540)
12	Livestock Cooling and Heat Stress Reduction	2,411	Livestock	Capital Costs (1,008), Ease of Implementation (540), Climate Vulnerability (375)

Conservation Agriculture achieved the highest total of 7660 points, with its largest contributions from capital costs (1877 points) and soil conservation (1500 points). Agroforestry ranked second at 7407 points, driven by capital cost (1629 points), soil conservation (1500 points) and strong climate performance (1125 points). Climate-Smart Soil Management ranked third at 6,336 points, with notable contributions from capital costs (1,784 points), soil conservation (1,500 points), climate vulnerability reduction (750 points), and job creation (571 points).

2.3.2 Result examination and sensitivity analysis

Following the completion of the scoring and weighting procedures, the results of the MCA were reviewed together with the Agriculture Sectoral Working Group (SWG) to confirm that the prioritisation outcomes were consistent with national adaptation priorities and the practical realities of implementation in Kazakhstan.

In examining the prioritisation results, several considerations were considered before selecting the final technologies for further analysis. First, stakeholders acknowledged that while this TNA is primarily a climate change project aimed at identifying effective adaptation technologies, the adopted weighting scheme assigned 49% combined weight to cost and economic criteria (Capital Expenditure 19%, O&M 8%, Job Creation 10%, Income Enhancement 12%), compared to 30% for climate and environmental criteria (Climate Vulnerability Reduction 15%, Soil Conservation 15%). This distribution reflects the practical reality that technology adoption in Kazakhstan's agriculture sector depends heavily on economic viability for farmers and implementing institutions. However, the sensitivity analysis was specifically designed to test whether significantly increasing the climate criterion weight would alter the ranking outcomes. Second, the highest-scoring technologies may already be receiving significant attention through existing national programmes, donor initiatives or private sector investment. In such cases, the TNA process should avoid duplicating ongoing efforts and instead focus on technologies where additional analysis and targeted enabling actions can accelerate adoption. Third, weight distribution among criteria could have other distribution, particularly if stakeholders differ in their valuation of costs, economic benefits, environmental performance or institutional feasibility. For this reason, sensitivity analysis is recommended as part of the result examination process (UNEP CCC, 2024).

A sensitivity analysis was conducted to test the robustness of the MCA ranking under alternative weighting scenarios and to evaluate whether reasonable changes in stakeholder

preferences could significantly alter the prioritisation outcomes. Given that climate adaptation is the primary objective of this TNA, particular attention was paid to testing scenarios where climate-related criteria receive substantially higher weight. Three alternative weighting schemes were applied to the Decision Matrix, reflecting different emphasis areas that may arise in national decision-making.

a) Scenario A (Climate and Environmental Focus): Assigned 40% combined weight to climate vulnerability reduction (20%) and soil conservation (20%), with cost criteria reduced to 25% combined. This scenario directly tests whether prioritising climate resilience above economic considerations would change the technology ranking.
b) Scenario B (Economic Focus): Assigned 40% combined weight to cost criteria (Capital Expenditure 20%, O&M 20%) and 12% to income enhancement, with climate and environmental criteria reduced to 22% combined.
c) Scenario C (Balanced Distribution): Applied equal weighting (11% each) across all nine criteria to test whether removing any dominant criterion group would alter the ranking.

Table 2.6 presents the ranking outcomes under each weighting scenario.

Table 2.6. Sensitivity analysis: Technology rankings under alternative weighting scenarios

Technology	**Base Case**	**Scenario A (Climate)**	**Scenario B (Economic)**	**Scenario C (Equal)**
Conservation Agriculture	1 (7,660)	**2 (7,624)**	1 (7,943)	1 (7,505)
Agroforestry	2 (7,407)	**1 (7,662)**	2 (7,559)	2 (7,234)
Climate-Smart Soil Management	3 (6,336)	**3 (6,631)**	3 (6,665)	5 (5,751)
Drip Irrigation Systems	4 (6,085)	4 (6,288)	10 (5,030)	3 (6,398)
Drought-resistant Feed Production	5 (6,084)	6 (5,587)	4 (6,597)	4 (6,325)
Transition to Winter Crops	6 (5,717)	5 (5,695)	5 (6,189)	7 (5,375)

Source: MCA Decision Matrix sensitivity analysis (Annex 3)

The sensitivity analysis indicates that the prioritisation results are stable. Critically, under Scenario A where climate and environmental criteria received 40% combined weight (compared to 30% in the base case), the composition of the top three technologies remained unchanged: Conservation Agriculture and Agroforestry exchanged first and second positions, while Climate-Smart Soil Management retained third place. This demonstrates that a significant increase in the weight assigned to climate-related criteria does not alter which technologies are prioritised—only their relative ordering within the top tier. The stability occurs because the highest-ranked

technologies perform strongly on both economic and climate criteria simultaneously; they offer low implementation costs while also delivering substantial climate resilience and soil conservation benefits. Conservation Agriculture and Agroforestry consistently occupy the top two positions across all scenarios, and the top-ranked technology group remains stable regardless of whether economic or climate criteria are emphasized.

Based on the combined review of MCA ranking outcomes and sensitivity testing, the SWG confirmed the final technology prioritisation. The three highest-ranked technologies—Conservation Agriculture, Agroforestry, and Climate-Smart Soil Management—all address soil degradation and land management challenges. This concentration reflects the critical importance of reversing soil fertility decline as a foundational adaptation priority for Kazakhstan's agriculture sector, where 76.1% of territory shows high or very high sensitivity to desertification. The top-ranked technologies achieved their positions due to strong performance across multiple criteria: low capital costs enabling widespread adoption, high soil conservation benefits addressing the country's most pressing land degradation challenges, and significant contributions to climate vulnerability reduction. Their selection provides a technically coherent foundation for the Barrier Analysis and Enabling Framework, as improvements in soil health underpin the effectiveness of other adaptation measures. These technologies provide a strong evidence base for selecting two to three technologies for the Barrier Analysis and Enabling Framework and for developing Technology Action Plans in the subsequent stages of the TNA process.

Table 0.7. Short list technologies with averaged MCA scores

Technology	**Total score**	**Ranking**
Conservative Agriculture (No-Till/Crop Rotation)	7660	1
Agroforestry Systems for Erosion Control and Soil Protection	7407	2
Climate-Smart Soil Management (mulch/biochar/compost)	6336	3

Chapter 3 Summary and Conclusions

This chapter summarises the key findings and conclusions from the Technology Needs Assessment (TNA) for Kazakhstan's agriculture sector. The assessment followed the UNEP-CCC methodology (UNEP CCC, 2024) and was implemented through stakeholder engagement led by the Ministry of Ecology and Natural Resources and the International Green Technologies and Investment Projects Center.

Key Conclusions

- **Sector Priority:** The agriculture sector was selected as the national priority for adaptation due to high exposure to rising temperatures, drought, declining soil fertility, pasture

degradation, and water stress. The sector employs 11–13% of the workforce and is essential for food security and rural livelihoods.

- **Technology Identification:** An extended list of 28 adaptation technologies was developed and narrowed to 12 priority technologies through stakeholder screening, covering Water Resources and Irrigation, Soil and Land Management, Climate-Resilient Crops, Livestock Systems, and Agroforestry.
- **Prioritisation Methodology:** Multi-Criteria Analysis (MCA) was applied using nine evaluation criteria across cost, economic, social, environmental, climate, and institutional dimensions. Stakeholder-validated weights assigned 49% to cost and economic criteria and 30% to climate and environmental criteria (Climate Vulnerability Reduction 15%, Soil Conservation 15%).
- **Prioritised Technologies:** The three highest-ranked technologies are: (1) Conservation Agriculture, (2) Agroforestry for Erosion Control, and (3) Climate-Smart Soil Management. All three address soil degradation and land management, reflecting the critical importance of reversing soil fertility decline in Kazakhstan, where 76.1% of territory shows high sensitivity to desertification.
- **Robustness of Climate Resilience Prioritisation:** Sensitivity analysis confirmed that the ranking is stable under alternative weighting scenarios. Critically, when climate and environmental criteria were increased to 40% combined weight, the composition of the top three technologies remained unchanged. This demonstrates that the prioritised technologies maintain strong climate resilience performance regardless of whether economic or climate criteria are emphasised.

Table 3.1 presents the sensitivity analysis results demonstrating the robustness of the prioritisation under different weighting scenarios, including increased emphasis on climate resilience criteria.

Table 3.1. Sensitivity analysis: Technology rankings under alternative weighting scenarios

Technology	**Base Case**	**Scenario A**	**Scenario B**	**Scenario C**
	Climate 30%	**Climate 40%**	Economic 62%	Equal 11%
Conservation Agriculture	1 (7,660)	2 (7,624)	1 (7,943)	1 (7,505)
Agroforestry	2 (7,407)	1 (7,662)	2 (7,559)	2 (7,234)
Climate-Smart Soil Management	3 (6,336)	3 (6,631)	3 (6,665)	5 (5,751)
Drip Irrigation Systems	4	4	4	3
Drought-resistant Feed	5	6	5	4
Transition to Winter Crops	6	5	6	5

Note: Scenario A (Climate Focus) assigns 40% weight to climate and environmental criteria. Green shading highlights climate-focused scenario. Yellow shading indicates technologies selected for BAEF. Numbers in parentheses show MCA weighted scores.

- **Technologies for Barrier Analysis and Enabling Framework (BAEF):** Based on the MCA results and sensitivity analysis, Conservation Agriculture and Agroforestry have been selected to proceed to Phase II of the TNA process for detailed barrier analysis and development of Technology Action Plans. These technologies demonstrated robust climate resilience performance and provide a coherent foundation for scaling adaptation measures across Kazakhstan's agriculture sector.
- **Policy Alignment:** The prioritised technologies support Kazakhstan's Third Nationally Determined Contribution (NDC 3.0), the Strategy for Achieving Carbon Neutrality by 2060, the Concept of Development of the Agro-Industrial Complex 2021–2030, and the forthcoming National Adaptation Plan.
- **Expected Co-benefits:** The prioritised technologies deliver multiple co-benefits including reduced land degradation, improved water retention, enhanced productivity, strengthened rural livelihoods, and carbon sequestration potential.

The TNA process provides Kazakhstan with a clear evidence base for advancing climate-resilient agricultural transformation. The next phase will focus on analysing barriers and enabling conditions for the selected technologies and preparing Technology Action Plans to guide implementation, investment mobilisation, and institutional support mechanisms.

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Annex 1. TFS

Technology 1: Drip Irrigation Systems

Section	Content
Sector	Agriculture
Introduction	Drip irrigation is a highly efficient water delivery system that applies water directly to the root zone of plants through a network of pipes, valves, and emitters. This technology is particularly relevant for Kazakhstan's arid and semi-arid agricultural zones where water scarcity is a critical constraint. The system enables precise control of water application, reducing evaporation losses and ensuring optimal soil moisture for crop growth. In Kazakhstan, drip irrigation is being promoted as a key adaptation technology under the State Program for Agricultural Development 2017-2021 and subsequent initiatives. The technology is especially suitable for high-value crops such as vegetables, fruits, and cotton in the southern regions.
Technology characteristics/highlights	• High water use efficiency (85-95% compared to 40-60% for flood irrigation) • Suitable for both small-scale farms and large agricultural enterprises • Can be integrated with fertigation systems for nutrient delivery • Adaptable to various terrains including slopes and irregular fields • Significant potential to reduce vulnerability to rainfall variability and droughts
Institutional and organizational requirements	Implementation requires coordination with local water management authorities (Basin Inspections) and agricultural extension services. Training programs for farmers on system operation, maintenance, and water scheduling are essential. Financial support mechanisms through Kazakhstan's agricultural subsidies program are available for technology adoption.
Operation and maintenance	Regular inspection and cleaning of filters and emitters is required (weekly during growing season). Drip lines should be flushed periodically to prevent clogging from mineral deposits. System pressure must be monitored and maintained within design parameters. Annual replacement of filters and damaged emitters

	may be necessary. Winter drainage is essential to prevent frost damage in northern regions.
Endorsement by experts	Recommended by FAO, ICARDA, and Kazakhstan's Kazakh Research Institute of Water Management. Endorsed in the National Water Strategy 2040 as a priority technology for water conservation in agriculture.
Adequacy for current and future climate	Highly suitable for current and projected climate conditions in Kazakhstan. The technology addresses increasing water scarcity due to glacier retreat and changing precipitation patterns. Particularly effective in reducing crop losses during drought years which have become more frequent since 2010.
Scale/Size of beneficiaries group	Large potential covering approximately 1.8 million hectares of irrigated land. Primary beneficiaries include vegetable and fruit farmers in Almaty, Turkestan, Zhambyl, and Kyzylorda regions. Can benefit both smallholders (1-10 ha) and large agricultural enterprises.
Disadvantages	High initial capital investment may limit adoption by small farmers. Requires reliable electricity supply for pumping systems. Susceptible to clogging from poor water quality. Not suitable for all crop types (e.g., rice, some cereals). May require redesign of existing farm layouts. Limited availability of spare parts in remote areas.
Capital costs	$800-2,500 per hectare depending on automation level, terrain, and water source. Basic systems with manual controls: $800-1,200/ha. Semi-automated systems: $1,200-1,800/ha. Fully automated with sensors: $1,800-2,500/ha. Additional costs for water source development (wells/reservoirs): $200-500/ha.
Lifetime	10-15 years for main infrastructure; drip lines require replacement every 5-7 years
Reduction of vulnerability to climate change	Maintains crop yields during drought periods (30-50% yield improvement vs. rainfed). Reduces water consumption by 40-60% compared to surface irrigation. Enables continued production under increasing climate variability. Protects farmer income during water-stressed growing seasons.
Economic benefits	Increased crop yields by 30-50%; reduced water costs by 40-60%; higher-value crop production potential; reduced labor costs for irrigation management; improved product quality commanding premium prices

Social benefits	Reduced labor burden especially for women; improved food security; skill development in modern farming; enhanced rural employment in installation and maintenance
Environmental benefits	Reduced water withdrawal from rivers and aquifers. Lower fertilizer runoff and groundwater contamination through precise application. Reduced soil salinization compared to flood irrigation. Decreased energy consumption per unit of crop produced.
Barriers to implementation	Access to financing (addressed through agricultural credit programs), technical knowledge gaps (extension services needed), water quality issues (pre-treatment may be required), land fragmentation limiting economies of scale, limited local manufacturing capacity.
Opportunities	Growing government support through subsidies (up to 50% cost coverage). Increasing water tariffs making efficient irrigation economically attractive. Export market demand for quality produce. Climate finance mechanisms under NDC implementation.
Market potential	Nationwide potential with priority in southern and southeastern regions. Current coverage: approximately 120,000 ha. Potential expansion: 500,000+ ha by 2030.
Status	Expanding adoption, currently at 7% of irrigated area. Government target: 25% of irrigated land by 2030.
Timeframe for implementation	Short to medium term (1-3 years for full implementation)
Acceptability to local stakeholders	High acceptance among progressive farmers and agricultural enterprises. Some resistance from traditional farmers due to high costs and technical complexity. Positive experience from demonstration projects improving adoption rates.

Technology 2: Snow Retention Structures

Section	Content
Sector	Agriculture
Introduction	Snow retention structures are physical barriers designed to accumulate and retain snow cover during winter months, increasing soil moisture recharge during spring snowmelt. This traditional technology is particularly valuable for dryland agriculture in Kazakhstan's northern grain-producing regions (Kostanay, Akmola, North Kazakhstan) where annual precipitation is limited and largely falls as snow. The technology helps counteract the effects of strong winter winds that can blow snow from fields, leaving soil exposed to frost damage and reducing spring moisture availability for crop germination.
Technology characteristics/highlights	• Low-tech, locally adaptable solution • Uses readily available materials (straw, stubble, wooden barriers) • Increases soil moisture by 20-40mm in spring • Protects winter crops from frost damage • Compatible with existing farming practices
Institutional and organizational requirements	Minimal institutional support required. Integration with agricultural extension services for optimal placement design. Can be implemented at individual farm level without external coordination.
Operation and maintenance	Installation before snowfall season (October-November). Annual repair or reconstruction of barriers. Removal or incorporation of organic barriers (straw) into soil in spring. Minimal ongoing maintenance during winter. Total labor requirement: 2-4 person-days per hectare annually.
Endorsement by experts	Recommended by Barayev Grain Research Institute. Endorsed in regional agricultural development programs for Kostanay and Akmola oblasts.
Adequacy for current and future climate	Highly appropriate for current and projected climate. Addresses increasing wind erosion due to reduced snow cover duration. Compensates for declining spring precipitation. Enhances resilience to drought conditions during critical crop establishment phase.

Scale/Size of beneficiaries group	Potential coverage: 10+ million hectares of dryland grain production. Primary beneficiaries: wheat farmers in northern regions. Suitable for farms of all sizes from 50 ha to 10,000+ ha.
Disadvantages	Labor-intensive installation. May impede mechanized operations in spring. Effectiveness depends on wind patterns and snow characteristics. Not effective in areas with very low snowfall. May harbour pests or diseases if organic materials used.
Capital costs	$100-300 per hectare for initial installation. Straw barriers: $100-150/ha. Wooden slat fences: $200-300/ha. Annual maintenance: $10-20/ha.
Lifetime	1-3 years (annual reconstruction for straw barriers); 10-15 years for permanent wooden structures
Reduction of vulnerability to climate change	Increases available soil moisture by 15-25% at planting. Reduces crop failure risk during dry springs. Improves germination rates by 10-20%. Stabilizes yields in variable precipitation years.
Economic benefits	Increased yields by 10-20% in drought years; reduced crop failure risk; lower irrigation costs where applicable; minimal investment with significant returns in dry years
Social benefits	Community cooperation opportunities; preservation of traditional knowledge; reduced rural-urban migration through improved farm viability; food security enhancement
Environmental benefits	Reduces wind erosion and dust storms. Protects soil organic matter. Improves microclimate for beneficial soil organisms. No chemical inputs required.
Barriers to implementation	Labor availability during installation period. Competition for straw resources (livestock feed, bedding). Lack of awareness among some farmers. Climate change reducing snow reliability in some areas.
Opportunities	Low cost enables widespread adoption. Can be combined with other conservation practices. Potential for mechanized installation systems. Integration with cover crop strategies.
Market potential	Primary relevance in northern grain regions. Potential: 5-10 million hectares. Current adoption: approximately 2 million hectares.
Status	Traditional practice with renewed interest due to climate variability. Active promotion by regional agricultural departments.
Timeframe for implementation	Immediate implementation possible

Acceptability to local stakeholders	High acceptance in traditional grain-farming communities. Farmers familiar with practice from Soviet-era agricultural systems. Knowledge transfer from experienced farmers to younger generation needed.

Technology 3: Conservation Agriculture (No-Till/Crop Rotation)

Section	Content
Sector	Agriculture
Introduction	Conservation agriculture is a farming system based on three interconnected principles: minimal mechanical soil disturbance (no-till or reduced tillage), permanent soil cover with crop residues or cover crops, and diversified crop rotations. Kazakhstan has become a global leader in no-till adoption, with over 3 million hectares under this system. The technology is particularly suited to Kazakhstan's extensive dryland grain production, where it addresses wind erosion, moisture conservation, and soil degradation while reducing fuel costs and labor requirements.
Technology characteristics/highlights	• Eliminates or minimizes tillage operations • Maintains crop residue cover (>30% soil coverage) • Implements diverse crop rotations (wheat-legumes-oilseeds) • Reduces fuel consumption by 50-70% • Improves soil structure and water infiltration over time
Institutional and organizational requirements	Requires access to specialized seeding equipment (no-till drills). Extension services for training on residue management and weed control. Research support for crop rotation optimization. Farmer-to-farmer learning networks important for knowledge transfer.
Operation and maintenance	Shift from tillage to herbicide-based weed management. Careful calibration and maintenance of no-till seeders. Residue management to ensure uniform distribution. Monitoring of soil compaction and pest/disease dynamics. Integration with integrated pest management practices.
Endorsement by experts	Strongly recommended by FAO, ICARDA, and CIMMYT. Endorsed in Kazakhstan's National Agricultural Development Concept. Supported by Barayev Research Institute and leading agricultural universities.
Adequacy for current and future climate	Highly effective for current and projected climate conditions. Improves soil water storage critical for drought resilience. Reduces soil temperature extremes. Enhances carbon sequestration contributing to climate mitigation. Builds adaptive capacity through improved soil health.
Scale/Size of beneficiaries group	Current adoption: 3.2 million hectares (2023). Potential: 15+ million hectares of arable land. Benefits farms of all sizes but

	economies of scale favor larger operations. Primary regions: Kostanay, Akmola, North Kazakhstan, Pavlodar.
Disadvantages	Initial yield decline possible in first 2-3 years during transition. Increased reliance on herbicides raising resistance concerns. Higher equipment costs for no-till seeders. Requires fundamental change in farming mindset and practices. Pest and disease management more complex.
Capital costs	$50-150 per hectare for equipment (distributed over equipment life). No-till seeder: $80,000-200,000 (serves 2,000-5,000 ha). Transition period costs (yield reduction, learning): $25-50/ha/year for 2-3 years.
Lifetime	Ongoing practice; equipment lifetime 15-20 years; soil benefits accumulate over 5-10+ years
Reduction of vulnerability to climate change	Increases plant available water by 20-40mm. Reduces yield variability by 15-25% in drought years. Improves soil resilience to extreme weather. Provides stable foundation for long-term productivity.
Economic benefits	Reduced fuel and machinery costs by 30-50%; lower input costs over time; stabilized yields reducing income variability; potential carbon credit revenue; improved land value
Social benefits	Reduced workload and farming stress; improved work conditions (less dust); knowledge sharing among farmers; enhanced food security; rural employment stability
Environmental benefits	Carbon sequestration: 0.3-0.5 tCO2/ha/year. Reduced wind erosion by 80-90%. Improved biodiversity in soil biota. Lower fuel consumption and GHG emissions. Enhanced water quality through reduced runoff.
Barriers to implementation	High cost of specialized equipment. Knowledge and skills gaps. Herbicide availability and cost. Mindset change from traditional tillage farming. Need for long-term commitment (5+ years to see full benefits).
Opportunities	Growing farmer networks sharing experience. Government subsidy programs for equipment. Carbon credit potential under Article 6 mechanisms. Export markets valuing sustainable production. Research and demonstration farm support.
Market potential	National potential covering majority of grain production area. Strong growth trajectory with 10-15% annual expansion. Kazakhstan positioned as regional leader attracting international interest.

Status	Rapidly expanding with strong government and farmer support. Active research and extension programs. International recognition as success story.
Timeframe for implementation	Medium term (3-5 years for full transition benefits)
Acceptability to local stakeholders	High and growing acceptance among progressive farmers. Success stories driving adoption. Farmer organizations actively promoting. Some resistance from traditional farmers and equipment dealers.

Technology 4: Climate-Smart Soil Management (Mulching/Biochar/Compost)

Section	Content
Sector	Agriculture
Introduction	Climate-smart soil management encompasses a suite of practices designed to improve soil organic matter, water retention, and nutrient cycling while building resilience to climate variability. Key practices include organic mulching, biochar application, and composting. These technologies address soil degradation affecting over 75% of Kazakhstan's agricultural land. The integration of organic amendments helps restore soil fertility degraded by intensive Soviet-era agriculture while adapting to increasing temperatures and erratic precipitation patterns.
Technology characteristics/highlights	• Multiple practice options adaptable to local conditions • Builds soil organic carbon over time • Improves water holding capacity by 10-25% • Reduces need for synthetic fertilizers • Can utilize agricultural waste products
Institutional and organizational requirements	Coordination with waste management for organic material sourcing. Training on composting techniques and application rates. Laboratory support for soil testing. Integration with fertilizer subsidy programs.
Operation and maintenance	Compost production requires ongoing management (turning, moisture, C:N ratio). Biochar production needs specialized equipment or purchasing. Mulch application timing and distribution. Annual or biennial applications typically needed. Soil testing to monitor improvements.
Endorsement by experts	Recommended by IPCC as climate mitigation strategy. Endorsed by FAO and World Bank climate-smart agriculture programs. Supported by Kazakhstan's soil science institutes.
Adequacy for current and future climate	Highly appropriate for addressing soil degradation under climate stress. Improves drought resilience through enhanced water retention. Reduces soil temperature extremes protecting root systems. Long-term carbon storage contributing to NDC targets.
Scale/Size of beneficiaries group	Applicable to all 24 million hectares of arable land. Priority for degraded soils in grain and cotton regions. Benefits all farm sizes with scalable practices. Particular value for irrigated vegetable and fruit production.
Disadvantages	High labor requirements for compost production. Limited availability of organic materials in some regions. Biochar

	production technology not widely available. Slow visible results (2-5 years for soil improvement). Potential for weed seed introduction if compost improperly prepared.
Capital costs	Composting: $150-400/ha initial setup, $30-60/ha annual application. Biochar: $200-500/ha for application (purchased). Mulching: $50-100/ha annually depending on materials. Soil testing: $20-50/ha annually.
Lifetime	Ongoing practice; biochar effects persist 50-100+ years; compost benefits 1-3 years per application
Reduction of vulnerability to climate change	Increases drought tolerance through improved water retention. Reduces crop stress during heat waves. Stabilizes yields under variable conditions. Builds long-term soil resilience.
Economic benefits	Reduced fertilizer requirements by 20-30%; increased crop yields 10-25%; potential premium prices for organic products; reduced irrigation needs; long-term soil asset value increase
Social benefits	Employment in composting operations; community waste management benefits; knowledge transfer and capacity building; improved nutrition through better crop quality
Environmental benefits	Carbon sequestration: 0.5-2 tCO2/ha/year depending on practice. Improved nutrient cycling reducing fertilizer runoff. Enhanced soil biodiversity. Reduced waste through recycling agricultural residues. Lower N2O emissions from improved nitrogen management.
Barriers to implementation	Knowledge gaps on proper techniques. Labor and time requirements. Material sourcing and transport costs. Slow return on investment. Competition for crop residues (livestock, conservation agriculture).
Opportunities	Growing organic market demand. Carbon credit programs. Integration with livestock systems (manure management). Municipal organic waste utilization. Climate finance opportunities.
Market potential	Applicable nationwide with priority in areas of severe soil degradation. Growing organic agriculture sector creating demand. Export market premiums for sustainable production.
Status	Limited current adoption, mostly on demonstration farms. Growing interest from progressive farmers. Research programs active in several regions.
Timeframe for implementation	Medium term (3-5 years for visible soil improvements)

Acceptability to local stakeholders	Moderate acceptance with growing awareness. Traditional knowledge of composting in some communities. Biochar relatively unknown requiring demonstration. Interest growing among younger farmers and organic producers.

Technology 5: Saline Soil Reclamation (Gypsum/Halophytes)

Section	Content
Sector	Agriculture
Introduction	Soil salinization affects approximately 30% of irrigated land in Kazakhstan, particularly in the Aral Sea region and southern irrigation zones. Restoration technologies combine chemical amendments (gypsum application) with biological approaches (halophyte cultivation) to reclaim degraded land for agricultural production. Climate change is exacerbating salinization through increased evapotranspiration and changes in water availability, making restoration technologies increasingly critical for maintaining agricultural productivity.
Technology characteristics/highlights	• Combines chemical (gypsum) and biological (halophyte) approaches • Addresses severe degradation limiting agricultural productivity • Requires 3-5 years for full land restoration • Can restore land to productive use • Halophytes provide additional economic value (fodder, bioenergy)
Institutional and organizational requirements	Coordination with land reclamation agencies. Technical support from soil science institutes. Access to gypsum supplies (mining operations). Research on suitable halophyte species. Drainage infrastructure in some cases.
Operation and maintenance	Gypsum application typically 2-10 t/ha depending on salinity level. Leaching irrigation to remove displaced sodium. Halophyte establishment and management. Monitoring of soil salinity levels. Gradual transition to conventional crops over 3-5 years.
Endorsement by experts	Recommended by ICBA (International Center for Biosaline Agriculture). Endorsed by Kazakh Research Institute of Soil Science. Supported in National Land Reclamation Program.
Adequacy for current and future climate	Essential for adapting to increasing salinization pressures. Restores land productivity under water-stressed conditions. Some halophytes highly drought tolerant. Prevents permanent loss of agricultural land.
Scale/Size of beneficiaries group	Priority area: 1.5 million hectares of moderately to severely salinized land. Concentrated in Kyzylorda, Turkestan, and Almaty regions. Benefits medium to large farms in irrigation zones. Potential to restore abandoned agricultural land.

Disadvantages	High initial costs for severely affected land. Requires reliable water supply for leaching. Gypsum transport costs significant in remote areas. Long restoration timeline. Halophytes may have limited markets. Risk of re-salinization without proper management.
Capital costs	Gypsum application: $100-500/ha depending on severity. Drainage improvement: $200-2,000/ha if required. Halophyte establishment: $50-200/ha. Total restoration program: $350-2,500/ha over 3-5 years.
Lifetime	5-10 years for initial restoration; ongoing maintenance required; halophyte plantings 3-5 years
Reduction of vulnerability to climate change	Prevents permanent land loss to salinization. Restores productive capacity of degraded areas. Halophytes provide drought-resilient fodder source. Improves long-term food security.
Economic benefits	Restoration of previously unproductive land; new income from halophyte products (fodder, seeds); increased land value; diversified farm income
Social benefits	Recovery of abandoned communities; employment in restoration activities; improved livelihoods in degraded areas; intergenerational land stewardship
Environmental benefits	Prevents desertification and land degradation. Restores ecosystem services. Some halophytes support biodiversity. Can sequester carbon in restored soils. Reduces dust storms from abandoned saline land.
Barriers to implementation	High costs for severe salinization. Limited gypsum supply and high transport costs. Lack of drainage infrastructure. Long investment horizon discouraging private investment. Limited halophyte markets.
Opportunities	Land degradation neutrality commitments under UNCCD. Climate finance for adaptation. Halophyte products (seeds, fodder, biofuel). Integration with Aral Sea restoration programs. Carbon credits from restored land.
Market potential	Primary focus: Kyzylorda, Turkestan regions. Potential restoration: 500,000+ ha over 10 years. Critical for maintaining irrigated agriculture area.
Status	Limited current implementation. Several pilot projects in Kyzylorda region. Research programs on halophyte species ongoing.
Timeframe for implementation	Long term (5-10 years for full restoration)

Acceptability to local stakeholders	Acceptance growing as salinization worsens. Farmers recognize need but discouraged by costs and timeline. Government programs needed for widespread adoption. Community-level approaches showing promise.

Technology 6: Rainwater Harvesting (Ponds/Reservoirs)

Section	Content
Sector	Agriculture
Introduction	Rainwater harvesting systems capture and store precipitation for agricultural use during dry periods. Technologies range from simple farm ponds to lined reservoirs with advanced filtration. This approach is increasingly relevant for Kazakhstan as climate change alters precipitation patterns, concentrating rainfall in fewer, more intense events. Farm-scale water storage enables supplementary irrigation during critical crop growth stages, significantly reducing climate vulnerability in semi-arid regions.
Technology characteristics/highlights	• Captures rainfall and snowmelt runoff • Provides supplementary irrigation during dry spells • Can be integrated with drip irrigation systems • Scale ranges from 500 m^3 to 50,000+ m^3 • Enables crop diversification through water availability
Institutional and organizational requirements	Permits for water storage may be required. Coordination with local water authorities. Technical design support for larger systems. Integration with agricultural extension services. Land use planning considerations.
Operation and maintenance	Regular inspection of embankments and linings. Sediment removal every 3-5 years. Pump and pipeline maintenance. Water quality monitoring. Vegetation management on embankments.
Endorsement by experts	Recommended by FAO water management programs. Endorsed in National Water Strategy. Supported by regional water committees.
Adequacy for current and future climate	Highly appropriate for adapting to changing precipitation patterns. Buffers against drought and dry spells. Captures intense rainfall events. Enables production stability under climate variability.
Scale/Size of beneficiaries group	Potential in all agricultural regions receiving 250+ mm annual precipitation. Priority regions: Almaty, East Kazakhstan, Kostanay (eastern). Benefits individual farms and farm clusters. Suitable for smallholders with group systems.
Disadvantages	Significant land requirement for storage. High construction costs for lined systems. Evaporation losses in hot climate (10-20% annually). May require regular maintenance. Site-specific design needs. Water rights and allocation considerations.

Capital costs	Simple earth dam pond: $500-1,200/unit (5,000-10,000 m³). Lined reservoir: $1,500-3,000/unit. Full system with pumping: $2,500-5,000/unit. Cost per hectare served: $400-800 depending on scale.
Lifetime	20-30 years for earthen structures with proper maintenance; lined ponds 15-20 years
Reduction of vulnerability to climate change	Provides water security during dry periods. Enables 20-50% yield improvement through supplementary irrigation. Reduces crop failure risk. Stabilizes income in variable climate years.
Economic benefits	Reduced irrigation costs; supplemental income from aquaculture potential; increased cropping intensity; drought risk mitigation preserving farm income
Social benefits	Community water security; multiple-use benefits (domestic, livestock, irrigation); reduced conflicts over water access; improved sanitation potential
Environmental benefits	Reduces flood runoff and erosion. Recharges local groundwater. Creates habitat for wildlife and aquatic species. Can be integrated with agroforestry.
Barriers to implementation	High initial investment. Land requirements. Technical expertise for design. Evaporation losses. Potential conflicts over water rights. Maintenance requirements.
Opportunities	Growing water scarcity increasing value. Government infrastructure programs. Climate finance mechanisms. Integration with irrigation modernization. Multipurpose use (livestock, aquaculture).
Market potential	Applicable to 3-5 million hectares in suitable rainfall zones. Growing interest among farmers facing water shortages. Potential for cluster/community systems.
Status	Growing adoption with government support. Numerous new installations in recent years. Demonstration projects expanding.
Timeframe for implementation	Short to medium term (1-2 years for construction)
Acceptability to local stakeholders	High acceptance where water scarcity recognized. Traditional knowledge of water harvesting in some regions. Growing demand among farmers experiencing drought impacts.

Technology 7: Drought-Resistant Feed Production/Conservation

Section	Content
Sector	Agriculture
Introduction	Drought-resistant fodder production involves cultivating forage species adapted to limited water availability, including improved varieties of traditional crops (alfalfa, sainfoin) and introduced species (sorghum, sudan grass). This technology addresses the critical challenge of livestock feed security in Kazakhstan's pastoral and semi-arid zones. Climate change is increasing drought frequency and severity, making traditional pastures and rain-fed fodder production increasingly unreliable.
Technology characteristics/highlights	• Utilizes drought-tolerant species and varieties • Requires 30-50% less water than conventional fodder crops • Maintains productivity under water stress conditions • Can include both annual and perennial species • Supports livestock production in marginal areas
Institutional and organizational requirements	Access to improved seed varieties through research institutes. Extension service support for species selection and management. Seed multiplication and distribution systems. Integration with livestock development programs.
Operation and maintenance	Appropriate species selection for local conditions. Proper establishment practices for perennials. Rotational harvest management. Fertilization based on soil tests. Stand renovation every 5-8 years for perennials.
Endorsement by experts	Recommended by Kazakh Livestock Research Institute. Endorsed by FAO grassland management programs. Supported in National Livestock Development Program.
Adequacy for current and future climate	Specifically designed for drought conditions. Improves resilience to increasing aridity. Reduces livestock vulnerability to feed shortages. Enables sustainable production under climate stress.
Scale/Size of beneficiaries group	Relevant for 8+ million hectares of fodder production. Benefits both smallholder livestock keepers and large farms. Priority regions: central and western Kazakhstan. Critical for pastoral communities.
Disadvantages	Seed availability limited for some species. May require establishment period (2-3 years for perennials). Lower palatability of some drought-tolerant species. May not achieve

	yields of irrigated fodder in normal years. Limited local experience with some introduced species.
Capital costs	Seed costs: $80-200/ha depending on species. Establishment costs: $40-250/ha including tillage and planting. Total establishment: $120-450/ha. Annual maintenance: $25-45/ha.
Lifetime	Perennial varieties 5-10 years; annual varieties require yearly replanting; irrigation infrastructure 10-15 years
Reduction of vulnerability to climate change	Maintains fodder production during drought (40-60% yield retention). Reduces need for emergency feed purchases. Enables stable livestock numbers. Protects herder livelihoods during climate extremes.
Economic benefits	Reduced feed purchase costs by 30-50%; improved livestock weight gain and milk production; decreased livestock mortality during droughts; more stable farm income
Social benefits	Livestock keeper livelihood security; reduced distress sales of animals; community feed banks potential; women's involvement in fodder management
Environmental benefits	Reduces overgrazing pressure on natural pastures. Improves soil cover and reduces erosion. Some species fix nitrogen improving soil fertility. Supports pasture restoration goals.
Barriers to implementation	Limited availability of improved seed. Knowledge gaps on new species management. Initial establishment costs. Perception that drought-tolerant means lower quality. Seed certification and distribution systems.
Opportunities	Growing feed security concerns driving demand. Research programs developing adapted varieties. Integration with pasture restoration programs. Climate finance for resilient agriculture.
Market potential	National potential across all livestock regions. Growing commercial fodder production sector. Strong farmer demand for reliable feed sources.
Status	Expanding adoption with research institute support. Several successful demonstration programs. Seed production capacity building underway.
Timeframe for implementation	Short to medium term (1-3 years for establishment)
Acceptability to local stakeholders	Moderate to high acceptance as drought impacts increase. Traditional knowledge of some drought-tolerant species. Growing openness to new varieties and approaches.

Technology 8: GPS-Based Rotational Grazing Systems

Section	Content
Sector	Agriculture
Introduction	GPS-based rotational grazing combines traditional rotational grazing principles with modern positioning technology to optimize pasture use and recovery. GPS-enabled virtual fencing and livestock tracking enable precise management of grazing patterns, preventing overgrazing while maximizing sustainable productivity. This technology addresses pasture degradation affecting approximately 70% of Kazakhstan's 182 million hectares of pastureland, which is being exacerbated by climate change-induced vegetation stress.
Technology characteristics/highlights	• Uses GPS collars/ear tags for livestock tracking • Virtual fencing reduces infrastructure costs • Enables adaptive grazing based on vegetation condition • Supports large-scale pastoral operations • Data-driven decision making for herd management
Institutional and organizational requirements	Mobile network or satellite connectivity for data transmission. Technical support for equipment setup and maintenance. Training on system operation and interpretation. Integration with pasture monitoring systems (remote sensing).
Operation and maintenance	GPS device battery replacement/charging (solar options available). Data management and analysis. Virtual fence boundary adjustments. Integration with regular herd management practices. Software updates and system maintenance.
Endorsement by experts	Recommended by international rangeland management experts. Emerging technology with growing research support. Aligned with Kazakhstan's digitalization agenda.
Adequacy for current and future climate	Enables adaptive management responding to climate variability. Protects vegetation during drought periods. Optimizes use of patchy rainfall patterns. Supports pasture recovery and resilience building.
Scale/Size of beneficiaries group	Primarily suitable for large pastoral operations (1,000+ head). Potential application on 50+ million hectares. Benefits both private ranches and community pastures. May be adapted for medium-sized operations through cost sharing.
Disadvantages	High technology costs limiting smallholder access. Requires reliable connectivity (challenge in remote areas). Technical

	complexity for traditional herders. Animal welfare concerns with some virtual fence systems. Limited local experience and support infrastructure.
Capital costs	GPS collars/tags: $50-200 per head. Virtual fence system: $5,000-20,000 for base station. Software/subscription: $500-2,000 annually. Per hectare cost depends on herd density: typically, $0.50-2.00/ha/year.
Lifetime	GPS equipment 5-7 years; fencing infrastructure 15-20 years; water points 20+ years
Reduction of vulnerability to climate change	Prevents overgrazing that compounds climate impacts. Enables rapid response to drought conditions. Maintains pasture productivity under stress. Protects long-term productive capacity.
Economic benefits	Improved livestock productivity by 15-25%; reduced supplemental feeding costs; potential for increased stocking rates; labor efficiency gains
Social benefits	Reduced herding labor; improved working conditions; knowledge modernization; youth engagement through technology; conflict reduction over grazing areas
Environmental benefits	Reduces pasture degradation and desertification. Improves carbon sequestration in grasslands. Supports biodiversity in well-managed pastures. Reduces soil erosion and dust storms.
Barriers to implementation	High initial costs. Technology literacy requirements. Limited connectivity in remote areas. Resistance from traditional herders. Lack of local service providers. Concerns about surveillance and data privacy.
Opportunities	Digital agriculture development programs. Smart farming initiatives. Carbon credit programs for improved pasture management. Integration with livestock traceability systems. Demonstration projects building experience.
Market potential	Primarily for commercial ranching sector initially. Growing interest from progressive pastoralists. Potential scaling through cost reduction and shared systems.
Status	Early adoption stage with pilot projects. Several demonstration programs in operation. Growing research and development activity.
Timeframe for implementation	Medium term (2-4 years for widespread adoption)
Acceptability to local stakeholders	Low to moderate initially due to costs and complexity. Growing interest among younger, tech-savvy farmers. Demonstration of

	benefits important for scaling. Traditional herders may prefer conventional approaches.

Technology 9: Integrated Livestock Hydration and Shade Systems

Section	Content
Sector	Agriculture
Introduction	Livestock water and shade infrastructure provides cattle, sheep, and other animals with reliable access to drinking water and protection from heat stress. As temperatures rise due to climate change, heat-related livestock productivity losses and mortality are increasing across Kazakhstan's pasture lands. Infrastructure includes wells with solar pumps, water troughs, shade structures (artificial and planted), and windbreaks. These investments maintain animal welfare and productivity under increasingly challenging conditions.
Technology characteristics/highlights	• Solar-powered water pumping systems • Strategically located water points for pasture management • Artificial shade structures for intensive operations • Tree/shrub plantings for natural shade and windbreaks • Combined water/shade rest areas for livestock
Institutional and organizational requirements	Coordination with land use planning. Permits for well drilling. Extension support for system design. Integration with pasture infrastructure programs. Community agreements for shared infrastructure.
Operation and maintenance	Regular pump and solar panel maintenance. Water trough cleaning and repair. Shade structure upkeep. Tree/shrub maintenance and protection. Well monitoring and water quality testing.
Endorsement by experts	Recommended by FAO and OIE animal welfare guidelines. Endorsed in National Livestock Development Program. Supported by veterinary services.
Adequacy for current and future climate	Directly addresses increasing heat stress from climate change. Critical for maintaining production under warming conditions. Enables continued pasture use during hot periods. Essential adaptation for livestock sector.
Scale/Size of beneficiaries group	Relevant for all 7+ million cattle and 18+ million sheep in Kazakhstan. Priority for southern and central regions with highest temperatures. Benefits all livestock producers from smallholders to large ranches.
Disadvantages	Infrastructure costs can be high. Water point placement affects grazing patterns (can cause localized degradation). Maintenance requirements in remote locations. Tree establishment difficult in

	arid conditions. Shade structures may obstruct livestock movement.
Capital costs	Solar pump and well: $3,000-8,000 per unit. Water trough: $200-500 per unit. Artificial shade structure: $50-150 per animal capacity. Tree planting: $200-400/ha. Per animal cost varies: $20-100 depending on system.
Lifetime	20-30 years for concrete water points; 15-20 years for shade structures with maintenance
Reduction of vulnerability to climate change	Reduces heat-related productivity losses (5-15% improvement). Prevents heat-related mortality during extreme events. Enables grazing use of more distant pastures. Maintains body condition and reproduction rates.
Economic benefits	Reduced livestock mortality (2-5% improvement); increased milk production by 10-15%; improved weight gain; reduced veterinary costs from heat-related illness
Social benefits	Improved animal welfare; reduced workload for water transport; community gathering points; better working conditions for livestock keepers
Environmental benefits	Improved pasture distribution reduces localized degradation. Tree plantings provide carbon sequestration. Shade trees support biodiversity. Solar pumping reduces fossil fuel use.
Barriers to implementation	Initial investment costs. Remote location access challenges. Water availability limitations in some areas. Technical skills for maintenance. Community coordination for shared infrastructure.
Opportunities	Growing recognition of climate impacts on livestock. Government infrastructure programs. Solar technology cost reductions. Integration with pasture improvement programs. Carbon and ecosystem service payments.
Market potential	National need across all livestock regions. Priority for hot, arid zones. Strong potential for scaling with appropriate financing.
Status	Growing implementation with government support. Various programs installing water points. Shade infrastructure less common but increasing.
Timeframe for implementation	Short to medium term (1-3 years for installation)
Acceptability to local stakeholders	High acceptance for water infrastructure. Moderate acceptance for shade structures (perception of cost vs. benefit). Growing appreciation as heat events intensify.

Technology 10: Agroforestry for Erosion Control and Soil Protection

Section	Content
Sector	Agriculture
Introduction	Agroforestry integrates trees and shrubs with crop and livestock systems to provide multiple benefits including erosion control, microclimate improvement, and diversified production. In Kazakhstan, windbreaks (shelterbelts) and silvopastoral systems address severe wind erosion affecting millions of hectares. Historical shelterbelt systems from the Soviet era have largely degraded, while climate change is intensifying wind erosion through increased drought frequency and intensity. Agroforestry restoration and expansion is a priority adaptation strategy.
Technology characteristics/highlights	• Multiple configurations: shelterbelts, silvopasture, alley cropping • Provides windbreak protection for 15-20x tree height distance • Diversifies farm income (timber, fruits, nuts) • Improves microclimate for crops and livestock • Long-term carbon sequestration
Institutional and organizational requirements	Forestry sector coordination for tree species selection. Nursery capacity for seedling production. Extension services for design and establishment. Land tenure considerations for long-term investment. Water access for establishment period.
Operation and maintenance	Tree planting and protection during establishment (2-5 years). Pruning and thinning for optimal growth. Replacement of failed trees. Integration with crop/livestock management. Fire protection measures.
Endorsement by experts	Strongly recommended by FAO and World Bank. Endorsed in National Forest Program. Supported by agricultural research institutes. Aligned with UNCCD Land Degradation Neutrality targets.
Adequacy for current and future climate	Highly appropriate for addressing climate-related erosion increase. Improves crop resilience through microclimate benefits. Provides climate mitigation through carbon sequestration. Long-term adaptation investment.
Scale/Size of beneficiaries group	Priority for 10+ million hectares affected by wind erosion. Potential integration with 5+ million hectares of cropland. Benefits all farm sizes with appropriate designs. Community-level approaches for landscape impact.

Disadvantages	Long establishment period (5-10 years for full protection). Competition for water during establishment. Land removed from production for tree rows. Initial investment with delayed returns. Management complexity compared to monoculture. Some pest/disease risks.
Capital costs	Seedling production and planting: $200-450/ha of protected area. Establishment costs (irrigation, protection): $150-300/ha. Total establishment: $350-750/ha. Annual maintenance: $25-50/ha.
Lifetime	30-50+ years for established shelterbelts; full protection benefits achieved after 10-15 years
Reduction of vulnerability to climate change	Reduces wind speed by 40-60% in protected zone. Increases crop yields 15-25% through reduced wind damage. Protects livestock from weather extremes. Stabilizes agricultural production over long term.
Economic benefits	Diversified income from tree products (timber, fruits, nuts); 15-25% crop yield improvement in protected zones; potential carbon credit revenue; increased property value
Social benefits	Long-term community asset creation; employment in nurseries and planting; improved microclimate for communities; aesthetic and recreational value
Environmental benefits	Soil erosion reduction by 60-90%. Carbon sequestration: 2-5 tCO2/ha/year in tree biomass. Biodiversity habitat creation. Improved water infiltration. Dust storm reduction.
Barriers to implementation	Long investment horizon discouraging adoption. Water requirements for establishment. Limited nursery capacity. Land tenure uncertainties. Lack of extension support in some regions. Livestock damage to young trees.
Opportunities	Land degradation neutrality commitments. Carbon market potential. Restoration of historical shelterbelts. Diversification of farm income. Climate finance mechanisms. Integration with crop production subsidies.
Market potential	Critical national priority covering millions of hectares. Growing policy support. Increasing farmer awareness of erosion impacts.
Status	Active government programs for shelterbelt restoration. Research on suitable species ongoing. Several large-scale projects in implementation.
Timeframe for implementation	Long term (5-15 years for full benefits)

Acceptability to local stakeholders	Moderate acceptance growing with erosion impacts. Appreciation of historical shelterbelts. Concerns about water use and land competition. Younger farmers more receptive to diversification.

Technology 11: Transition to Winter Crops

Section	Content
Sector	Agriculture
Introduction	Transition from spring to winter crops (particularly winter wheat) takes advantage of autumn soil moisture and cooler temperatures for establishment, allowing crops to develop deeper root systems before summer drought stress. Winter crops mature earlier, escaping the hottest and driest period of the growing season. Climate change is making this adaptation increasingly attractive in northern Kazakhstan, where warmer winters improve winter crop survival while hotter summers increase spring crop stress.
Technology characteristics/highlights	• Utilizes autumn moisture for crop establishment • Earlier maturity escapes late-season drought • Higher yield potential in favourable years (15-25% over spring wheat) • Requires cold-tolerant varieties adapted to local conditions • Lower summer water requirements
Institutional and organizational requirements	Access to suitable winter wheat varieties. Seed multiplication and distribution systems. Extension services for management practices. Crop insurance adjustments for new risk profile. Weather forecasting for planting decisions.
Operation and maintenance	Timely autumn planting (late August-September). Snow retention practices for winter protection. Spring monitoring of stand survival. Adjusted fertilization and pest management timing. Earlier harvest logistics.
Endorsement by experts	Recommended by Barayev Grain Research Institute. Endorsed in National Agricultural Development Concept. Supported by climate adaptation strategies. Proven success in pilot programs.
Adequacy for current and future climate	Specifically designed as climate adaptation strategy. Addresses shifting growing season patterns. Reduces exposure to increasingly severe summer drought. Takes advantage of warming winter temperatures.
Scale/Size of beneficiaries group	Primary potential: 3-5 million hectares in northern grain regions. Benefits medium to large grain farms. Geographic expansion northward as winters warm. Already significant in Kostanay and Aktobe regions.
Disadvantages	Risk of winterkill in severe winters. Requires careful variety selection. Changed equipment and labor timing. Market

	preferences may favor spring wheat quality. Learning curve for new management practices. Weather uncertainty at planting time.
Capital costs	Minimal additional capital required. Seed costs similar to spring wheat. May require earlier combine availability. Possible storage adjustments for earlier harvest. Net cost: $30-80/ha for transition.
Lifetime	Ongoing practice; requires annual seed purchase; specialized equipment 15-20 years
Reduction of vulnerability to climate change	Reduces summer drought exposure. Stabilizes yields in climate variable years. Spreads production risk across seasons. Improves food security through yield stability.
Economic benefits	Reduced competition for harvest labor and equipment; diversified income timing; potentially higher prices for off-season products; reduced drought exposure
Social benefits	More stable employment throughout year; diversified food sources; reduced seasonal income stress; knowledge diversification for farmers
Environmental benefits	Better soil cover reducing wind erosion. Reduced tillage opportunity through early establishment. Lower fuel use from fewer spring operations. Supports soil organic matter through living roots.
Barriers to implementation	Winterkill risk (managed through variety choice and snow retention). Farmer experience and traditions. Seed availability for adapted varieties. Insurance and credit system adjustments. Market acceptance of winter wheat quality.
Opportunities	Climate trend favouring expansion. Demonstrated yield advantages. Government breeding program investments. Growing farmer experience base. Export market opportunities.
Market potential	Significant expansion potential in northern regions. Current area: approximately 1 million hectares. Target potential: 3-5 million hectares by 2030.
Status	Rapidly expanding with strong research support. Successful farmer adoption in suitable zones. New varieties continuously released.
Timeframe for implementation	Short term (immediate implementation)
Acceptability to local stakeholders	High and growing acceptance as benefits demonstrated. Successful farmer experiences driving adoption. Some regional concerns about winterkill remain. Generally positive trajectory.

Technology 12: Livestock Cooling and Heat Stress Reduction

Section	Content
Sector	Agriculture
Introduction	Livestock cooling technologies address heat stress that reduces milk production, weight gain, reproduction, and can cause mortality during extreme heat events. Systems include evaporative cooling (fans with misters), shade structures, and management practices adjusting feeding and activity timing. Climate change projections indicate significant increases in heat stress days across Kazakhstan's livestock regions, making cooling technologies increasingly essential for maintaining productivity and animal welfare.
Technology characteristics/highlights	• Multiple technology options for different scales and systems • Evaporative cooling highly effective in dry climates • Can be integrated with existing barn infrastructure • Management practices complement technological solutions • Particularly critical for dairy operations
Institutional and organizational requirements	Extension services for system design and operation. Veterinary guidance on heat stress indicators. Electricity supply for powered systems. Water supply for evaporative cooling. Integration with dairy development programs.
Operation and maintenance	Regular cleaning of cooling systems to prevent mineral buildup. Fan and pump maintenance. Monitoring of animal comfort indicators. Water and electricity consumption management. System operation during heat events.
Endorsement by experts	Recommended by FAO and dairy industry guidelines. Endorsed by veterinary services. Supported in livestock development programs. International best practices adapted for local conditions.
Adequacy for current and future climate	Directly addresses increasing heat stress from climate change. Essential for maintaining productivity as temperatures rise. Critical for dairy sector viability. Prevents acute losses during heat waves.
Scale/Size of beneficiaries group	Priority for intensive dairy operations (0.5+ million dairy cattle). Relevant for feedlot operations. Benefits both large commercial and medium family farms. Geographic priority: southern and central regions.
Disadvantages	High capital and operating costs. Electricity requirements for powered systems. Water consumption for evaporative cooling.

	Technical complexity for small-scale farmers. May not be viable for extensive pastoral systems.
Capital costs	Evaporative cooling system: $400-800/animal capacity. Fan systems: $200-400/animal capacity. Shade structures: $50-150/animal capacity. Total system per dairy cow: $500-1,000.
Lifetime	10-15 years for cooling infrastructure; fans and misters 5-10 years; ventilation systems 15-20 years
Reduction of vulnerability to climate change	Maintains milk production during heat events (prevents 10-30% losses). Reduces heat-related mortality risk. Preserves reproduction rates. Protects farmer income during heat waves.
Economic benefits	Maintained milk production during heat waves (15-25% improvement); reduced mortality; improved reproduction rates; better feed conversion efficiency
Social benefits	Improved working conditions in livestock facilities; reduced stress during heat waves; animal welfare improvements; modern skill development
Environmental benefits	Maintains production efficiency reducing emissions intensity. Improves animal welfare. Efficient cooling systems minimize energy use. Water can be recycled in some systems.
Barriers to implementation	High investment costs. Energy costs and availability. Water availability in some regions. Technical knowledge requirements. Low priority perception among some farmers. Infrastructure limitations.
Opportunities	Growing recognition of heat stress impacts. Dairy sector modernization programs. Energy efficiency improvements. Climate finance for adaptation. Insurance incentives for heat stress management.
Market potential	Priority for commercial dairy sector. Growing relevance for beef feedlots. Increasing demand as heat events intensify.
Status	Limited adoption primarily in commercial dairy operations. Growing awareness and interest. Demonstration projects expanding.
Timeframe for implementation	Short to medium term (1-3 years for installation)
Acceptability to local stakeholders	Moderate acceptance, limited by cost awareness. High acceptance among modern dairy operations. Growing interest as heat impacts recognized. Cost-benefit demonstration needed for scaling.

Annex 2. Scoring and Decision Matrices for MCA

Table Performance Matrix

Performance matrix									
	Cost		Benefits						
			Economic		Social	Environmental	Climatic	Institutional and organizational	
	Capital expenditure $/ha	Operating and maintenance costs, $/ha	Job Creation	Potential to increase farm income and investment opportunities	Gender equality and social inclusion	Preservation and increase of soil fertility (Humus content, %)	Contribution to reducing vulnerability to climate change impacts	Ease of implementation	Alignment with national adaptation and sustainable development priorities
Drip irrigation systems	2500	180	8	9	6	7	9	5	8
Snow retention structures	150	15	2	3	3	6	6	8	6
Conservatiion Agriculture (No-Till/Crop Rotation)	80	25	4	6	5	9	7	7	9
Climate-Smart Soil Management	200	45	5	4	4	9	7	5	7
Saline soil reclamation (gypsum/halophytes)	350	60	2	5	4	8	5	5	7
Rainwater harvesting (ponds/reservoirs)	1800	40	7	7	6	6	7	3	7
Drought-resistant feed production/conservation	120	30	3	6	6	5	6	8	7
GPS-based Rotational Grazing Systems	450	55	1	4	5	7	6	6	5
Livestock Watering Infrastructure and Mobile Shade Structures	380	50	2	3	4	3	5	6	6
Agroforestry for Erosion Control and Soil Protection	400	35	7	4	5	9	8	5	9
Transition to winter crops	50	20	1	3	4	5	8	8	7
Livestock cooling and heat stress reduction	**1200**	**150**	**2**	**4**	**3**	**3**	**6**	**6**	**5**
Preferred value (H-high, L-Low)	**L**	**L**	**H**	**H**	**H**	**H**	**H**	**H**	**H**

Table Scoring Matrix (Normalized 0-100)

	Scoring Matrix								
	Cost		Benefits						
			Economic		Social	Environmental	Climatic	Institutional	
	Capital expenditure $/ha	Operating and maintenance costs, $/ha	Job Creation	Potential to increase farm income and investment opportunities	Gender equality and social inclusion	Preservation and increase of soil fertility (Humus content, %)	Contribution to reducing vulnerability to climate change impacts	Ease of implementation	Alignment with national adaptation and sustainable development priorities
Drip irrigation systems	0	0	100	100	100	67	100	40	75
Snow retention structures	96	100	14	0	0	50	25	100	25
Conservatiion Agriculture (No-Till/Crop Rotation)	99	94	43	50	67	100	50	80	100
Climate-Smart Soil Management (mulch/biochar/compost)	94	82	57	17	33	100	50	40	50
Saline soil reclamation (gypsum/halophytes)	88	73	14	33	33	83	0	40	50
Rainwater harvesting (ponds/reservoirs)	29	85	86	67	100	50	50	0	50
Drought-resistant feed production/conservation	97	91	29	50	100	33	25	100	50
GPS-based Rotational Grazing Systems	84	76	0	17	67	67	25	60	0
Livestock Watering Infrastructure and Mobile Shade Structures	87	79	14	0	33	0	0	60	25
Agroforestry for Erosion Control and Soil Protection	86	88	86	17	67	100	75	40	100
Transition to winter crops	100	97	0	0	33	33	75	100	50
Livestock cooling and heat stress reduction	53	18	14	17	0	0	25	60	0
Criterion weight	**19**	**8**	**10**	**12**	**5**	**15**	**15**	**9**	**7**

Table Decision Matrix

	Cost		Benefits							Total	Ranking
			Economic		Social	Environmental	Climatic	Institutional and organizational			
	Capital expenditure $/ha	Operating and maintenance costs, $/ha	Job Creation	Potential to increase farm income and investment opportunities	Gender equality and social inclusion	Preservation and increase of soil fertility (Humus content, %)	Contribution to reducing vulnerability to climate change impacts	Ease of implementation	Alignment with national adaptation and sustainable development priorities		
Drip irrigation systems	0	0	1000	1200	500	1000	1500	360	525	6085	4
Snow retention structures	1822	800	143	0	0	750	375	900	175	4965	8
Conservatiion Agriculture (No-Till/Crop Rotation)	1877	752	429	600	333	1500	750	720	700	7660	1
Climate-Smart Soil Management (mulch/biochar/compost)	1784	655	571	200	167	1500	750	360	350	6336	3
Saline soil reclamation (gypsum/halophytes)	1667	582	143	400	167	1250	0	360	350	4919	9
Rainwater harvesting (ponds/reservoirs)	543	679	857	800	500	750	750	0	350	5229	7
Drought-resistant feed production/conservation	1846	727	286	600	500	500	375	900	350	6084	5
GPS-based Rotational Grazing Systems	1590	606	0	200	333	1000	375	540	0	4644	10
Livestock Watering Infrastructure and Mobile Shade Structures	1644	630	143	0	167	0	0	540	175	3299	11
Agroforestry for Erosion Control and Soil Protection	1629	703	857	200	333	1500	1125	360	700	7407	2
Transition to winter crops	1900	776	0	0	167	500	1125	900	350	5717	6
Livestock cooling and heat stress reduction	1008	145	143	200	0	0	375	540	0	2411	12
Criterion weight	19	8	10	12	5	15	15	9	7	100	

Annex 3. Sensitivity Analysis

Case A. Climate and Environmental Scenario

	Cost		Benefits							Total	Ranking
			Economic		Social	Environmental	Climatic	Institutional and organizational			
	Capital expenditure $/ha	Operating and maintenance costs, $/ha	Job Creation	Potential to increase farm income and investment opportunities	Gender equality and social inclusion	Preservation and increase of soil fertility (Humus content, %)	Contribution to reducing vulnerability to climate change impacts	Ease of implementation	Alignment with national adaptation and sustainable development priorities		
Drip irrigation systems	0	0	1000	1000	300	1333	2000	280	375	6288	4
Snow retention structures	1727	700	143	0	0	1000	500	700	125	4894	8
Conservatiion Agriculture (No-Till/Crop Rotation)	1778	658	429	500	200	2000	1000	560	500	7624	2
Climate-Smart Soil Management (mulch/biochar/compost)	1690	573	571	167	100	2000	1000	280	250	6631	3
Saline soil reclamation (gypsum/halophytes)	1580	509	143	333	100	1667	0	280	250	4862	9
Rainwater harvesting (ponds/reservoirs)	514	594	857	667	300	1000	1000	0	250	5182	7
Drought-resistant feed production/conservation	1749	636	286	500	300	667	500	700	250	5587	6
GPS-based Rotational Grazing Systems	1506	530	0	167	200	1333	500	420	0	4656	10
Livestock Watering Infrastructure and Mobile Shade Structures	1558	552	143	0	100	0	0	420	125	2897	11
Agroforestry for Erosion Control and Soil Protection	1543	615	857	167	200	2000	1500	280	500	7662	1
Transition to winter crops	1800	679	0	0	100	667	1500	700	250	5695	5
Livestock cooling and heat stress reduction	955	127	143	167	0	0	500	420	0	2312	12
Criterion weight	18	7	10	10	3	20	20	7	5		

Case B. Economy Scenario

	Cost		Benefits								
			Economic		Social	Environmental	Climatic	Institutional and organizational		Total	Ranking
	Capital expenditure $/ha	Operating and maintenance costs, $/ha	Job Creation	Potential to increase farm income and investment opportunities	Gender equality and social inclusion	Preservation and increase of soil fertility (Humus content, %)	Contribution to reducing vulnerability to climate change impacts	Ease of implementation	Alignment with national adaptation and sustainable development priorities		
Drip irrigation systems	0	0	1000	1200	300	800	1000	280	450	5030	10
Snow retention structures	1918	2000	143	0	0	600	250	700	150	5761	6
Conservatiion Agriculture (No-Till/Crop Rotation)	1976	1879	429	600	200	1200	500	560	600	7943	1
Climate-Smart Soil Management (mulch/biochar/compost)	1878	1636	571	200	100	1200	500	280	300	6665	3
Saline soil reclamation (gypsum/halophytes)	1755	1455	143	400	100	1000	0	280	300	5433	8
Rainwater harvesting (ponds/reservoirs)	571	1697	857	800	300	600	500	0	300	5626	7
Drought-resistant feed production/conservation	1943	1818	286	600	300	400	250	700	300	6597	4
GPS-based Rotational Grazing Systems	1673	1515	0	200	200	800	250	420	0	5059	9
Livestock Watering Infrastructure and Mobile Shade Structures	1731	1576	143	0	100	0	0	420	150	4119	11
Agroforestry for Erosion Control and Soil Protection	1714	1758	857	200	200	1200	750	280	600	7559	2
Transition to winter crops	2000	1939	0	0	100	400	750	700	300	6189	5
Livestock cooling and heat stress reduction	1061	364	143	200	0	0	250	420	0	2438	12
Criterion weight	20	20	10	12	3	12	10	7	6		

Case C. Equal Criteria Scenario

	Cost		Benefits								
			Economic		Social	Environmental	Climatic	Institutional and organizational		Total	Ranking
	Capital expenditure $/ha	Operating and maintenance costs, $/ha	Job Creation	Potential to increase farm income and investment opportunities	Gender equality and social inclusion	Preservation and increase of soil fertility (Humus content, %)	Contribution to reducing vulnerability to climate change impacts	Ease of implementation	Alignment with national adaptation and sustainable development priorities		
Drip irrigation systems	0	0	1100	1100	1100	733	1100	440	825	6398	3
Snow retention structures	1055	1100	157	0	0	550	275	1100	275	4512	9
Conservatiion Agriculture (No-Till/Crop Rotation)	1087	1033	471	550	733	1100	550	880	1100	7505	1
Climate-Smart Soil Management (mulch/biochar/compost)	1033	900	629	183	367	1100	550	440	550	5751	5
Saline soil reclamation (gypsum/halophytes)	965	800	157	367	367	917	0	440	550	4562	8
Rainwater harvesting (ponds/reservoirs)	314	933	943	733	1100	550	550	0	550	5674	6
Drought-resistant feed production/conservation	1069	1000	314	550	1100	367	275	1100	550	6325	4
GPS-based Rotational Grazing Systems	920	833	0	183	733	733	275	660	0	4339	10
Livestock Watering Infrastructure and Mobile Shade Structures	952	867	157	0	367	0	0	660	275	3277	11
Agroforestry for Erosion Control and Soil Protection	943	967	943	183	733	1100	825	440	1100	7234	2
Transition to winter crops	1100	1067	0	0	367	367	825	1100	550	5375	7
Livestock cooling and heat stress reduction	584	200	157	183	0	0	275	660	0	2059	12
Criterion weight	11	11	11	11	11	11	11	11	11		

Annex 4. Working Group in Agriculture

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10	**Vadim Lopukhin**	President of the Association of Organic Agriculture in Kazakhstan
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12	**Vladimir Oleshchenko**	CEO BIRCH PRIVATE COMPANY (https://birch.green/)
13	**Alibek Saimov**	Head of LLP "Soil Solutions"
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