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Supply Chain Resilience and Sustainable Food Systems: Comparative
Insights from Kazakhstan and Uzbekistan

School of Water, Energy and Environment
Food Systems and Management

MSc
Academic Year: 2024 - 2025

Supervisor: Theresa Mercer
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ACADEMIC INTEGRITY DECLARATION

I declare that:

- the thesis submitted has been written by me alone.
- the thesis submitted has not been previously submitted to this university or any other.
- that all content, including primary and/or secondary data, is true to the best of my knowledge.
- that all quotations and references have been duly acknowledged according to the requirements of academic research.

I understand that to knowingly submit work in violation of the above statement will be considered by examiners as academic misconduct.

ABSTRACT

This thesis explores how supply chain resilience affects the possibility of sustainable food systems in Kazakhstan and Uzbekistan. Drawing from policy analysis and expert interviews, the study examines risks, barriers, and enabling factors for food security in two landlocked economies affected by climate change. Particular attention is given to institutional responses toward irrigation management, border and trade corridor reliability and post-harvest logistics, which remain key chokepoints for regional agri-food systems. The study also highlights how the quality of governance, subsidy policy and design, and digitalisation initiatives affect predictability in supply chains, often more than resource endowment itself. While both countries have committed to ambitious agricultural reform programs, significant gaps remain between strategic vision and implementation. The study argues that improving cross-border coordination, infrastructure services, and smallholder inclusion is necessary for more sustainable and resilient food systems. By placing these dynamics into the context of food security and agricultural policy reforms, which are already of concern to Central Asian governments, the study will also generate evidence relevant to national reform agendas and regional cooperation.

Keywords:

Food security, Supply chain resilience, Resilient food systems, Central Asia agriculture, Kazakhstan food systems, Uzbekistan food systems

Word count: 7380 words

ACKNOWLEDGEMENTS

I would like to express special gratitude to the British Council Women in STEM Scholarship for fully funding my studies and allowing me to pursue my long-held dream of studying in the UK as a master's student.

Huge thanks to my parents for their love and unwavering support. To my lovely son, Khamza: despite our time apart, he waited with patience and resilience. I hope to be a good role model for him, showing that it's never too late to achieve your dream if you work hard.

I am grateful to my supervisor, Dr Theresa Mercer, for her guidance and support throughout this journey. I also thank all the amazing tutors at Cranfield University for the lessons, creative approaches, and the experience they shared with us.

Heartfelt appreciation to my interview respondents, who kindly agreed to take part in the research and shared their valuable expert opinions, bringing a more diverse picture to this study.

Finally, I thank all my international friends at Cranfield, who surrounded me with help, guidance, and many warm memories.

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LIST OF ABBREVIATIONS

ADB – Asian Development Bank

AIC – Agro-Industrial Complex (Kazakhstan)

CIRAD – Centre de coopération internationale en recherche agronomique pour le développement

FAO – Food and Agriculture Organization of the United Nations

GCF – Green Climate Fund

GDP – Gross Domestic Product

HLPE – High Level Panel of Experts on Food Security and Nutrition (Committee on World Food Security)

ICT – Information and Communication Technology

IFAD – International Fund for Agricultural Development

IFI – International Financial Institution

IFPRI – International Food Policy Research Institute

JICA – Japan International Cooperation Agency

OECD – Organisation for Economic Co-operation and Development

O&M - Operations & maintenance

SDG – Sustainable Development Goal

SLI - Service-level indicator

SME – Small and Medium-sized Enterprise

SPS – Sanitary and Phytosanitary

UNDP – United Nations Development Programme

UNECE - United Nations Economic Commission for Europe

WDI – World Development Indicators (World Bank)

1 INTRODUCTION

1.1 Background and motivation

Food systems are increasingly vulnerable to multiple disruptions as a result of climate change, pandemics, geopolitical shocks and economic instability (FAO, 2021; HLPE, 2020; Kc *et al.*, 2024). A substantial portion of this institutional weakness stems from the lack of sufficient funding and policy coordination, which invariably undermines the strategy implementation efforts (Iyappan & Babu, 2018; OECD, 2021). Central Asia is highly relevant in the context of these socioeconomic and environmental processes (FAO, 2020; FAO & CIRAD, 2023; Mirzabaev, 2018; Wang *et al.*, 2022). Kazakhstan and Uzbekistan are underrepresented in the international scholarly literature (Babu & Blom, 2014; Dupouy & Gurinovic, 2020). Kazakhstan's grain sector is crucial for the regional wheat markets' stability, while Uzbekistan's agricultural industry is more diversified due to the rapidly developing horticulture industry (FAO & CIRAD, 2023; Zhenskhan *et al.*, 2022). Both inherited system-wide characteristics from the Soviet period, which potentially constrain their ability to deliver infrastructure-related services (Burkitbayeva *et al.*, 2020; Lerman & Sedik, 2018).

Against this background, the study adopts the following working definitions: Sustainable food systems strive to ensure food availability, accessibility, and quality while safeguarding environmental, social, and economic aspects for current and future generations (FAO, 2021). Food system resilience is the capacity to absorb, adapt and transform in response to shocks and long-term stresses (HLPE, 2020; Tendall *et al.*, 2015; Kc *et al.*, 2024). Within this frame, supply chain resilience is treated as the operational dimension concerned with maintaining continuous flows and services under stress, with an emphasis on the predictability of key chokepoints. In this study, the relevant stresses are timing-related, including irrigation scheduling, rail-wagon availability, border and laboratory clearance, and payment cycles.

1.2 Context and problem framing: Kazakhstan and Uzbekistan

Figure 1 summarises seven indicators for Kazakhstan and Uzbekistan. Kazakhstan records higher access to safely managed drinking water and higher assessed food-safety capacity, relies far less on irrigation, and experiences lower measured water stress. Agriculture represents a smaller share of GDP, and the overall population is smaller. Uzbekistan is more irrigation-dependent and more water-stressed, and agriculture contributes a larger share of GDP. Food-supply variability is higher for Kazakhstan.

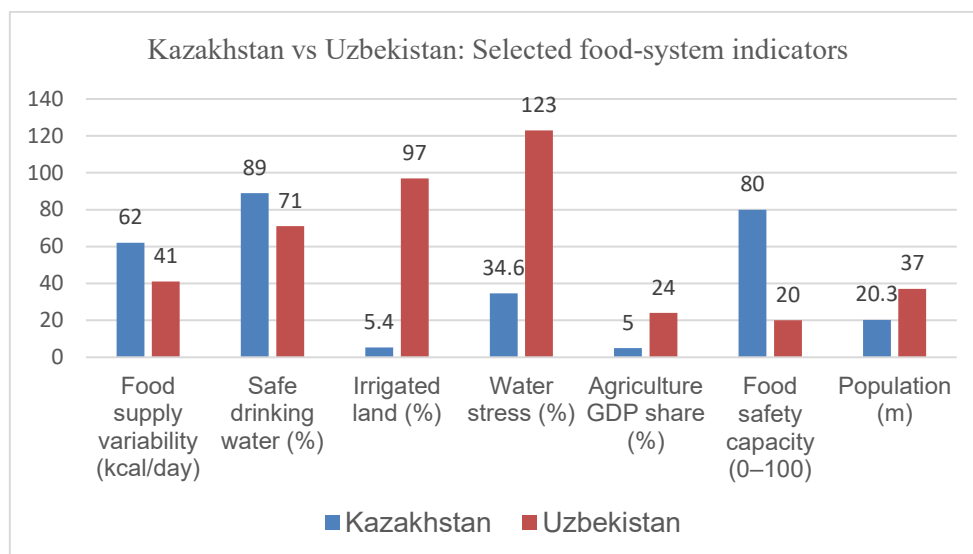


Figure 1. Kazakhstan vs Uzbekistan: selected food-system indicators (latest year, 2023–2025). Sources: Food Systems Dashboard; World Bank WDI/JMP. More details in Appendix B (Table B-1).

These differences help to understand where the pressure is concentrated. Kazakhstan’s largely rain-fed steppe agriculture ties performance to a small number of long rail corridors and border nodes, so slowdowns at these points can quickly propagate through prices and cash flow (Shmelev *et al.*, 2021). Uzbekistan’s denser, irrigated agriculture has profited from horticulture expansion. Yet, water allocation in the Syr and Amu Darya basins sets firm limits, as well as upstream choices affecting downstream results (UNECE, 2017; Wang *et al.*, 2022). Policy intent appears strong, with high-level goals such as digitalisation and technology adoption being a priority (ADB, 2019; OECD, 2021; UNDP, 2021). However, implementation at lower levels is often uneven and slow. In practice, supply chains broadly do well enough in normal years and then experience severe, asymmetric delays in stressed years.

1.3 Mechanisms: barriers and enabling conditions

Recent shocks, including COVID-19, the war in Ukraine and episodes of extreme weather, have highlighted both resilient features and weak seams in global and regional supply chains (FAO, 2021; OECD, 2025; Soujanya *et al.*, 2023). In Kazakhstan and Uzbekistan, several mechanisms recur:

- **Coordination and governance:** Siloed mandates, blurred responsibilities and limited cross-sector planning tend to slow crisis response and discourage longer-term investment. Subsidy programmes may concentrate benefits among larger actors (Burkitbayeva *et al.*, 2020; Lerman & Sedik, 2018; OECD, 2021).
- **Infrastructure and logistics:** Cold storage, rural roads and transport capacity often lag demand. Kazakhstan’s cold storage averages about 1,050 m³ per 100,000

people, with Uzbekistan lower still, which offers limited scope to bridge price troughs or buffer slower transit windows (FAO & CIRAD, 2023).

- Risk finance and inclusion. Access to credit, insurance and advisory services is uneven. Smaller producers, including many women and young farmers, are more likely to encounter gaps that reduce their capacity to adjust during disruptions (ADB, 2019; FAO, 2025).
- Knowledge and digitalisation. Traceability, e-certification and early warning tools can reduce uncertainty and assist rerouting. Uptake is mediated by cost, skills and connectivity, constraints that are often most evident outside major centres in Uzbekistan (FAO & CIRAD, 2023; OECD, 2025).
- Market and trade exposure. Kazakhstan's reliance on Russian transit and Uzbekistan's partial regional integration make supply chains vulnerable to changing border regulations and corridor bottlenecks (OECD, 2021; World Bank, 2023).
- Environment and water. Drought, temperature extremes and the governance of shared rivers add uncertainties that are difficult to hedge with purely national instruments (Kummu *et al.*, 2021; Wang *et al.*, 2022; World Bank, 2016).

The literature proposes a familiar set of enabling conditions: diversification of inputs, crops and markets; targeted digital tools that demonstrably shift behaviour, such as usable traceability, functioning early warning and credible water accounting; strengthened public–private collaboration; and regionally coordinated risk-sharing where incentives align (FAO, 2021; OECD, 2025; Soujanya *et al.*, 2023; World Bank, 2023). What remains less well specified is how such measures translate into timing outcomes at specific nodes. Do irrigation rotations become more predictable, do wagons arrive when scheduled, and are border or laboratory clearances steadier week to week? A further question is which options are likely to be feasible under current institutional and fiscal constraints rather than under ideal conditions.

1.4 Aim and research questions

Aim: To explain how supply-chain resilience can be strengthened in Kazakhstan and Uzbekistan by identifying the most consequential bottlenecks and the most plausible enabling measures in context.

Research questions:

- **RQ1:** What are the main risks and vulnerabilities facing the food supply chains of Kazakhstan and Uzbekistan, and how have institutions responded to recent shocks and disruptions?
- **RQ2:** What are the key barriers and enablers to strengthening the resilience of Kazakhstan and Uzbekistan's agri-food systems?

- **RQ3:** How can policies and regional cooperation make food systems more sustainable and resilient?

1.5 Research positioning and contribution

Debates on resilience are extensive, yet many frameworks assume capacities that are more typical of high-income settings and may fit imperfectly in transition economies (Candel *et al.*, 2025). Efficiency and resilience also continue to trade off in practice. Just-in-time arrangements can perform well in steady conditions but are vulnerable to cascading delays; by contrast, building redundancy imposes costs that smaller firms may struggle to carry (Béné, 2016; HLPE, 2020; Soujanya *et al.*, 2023). In Central Asia, empirically grounded, practitioner-aware work remains limited, and side-by-side comparisons between policy goals and operational experience are still uncommon (Burkitbayeva *et al.*, 2020; FAO & CIRAD, 2023; Mirzabaev, 2018). This thesis addresses that gap by combining policy analysis with expert interviews. The empirical contribution is to pinpoint where timing variability arises and to assess the plausibility of proposed fixes under current constraints. The conceptual contribution is to treat resilience as variance reduction at critical nodes, which redirects attention from adding capacity everywhere to securing predictability where it matters most. The policy contribution is a short, prioritised set of actions, technical, organisational and regional, intended to reduce variability for SMEs and smallholders in the near term while complementing longer-run reforms.

1.6 Thesis structure

Chapter 2 details the methodology, including data collection, analysis, and the associated limitations. Chapter 3 presents the results from policy documents and expert interviews, organised by theme and supply-chain node. Chapter 4 discusses and interprets the findings against the three research questions, with implications for national policy and regional cooperation. Chapter 5 concludes with a summary of the findings and provides recommendations for further research and implementation.

2 METHODS

This chapter explains how evidence was gathered and analysed to address the research questions on food supply-chain resilience in Kazakhstan and Uzbekistan. It sets out the research design, study area, data sources and collection, analytical procedures, ethical safeguards, measures to support rigour, and limitations. The aim is transparency and replicability in how policy and practice perspectives were triangulated.

2.1 Study area: Kazakhstan and Uzbekistan

The research focuses on Kazakhstan and Uzbekistan, Central Asia's two largest agricultural economies. Both are landlocked and shaped by continental climate variability, with agricultural production concentrated in distinct zones: Kazakhstan's northern steppe is dominated by large-scale rain-fed cereals, while Uzbekistan's agriculture relies heavily on irrigated lands along the Syr Darya and Amu Darya basins (Figure 2). These differences influence supply chain structures, infrastructure needs, and exposure to climate and market risks.

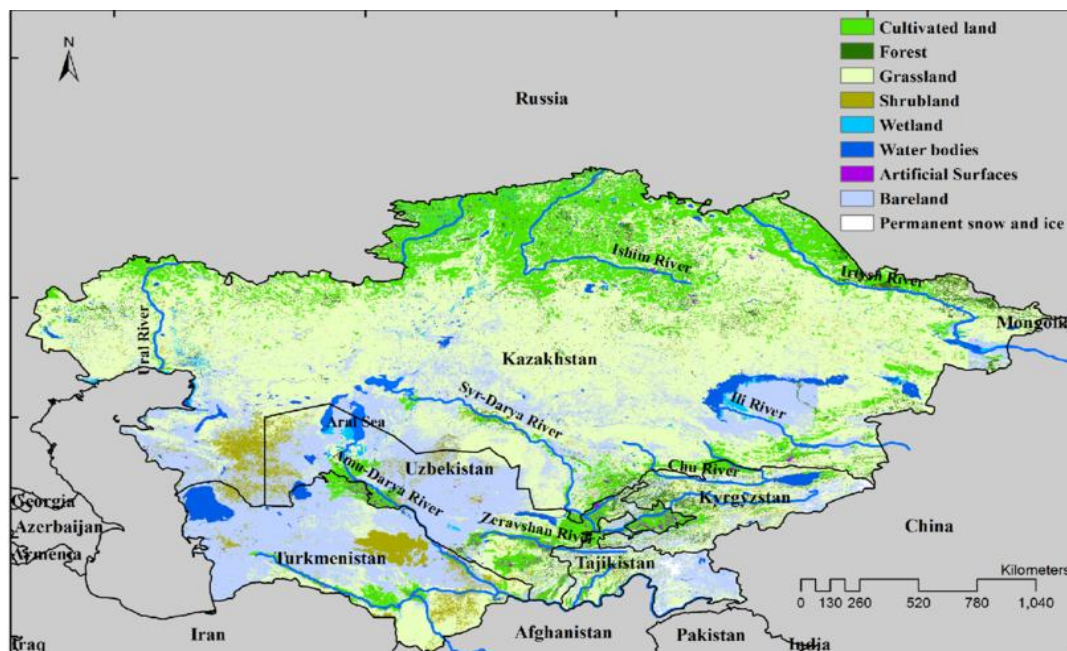


Figure 2. Study area: land cover and rivers in Central Asia. Rain-fed cropland dominates northern Kazakhstan, while irrigated oases cluster along the Syr and Amu Darya Rivers in Uzbekistan, shaping the contrasting risk profiles analysed in this thesis (Zhou et al, 2021).

2.2 Research design and rationale

The study uses a qualitative, comparative case study research design to explore how food system resilience is conceptualized and operationalized in two institutionally independent settings in close geographic proximity (Yin, 2018). Evidence was obtained from two sources:

1. Policy and strategy documents, which outline the expected narratives, policy instruments, and responsibilities.
2. Semi-structured expert interviews, which highlight practice-oriented perspectives on risks, responses and enabling or constraining factors.

This combination ensured that data obtained from one source could be used to validate the data collected from other sources, thereby reducing dependence on a single source (Lincoln & Guba, 1985).

2.3 Data sources and collection

2.3.1 Expert interviews

Semi-structured interviews were utilised to obtain expert insights into the supply chain risks, recent disruptions and institutional responses, as well as operational constraints. Purposive sampling targeted individuals holding analytical and managerial positions with direct experience in the agri-food systems (Patton, 2015). Fifteen individuals were contacted, and five agreed to participate. The number is modest but adequate for expert interviews considering the study's narrow scope and targeted sample, which aligns with relatively high information power (Malterud *et al.*, 2016). The respondents were from international, national, and regional organizations, the private sector, and academia (Table 1).

Table 1. Interview Respondent Overview

Code	Sector	Affiliation / Description
R1	International	World Bank
R2	National government	Ministry of Agriculture of Kazakhstan
R3	Regional organization	Islamic Organization for Food Security (IOFS)
R4	Academia	Australian National University
R5	Private sector	Aitas Holding (Kazakhstan)

Participants were identified through the author's professional networks and a targeted LinkedIn search by institution and experience. Each participant received an information sheet and a consent form. Due to workload, time zone differences, and seniority, the interviews were conducted asynchronously via e-mail. The interview guide covered five

broad areas: risks, shocks, institutional responses, barriers and enablers, and cooperation. This format facilitated a considered approach to responses, produced an immediate verbatim record, and allowed access to relevant documentation as required (Kallio *et al.*, 2016; Meho, 2006). The written exchanges were exported into NVivo 14 for analysis. Only minor typographical errors were corrected to ensure grammatical sense without changing the meaning. Appendix C presents one complete interview schedule as an example. All interviews followed the same thematic guide, with respondent-specific probes tailored to sector, role, and seniority.

While asynchronous e-mail interviews might be viewed as less dynamic than synchronous ones, they offered several advantages (Meho, 2006). In this particular study, first, the format respected the fact that respondents were senior and extremely busy, often working across different time zones. This reduced the risk of non-response and enabled the participation of experts who would otherwise be inaccessible. Second, it allowed respondents to take time to consult internal sources and data before providing answers, which enhanced the quality of responses as compared to an interview session. For example, some respondents submitted additional links to reports as part of their answers. Third, the verbatim written record reduced the risk of transcription errors and enabled immediate input into NVivo for coding. While the lack of conversational probing and spontaneity limited the method, the depth, precision, and documentation of responses made it appropriate for technical issues like agri-food system resilience.

2.3.2 Policy and strategy documents

The documentary analysis identified the strategic priorities, policy instruments, and official narratives for supply chain resilience, allowing for a comparison of these stated policy intentions with practitioners' perspectives. To be included, a document needed to:

- i. Be an official policy, strategy, law or other type of concept paper and action plan, as well as ministerial/IFI technical reports
- ii. Focus on agri-food systems or supply chains/food security/resilience
- iii. Be currently in force or published between 2019 and 2025
- iv. Be in Russian or English.

The retrieval process involved targeted searches of both countries' Ministry of Agriculture websites and systematic searches of IFI and UN agency repositories and citation tracking from publications, with a final search update conducted in August 2025. The official legislation database of Kazakhstan (adilet.zan.kz) was also used to find the relevant documents. Eight documents (five from Kazakhstan and three from Uzbekistan) met the criteria. The imbalance may reflect differences in public accessibility as much as variation in actual policy activity. For ease of reference, documents are cited in the text by short names (e.g., KZ1 for the 2021 Concept for the Development of the Agro-Industrial Complex of Kazakhstan; Appendix D).

2.3.3 Language considerations

Most policy and strategy sources (six of eight) and one interview (R5) were in Russian. Analysis and coding were conducted in the source language to retain legal and institutional nuance. Quotations were translated into English and cross-checked against the original; where a technical or legal term might be contested, the transliterated Russian term is provided on first use. Potential minor loss of meaning is acknowledged in the Limitations section.

2.4 Data processing and analysis

2.4.1 Analytical approach

The analysis used a hybrid deductive–inductive thematic approach in NVivo 14 (Braun & Clarke, 2006; Fereday & Muir-Cochrane, 2006). A framework matrix facilitated structured cross-case comparison (Gale *et al.*, 2013). Deductive parent codes reflected the main analytical domains described above, while inductive coding captured additional subthemes emerging from the data (Figure 3).



Figure 3. Sunburst diagram illustrating themes from policy documents and interviews, with parent codes in the inner ring and subcodes in the outer ring. Overlapping themes are merged to highlight areas where perspectives on food system resilience in Kazakhstan and Uzbekistan converge, while still indicating differences in emphasis between sources.

2.4.2 Coding procedures and integration

The analysis involved five steps. All interviews and policy documents were read in full, and reflexive memos noted initial patterns, contradictions and supply chain touchpoints. Second, the theory-informed codebook (domains) was piloted on a small subset of data, and open coding was employed to identify emerging subthemes and refine inclusion/exclusion criteria. Third, nodes were merged or renamed in cases where they seemed to overlap or lacked clarity and consistency. Labels were accordingly standardised, and decision rules (accompanied by short exemplars) were assigned to each node. Fourth, interviews and policy documents were coded separately (as distinct projects) in NVivo 14 but with overlapping codes where excerpts cut across themes; analytic memos synthesised emerging mechanisms, implementation gaps, and cross-

country differences. The integrated dataset in NVivo was then output to Excel as a series of framework-style matrices (cases/documents x domains) designed to facilitate comparison between policy and practitioner perspectives. The analysis followed the steps of data analysis as described by Gale *et al.* (2013), Miles *et al.* (2014), and Saldaña (2021).

Credibility and dependability were ensured through triangulation of policy documents and expert interviews, a documented audit trail (search logs, inclusion criteria, codebook versions), code–recode checks with explicit decision rules, supervisor debriefs and verified translations of quotations (Denzin, 1978; Jick, 1979; Lincoln & Guba, 1985). To explore the relationships between different codes, a hierarchical cluster analysis was completed in NVivo (Appendix F).

2.5 Ethical considerations and data management

Ethical approval was obtained from Cranfield University Research Ethics System (CURES) before data collection (Appendix A). All participants received information sheets and gave informed consent. Institutional affiliations are listed with participant consent; personal identifiers are not disclosed. Anonymisation was assured as a prerequisite for participation, and withdrawal was possible at any time without consequence. Given the use of e-mail, participants were advised of transmission risks; correspondence was stored on encrypted, access-restricted university systems in line with data-protection policy.

2.6 Limitations

Several limitations should be acknowledged. Although interview participants were experts in their sectors, perspectives from stakeholder groups such as NGOs, farmer organizations and downstream market actors were under-represented. Interviews were conducted asynchronously by email, which may have favoured participants more comfortable with written rather than verbal communication, potentially affecting how the issues were articulated (Harvey, 2011; Meho, 2006).

The policy document sample is also somewhat skewed toward Kazakhstan (five documents versus three for Uzbekistan) due to greater public availability, which may increase attention to Kazakhstani dynamics. A study with a small-N sample and expert perspectives risks over-emphasising institutional standpoints. A single researcher performed the coding, creating a risk of misclassification, but code–recode checks and supervisor debriefs were used to enhance consistency. However, a second coder might have interpreted some passages differently (Lincoln & Guba, 1985; O'Connor & Joffe, 2020).

All texts were coded in their original language, and the accuracy of quote translations was checked against the source, but some nuances may nevertheless have been lost. While the author is a Kazakh national with professional experience in a regional food security

organisation, Uzbekistan is less familiar (language, the socio-economic context, and specialised government web resources), which may have caused some imbalance in analysis between the two cases. To address these risks, mitigation steps included triangulation of document types, maintenance of an audit trail, and code–recode checks with supervisor debriefs; even so, some residual bias may remain.

3 RESULTS

This chapter presents the main findings from the document analysis and expert interviews, relating to the three research questions, and highlights key linkages across themes. Because several codes span more than one question, Figure 4 summarises the distribution of thematic coverage across RQ1–RQ3. The qualitative subcode RQ mapping and the underlying coding counts are provided in Appendix E.

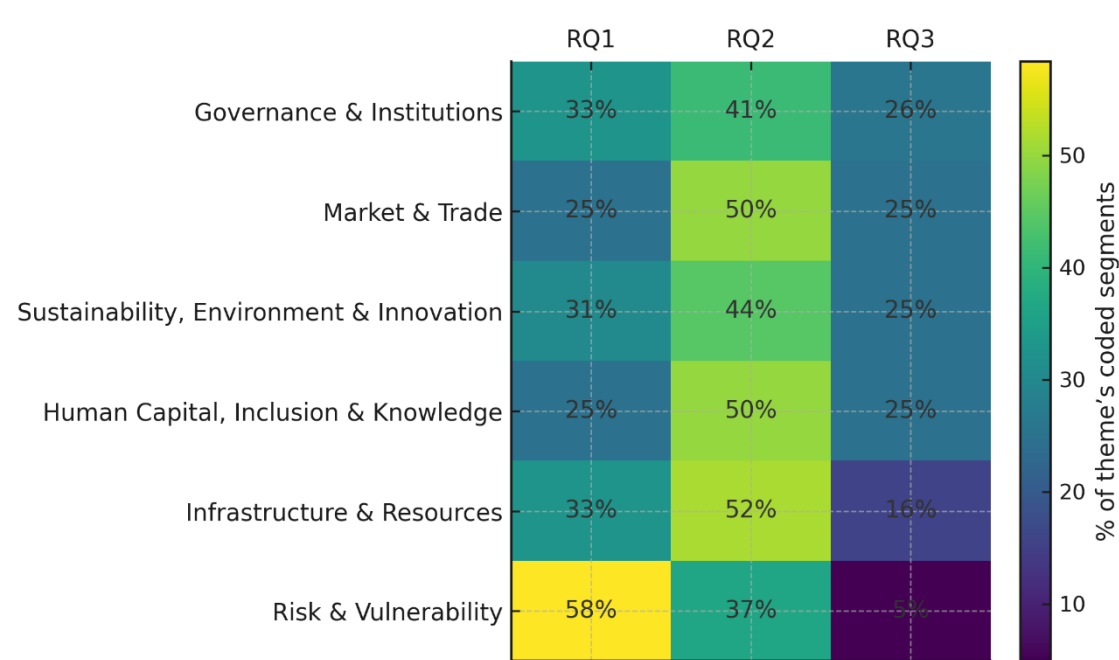


Figure 4. Theme coverage by research question. Cells show the share (%) of each theme mapped to RQ1–RQ3; rows sum to 100%. Source: NVivo 14; author’s calculation.

The six themes are discussed in sequence, starting with those that are most frequently referenced in the NVivo coding. This ordering reflects the relative prominence of each theme in the dataset rather than any judgement of importance. A tree map (Figure 5) is provided to help visualise the distribution of references across themes.

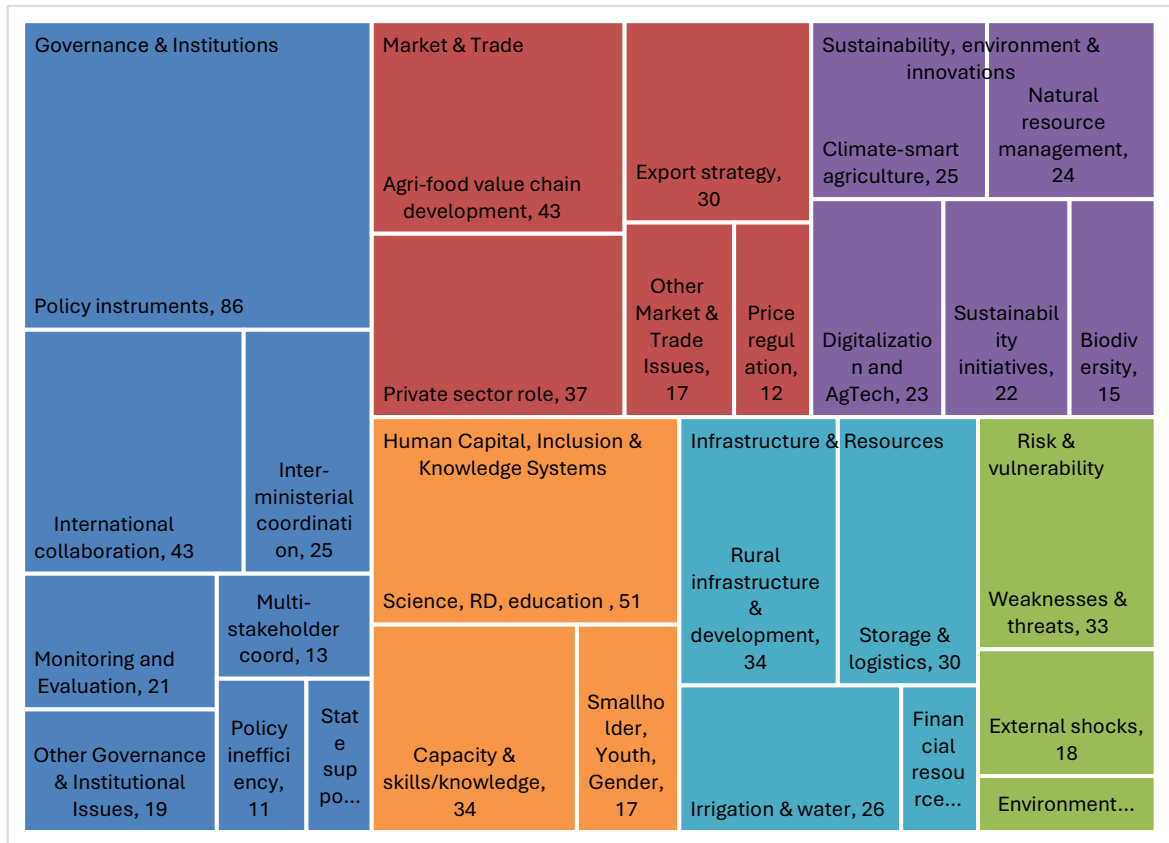


Figure 5. Tree map displaying the number of coded items per theme and sub-theme. The size of each box corresponds to the volume of data coded to that node, providing a visual summary of the thematic structure and coding density across the dataset.

3.1 Governance & Institutions

Kazakhstan and Uzbekistan rely on long-term strategies to govern agriculture - Concept for the Development of the Agro-Industrial Complex 2021-2030 in Kazakhstan [KZ1, KZ3, KZ4] and Strategy for Agricultural Development 2020-2030 in Uzbekistan [UZ1, UZ2], aimed at building more efficient, export-oriented food systems. Both put digitalisation as the key enabler of transparency and service delivery. In Kazakhstan, the Unified Digital Platform for Agro-Industrial Complex (E-AIC) integrates databases on subsidies, production, and land use. In Uzbekistan, “smart agriculture” projects focus on precision farming, e-extension, and traceability. “Digital tools are very important for the productivity of an enterprise and for the management of a state support system in agriculture” (R1). Others singled out climate information services, product traceability, and e-extension as the priorities for the next 12 months (R2). The direction is clear, but the pace is uneven.

Government support remains the foundation of policy, including subsidies, concessional loans, tax exemptions or reduced rates, and various investment incentives [KZ1, KZ3, UZ1, UZ2]. Access, however, appears unequal. As one expert noted, ‘a lion’s share of subsidies [is] captured by a small number of agricultural enterprises and agro-holdings’

(R4), while small producers are left on the margins. Another respondent added, ‘Many farmers are not covered by Government support systems’ (R1). The issue seems less the size of the budget than its accessibility.

International partnerships are part of the governance landscape. FAO, the World Bank, IFAD and JICA provide finance, technical assistance and policy advice to align resilience measures with international standards [KZ1, UZ1, UZ2]. Respondents said these partnerships can upgrade value chains and bring climate resilience into projects (R1, R2). Whether the benefits spread beyond pilot sites depends on national follow-through.

Coordination mechanisms seem effective on paper, for example, the Coordination Council in Uzbekistan, chaired by the Prime Minister [UZ2] and Kazakhstan’s inter-ministerial working groups and advisory councils [KZ1, KZ3]. However, respondents identified a “lack of inter-agency coordination” (R3) and “short-term policy planning cycles” (R2) as gaps that impede implementation. Here, opinions diverge: some saw steady progress through large programs like Agribusiness-2020, which “supported private investment in livestock and grain sectors, improving resilience through diversification and infrastructure development” (R2), while others argued that political motives frequently override decisions based on economic considerations (R4). Both can be true at different times.

3.2 Market & Trade

Both countries frame market development as a way to diversify their economies and increase rural incomes. National policies aim to broaden export markets, achieve higher value addition and enhance logistics [KZ1, KZ2, KZ3, UZ1, UZ3]. The policy focuses on increasing grain, meat, and oilseed product exports, and crowding in private investment in storage and transport infrastructure to build a reliable cold chain for high-value horticultural exports (fruit and vegetables).

Policy documents in both countries emphasise the need to diversify markets and reduce dependence on a limited number of trading partners. Kazakhstan targets China, Central Asia, and the Middle East, while Uzbekistan focuses on the EU and East Asia markets. Interviewees confirmed diversification efforts but mentioned several other issues, such as “export logistics costs sometimes exceeding the market value of the product” (R3) and high dependency on transit corridors through Russia.

Trade policy measures target the tools such as tariffs or export subsidies and agreements facilitating trade [KZ1, UZ1, UZ3]. Yet, participants pointed out that the restrictive measures, such as periodic bans on grain exports in Kazakhstan, prevent industries from being competitive (R4). Policy references merely note the use of these measures as tools for short-term price stabilisation, although they also understand the effects on a country’s export reputation [KZ2].

Quality infrastructure development (i.e., certification bodies, laboratories, compliance with international standards) is an important item on both countries' agendas [KZ1], [UZ1]. However, three respondents (R2, R3 & R4) indicated that the certification costs, in addition to the bureaucratic delays, prevent small-scale producers from accessing premium markets. "Farmers often do not have the financial capacity to meet certification requirements even when demand is there" (R2).

Efforts for regional trade cooperation will focus on the harmonisation of standards and the reduction of border delays in Central Asia [KZ1; UZ1]. However, in reality, the implementation is slow because of the differences in regulatory systems and occasional deterioration of political relationships.

3.3 Sustainability, Environment & Innovations

The countries' strategies pursue environmental goals, such as sustainable land and water use, climate-smart agriculture, and biodiversity protection [KZ1, KZ4, UZ1, UZ3]. Kazakhstan plans to focus on crop rotation, reduced tillage, and soil fertility restoration. Uzbekistan prioritises efficient irrigation, salinity control, and reforestation of the degraded lands. Both countries emphasize innovation as a policy priority, focusing on digital agriculture and precision farming as key tools [KZ1, KZ2, UZ1, UZ2, UZ3].

Interviewees strongly supported this direction, especially the role of data and digitalisation. National priorities highlight "supporting innovation and digital technologies, including climate information services, digital traceability, and e-extension platforms for agricultural producers" (R2). A GCF/UNDP project was also cited as "a regional model for climate-informed food system resilience" (R2). Stakeholders identify costs, connectivity gaps, skills, and incentives as barriers. The government needs to reform the state support system in agriculture so that farmers would be willing to use adaptive technologies (R1). Water sources needed for rice production were another emerging concern: "Climate change, particularly affecting water supply, may present some risk in the future" (R1). There was a call for "a transboundary, basin-level approach to secure vital irrigation supplies amidst shrinking glaciers and increasing demand" (R4). Climate-oriented priorities were also noted: "Developing drought-tolerant varieties" (R4). Coordination issues were also pointed out as "the lack of interagency coordination... without a unified mechanism for coordination" (R3).

The policy stresses the need to focus on the organic and other certification-dependent production niches [KZ3, UZ2] and states that the possibility to export such products is an opportunity. Interviewees acknowledged that it could be possible but cited several practical barriers such as finance, technical support and market access.

3.4 Human Capital, Inclusion & Knowledge

Policies in both countries emphasise the role of skilled labour and inclusive knowledge transfer for agricultural resilience (KZ1, KZ4, UZ1, UZ2). Both equally aspire to modernize vocational training, strengthen extension services, and broaden youth and women's involvement in agri-food systems. Kazakhstan emphasises digital literacy, management training and international internship programs for agricultural experts, while Uzbekistan focuses on farmer advisory networks, ICT integration into vocational education and rural entrepreneurship.

Interviewees were aligned on priorities but identified some gaps. “Without targeted support for younger farmers and rural women, policy commitments on inclusion will remain largely aspirational” (R4). “Extension services exist, but coverage is patchy and often not tailored to the specific needs of smallholders” (R2). Skills development was closely linked to technology adoption: without training on climate-smart agriculture practices, digital tools and certification, the new infrastructure investments do not yield intended results.

Policy frameworks (KZ1, UZ1) promote public-private partnerships in skills training. However, interview respondents felt that this avenue was not sufficiently explored. One respondent noted that “private companies often provide better technical training than state programmes, but there is little coordination” (R3). International donor projects (FAO, IFAD, World Bank) were praised for introducing participatory training methods (“farmer field schools”) but criticised because they did not continue after the projects ended.

Both governments also consistently mention “gender and youth empowerment,” but interviewees said there are no specific budgets or targets to measure progress. One respondent described it as “policy rhetoric without operational teeth” (R4).

3.5 Infrastructure & Resources

Both countries acknowledge that poor rural infrastructure limits farmers' productivity and market access, as well as constrains the sector's resilience [KZ1, KZ3, UZ1, UZ3]. Policy focus is on investments for irrigation, storage, transport, and energy systems. Kazakhstan targets the rehabilitation and expansion of irrigation systems, renovation of grain elevators, and enhancement of rural roads. Uzbekistan prioritizes upgrading pumping stations, expanding cold storage, and electrifying remote farming areas.

Interviewees identified the same bottlenecks. R4 noted that “the absence of proper storage forces farmers to sell immediately after harvest, often at low prices”. Another highlighted “cold chain gaps that mean perishable produce is lost before reaching export markets” (R2). Some respondents noted some improvement in grain storage capacity and rail links, which had been prioritised by recent investment programmes. But poor maintenance of infrastructure and the exclusion of marginalised communities remained serious problems.

Water infrastructure was identified as a priority by both policy and other stakeholders. Kazakhstan's strategy targets canal modernization and water metering improvements [KZ1], whereas Uzbekistan is implementing efficiency measures to minimize losses from its vast irrigation network [UZ3]. However, they indicated that the irrigation/canal network often leaked, the equipment was obsolete, and there was a lack of coordination between agencies responsible for different sections of the channel.

Integration of the renewable energy sources into rural infrastructure is emerging as a new priority [KZ4]. Solar-powered irrigation systems are being piloted in both countries and appear promising [UZ1]. However, the financial models needed to support such initiatives are poorly developed.

3.6 Risk & Vulnerability

The policy documents in both countries identify and analyse price volatility, exposure to external factors, as well as climate and water stress as the core risks [KZ1, KZ5, UZ1, UZ3]. Kazakhstan focuses on irrigation modernization and drought management, while Uzbekistan targets improving water use efficiency and reducing distribution losses. Both emphasise the need for reserves and support of food imports to prevent price fluctuations [KZ2, UZ3].

Interviewees broadly agreed on the risk profile. The supply chain costs are sometimes higher than the product value, making it difficult to export products with low-profit margins. Several informants considered price stability to be a "deep weakness," which was exposed during COVID-19 when the limited buffer and trade disruptions occurred (R2; R5). Geopolitical shocks are important: "The Ukraine war shifted the balance of the market in Russia's favour, making it harder for Kazakhstan to compete" (R3). Chain fragility ("one failure at any point causes a domino effect across the whole chain") and chain diversification ("you can't put all eggs in one basket," R5).

"Climate and water" policy analysis and interviews agree that the risks are increasing, but diverge on how well companies are prepared. One expert cautioned that "without effective transboundary water governance, climate change will turn competition for water into a major driver of regional instability" (R4). Another noted that "climate change particularly affecting water supply may present some risk in future" (R1). Subsidies and price controls divide views (governments see them as important for stability [KZ2, UZ3]); many interviewees argued that they create market distortions which hinder investments (R4; synthesis across interviews).

4 DISCUSSION

Resilience depends on reliable lead times at key points rather than high average capacity. In Kazakhstan and Uzbekistan, the most important points are irrigation maintenance and metering, border and rail clearance with wagon availability, and timing of testing/certification. Digital services also help by reducing variability and clarifying product information. There is a broad consensus on what needs to happen; however, there are still basic implementation problems, such as issues with subsidy design, trade practices, and scaling new approaches. Resilience scholars recognise that the ability to perform amidst disturbance is more important than theoretical capacity (Kc *et al.*, 2024).

4.1 RQ1 - Institutional responses and risks

Recent disturbances in Kazakhstan and Uzbekistan illustrate the same tension at three levels. The importance of timing applies to more than just the amount of moisture irrigation provides. When delivery windows slip, planting dates move, quality suffers, and storage plans are affected. The operational needs, such as routine maintenance, metering on secondary canals and other daily activities, should be addressed regularly. While “typical” service times were consistently reported, several outliers were noted mainly around peak periods for irrigation, border/rail clearance, and laboratory turnaround (R1–R5). Policy documents already point to the right direction: more metering and published allocation schedules, appointment systems and pre-arrival processing at borders, and standard turnaround targets in public labs (KZ1; UZ2). Respondents corroborated the findings in the policy papers, pointing out that metering coverage, routine O&M execution, and lab turnaround standards should be practical levers (R1–R5).

Border and rail processes are distinct. Clearance can be very efficient or exceedingly slow, and wagons and slots are unpredictable. Trade-facilitation work shows that what matters more to firms is the variability of speed rather than its average level; thus, reducing the “slow tail” is more important than small gains in average speed (R3; OECD 2021). Testing and certification add another timing layer. Small enterprises still struggle to anticipate lab turnaround times, and the connections between e-submission or traceability platforms and paper-based systems remain weak (FAO & CIRAD, 2023).

Institutional programmes and portals work best where they are tied to service standards; otherwise, new facilities mainly add capacity without improving predictability. Documents are mostly about funding, facilities and digital roll-outs, whereas interviews suggest only limited changes in service levels, appointments, pre-arrival processing and linked workflows. As a result, firms plan for the worst-case rather than the average, in line with studies separating level from variance (Kc *et al.*, 2024).

Country profiles shape exposure. In Kazakhstan, grain exports necessitate the allocation of logistics resources, such as railcars and border crossing slots, due to their high-volume

nature (Shmelev *et al.*, 2021). In Uzbekistan, the horticulture focus emphasises the short, timely irrigation windows and perishable test sequencing (FAO & CIRAD, 2023). The mechanism may look the same, but the exposure is not. Documents and interviews mostly agree that timing (when) is important, but a specific time range cannot be agreed on. Pace (how fast) is also important due to the possible perishability of food items, and its standardisation has been highlighted by both policy documents and interviews, although whether pace needs to improve or slow down has not been discussed.

4.2 RQ2 - Enablers and barriers

Focusing on enablers that improve timings at known choke points in the production process is likely to have the greatest impact on the performance metrics. Routine irrigation O&M and metering on secondary canals, enabling inspection of allocation and schedule compliance. Because these fall within the mandate of irrigation authorities, they can realistically be implemented within 12 months (KZ1; UZ2). The mechanism is lower variance in water-delivery times, which directly supports agricultural planning and reduces conflicts (Wang *et al.*, 2022).

Second, appointment windows and pre-arrival processing at priority border posts can compress the long tail of clearance times by smoothing arrivals and enabling risk-based screening. A limited pilot at one or two high-volume crossings would be feasible within a year. The targets for the median and 90th percentile clearance times could be published as a way to reinforce accountability.

Third, setting laboratory turnaround standards and expanding electronic certification can lessen timing risk for SPS compliance. These are mostly procedural under the national laboratory/SPS authorities and can be implemented within 12 months by defining 24 – 72 hour tiers and monitoring performance against them. Digitised testing, certification and traceability shorten cycles where interoperable systems allow product information exchange (FAO, 2020; World Bank, 2023).

Taken together, these measures act at three levels in the process: irrigation, borders and testing. Lower variability also allows the company to make longer-term pricing and contracting decisions, which in turn reduces risk. Interviewees consistently described extended planning horizons where such steps were in place (R1–R5).

Barriers remain where incentives and hand-offs are weak. Policy volatility can hinder longer-term success. The repeated and unpredictable visits by the certification auditors curtail the certified small businesses' access to higher-value markets (FAO & CIRAD, 2023). Delays at individual nodes (customs, testing, rail) can be reduced only through coordinated action of interconnected nodes. Partial digitalisation creates parallel paper and digital queues (OECD, 2021). Thus, variance, not just mean values, matters for stability (IFPRI, 2022). Targeted SME supports, such as fee caps, help desks, and phased

compliance windows, should accompany standardisation and other initiatives to keep reforms inclusive.

4.3 RQ3 - Policy and regional cooperation

A predictability-first approach is the most feasible over the next 12–24 months because it can be pursued largely within existing budgets, laws, and mandates. Three areas stand out nationally. For irrigation, routine maintenance budgets can be protected, backlogs cleared before the season, more meters installed on secondary canals, and allocation schedules published in advance (Mirzabaev 2018). At borders, authorities can set median and 90th percentile service time targets, implement appointment systems at busy border posts, and expand pre-arrival processing (World Bank, 2023). Testing/certification bodies can establish turnaround standards, enhance e-submission/traceability, and reduce documentation requirements for low-risk products (FAO & CIRAD, 2023). According to interviewees, consistency in applying those steps reduces the perceived risk and enhances planning (R1–R5).

From the interviews and policy documents, five key points have been identified that could improve current policy and regional cooperation:

- i. Publish the seasonal water allocation schedules, and protect canal O&M budgets;
- ii. Introduce appointment slots and pre-arrival processing at the two most congested posts;
- iii. Set daily lab turnaround standards and publish weekly performance dashboards;
- iv. Coordinate wagon “windows” at the corridor level during peak harvest periods;
- v. Pursue targeted mutual recognition of conformity assessment where risk profiles and accreditation are aligned.

Mutual recognition of selected test results and digital product certificates would cut unnecessary duplicate testing. Seasonal coordination of wagon windows for grain and horticulture would smooth peaks that are currently identified in policy documents. Transparent seasonal calendars for the cross-border release of dam waters help farmers adjust field operations in advance. These steps still depend on domestic labs, border posts, canal authorities and national portals working reliably. In practice, the biggest limitation is typically the timing of processes rather than the amount of available funding. Implementing regional steps sequentially after the domestic ones will also minimise the risk of transferring domestic variability across borders (R2, R3).

4.4 Synthesis, Implications and Robustness

Reducing variability at bottlenecks will be as important as adding capacity. When irrigation windows, border/rail clearance and lab turnaround are more predictable, firms can confidently choose the product mix to target, size inventories better and take on slightly longer contracts. Progress could be tracked with a small set of simple measures

published periodically, for example: the gap between 90th and 50th percentile border clearance at priority posts; median days from sample receipt to certificate issuance and portal uptime; and the share of secondary canals with working volumetric meters and executed maintenance budgets. These indicators are imperfect but observable and stable enough to track change over time.

Two points underlie this argument. First, the policy documents and interviews are aligned while differing slightly as to the timescale of anticipated improvement. Second, the analysis is largely product-agnostic: similar constraints are observed across grain and horticulture value chains.

Evidence for time variation at the three nodes (irrigation operations/metering; border or rail clearance; lab turnaround) appears reasonably strong since it derives from document review and interviews. Similar patterns can be found in the horticultural sector, meaning that the mechanisms described above were largely product-neutral. However, exposure varied by country, depending on the relative importance of rail-based grain exports as compared to perishables. The evidence is weaker when only one source is used or when country differences limit the opportunity to compare cases. In such cases, claims are considered provisional. Overall, the strength of the analysis arises from patterns across multiple documents rather than any single source.

4.5 Alternative interpretations and trade-offs

The focus on predictability comes at a price. Standardised procedures and appointments will create barriers for smaller firms unless adequate support measures such as help desks, phased requirements, and fee caps are implemented (FAO & CIRAD, 2023). Very tight targets also lessen flexibility in times of genuine shocks, especially if exception protocols are not clearly defined (IFPRI, 2022). A balanced approach would reduce variance while allowing some room for managed exceptions such as temporary waivers, escalation routes, and limited surge capacity. There is also a political-economy risk as groups that benefit from discretionary subsidies and appointments may block metering and stop it before it begins (R4). Phased roll-out, public dashboards, and stakeholders' forums can facilitate implementation while keeping the attention on the predictability benefits (R2, R3).

5 CONCLUSION

The study looks at supply-chain resilience in Kazakhstan and Uzbekistan with a focus on timing performance. The shared issue across irrigation, border/rail, and testing/certification is end-to-end spread. When the slow tail widens, firms shorten contracts and hold back on upgrades. Resilience improves where maintenance and metering are routine, borders use appointments and pre-arrival processing, labs meet turnaround targets, and e-systems interoperate.

The pattern is the same in both countries, but exposure differs: grain depends on rail-wagon slots and border timing; horticulture on irrigation windows and lab sequencing. A predictability-first approach that uses existing set-ups and budgets is a realistic near-term path, provided it stages into broader reforms once timing dispersion narrows.

The analysis has limits. It draws on documents and five expert interviews, so the results speak more to system-level mechanisms than precise cost figures. Nonetheless, the triangulation of various sources indicates that narrowing variability at a few chokepoints would facilitate firm behaviour and investment planning. The contribution is primarily practical: it suggests a way to operationalise resilience via a small set of service-level indicators (SLIs) and identifies measures that agencies could implement within 12–24 months.

A further implication is that incremental, procedural reforms, such as clarifying subsidy schedules, publishing irrigation allocations in advance, or introducing service-level targets for border clearance, may yield resilience benefits more quickly than ambitious structural reforms. While such measures cannot substitute for broader investments in infrastructure or governance, they can reduce unpredictability at critical nodes and demonstrate early gains. These visible improvements may, in turn, build trust and political momentum for deeper reforms.

Overall, reducing variability at bottlenecks seems to be as important as adding capacity. This can increase the credibility of public programmes, lower risk premiums for companies, and lay the foundation for gradual upgrading in products and markets.

5.1 Recommendations

In irrigation, ring-fence routine maintenance budgets, clear maintenance backlogs before the season, extend metering to secondary canals, and publish seasonal water allocation schedules in advance. Publish median and 90th percentile service targets; where congestion is most severe, use appointment systems; and widen pre-arrival processing. Standardize laboratory turnaround times, automate e-submission in testing and certification (traceable), and leverage documentation tools where the risks are demonstrably very low. Build the necessary equity and flexibility through SME help desks, phased-in requirements, and consideration of exceptions for genuine shocks.

By implementing the mutual recognition of accredited laboratory tests and digital certificates, coordinating timelines for the grain and horticulture seasons to manage wagon turnover, and publishing seasonal water release calendars in advance so farmers can adjust their plans accordingly, regional coordination and food system resiliency can be improved in both countries. By publishing a small set of SLIs and reviewing them regularly, clearance reliability at priority posts, lab turnaround with portal uptime, metered-canal coverage and routine O&M execution can be managed. The steps are based on already existing laboratories, border posts, canal authorities and portals and aim to improve timing governance rather than require large finances.

Further research into how food system resilience can be improved in Kazakhstan and Uzbekistan might be done by analysing how producers and firms adapt to timing uncertainty beyond formal policy frames, assessing regional coordination through indicators like acceptance without retesting and clearance variation in peak seasons, and examining who adopts digital tools under climate stress or the cost of reducing timing variability.

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Appendices

Appendix A - Ethical Approval Letter



4 June 2025

Dear Ms Karpbayeva ,

Reference: CURES/25504/2025

Project ID: 29065

Title: Unlocking Sustainable Food Systems in Central Asia: A Supply Chain Resilience Perspective from Kazakhstan and Uzbekistan

Thank you for your application to the Cranfield University Research Ethics System (CURES).

We are pleased to inform you your CURES application, reference CURES/25504/2025 has been reviewed. You may now proceed with the research activities you have sought approval for.

If you have any queries, please contact CURES Support.

We wish you every success with your project.

Regards,

CURES Team

Appendix B - Selected Food-System Indicators

Table B-1. Selected food-system indicators for Kazakhstan and Uzbekistan (latest available).

Theme	Indicator (definition/unit)	Kazakhstan	Uzbekistan	Source
1. Diets, nutrition & access	Cost of a healthy diet (PPP USD/day)	2.79	5.67	Food Systems Dashboard (FSD) / FAO
	People unable to afford a healthy diet (%)	6	15	FSD / FAO
	Safely managed drinking water (%)	89	71	WDI / WHO–UNICEF JMP
	Prevalence of undernourishment (% of population)	0	0	FAOSTAT
	Food insecurity (moderate or severe, % of adults)	2	—	FAO FIES
	Women's dietary diversity (MDD-W, % meeting threshold)	88	89	FSD / UNICEF
	Infant & young child dietary diversity (6–23 months, %)	49	23	UNICEF MICS
	Adults consuming soft drinks (%)	34	53	FSD / WHO
2. Production, environment & resources	Cropland nitrogen use efficiency (%)	96	34	FSD
	Cereal yield (t/ha)	1.38	4.98	WDI (FAO) (World Bank Open Data)
	Agriculture water withdrawal (% of renewable resources)	14	111	WDI (SDG 6.4.2)
	Functional integrity of agricultural land (%)	53	23	FSD
	Pesticide use (kg/ha of cropland)	0.3	—	FAOSTAT
	GHG emissions, agri-food systems (kT CO ₂ e)	58,474	66,147	FAOSTAT
3. Livelihoods & equity	Agriculture, value added (% of GDP)	5	24	WDI
	Rural unemployment rate (%)	3	5	WDI / ILOSTAT
	Social protection coverage (%)	49	25	World Bank ASPIRE
	Social protection adequacy (%)	43	28	World Bank ASPIRE
	Child labour (5–17 years, %)	—	18	UNICEF / ILO
4. Governance & institutions	Government effectiveness (WGI, –2.5 to +2.5)	0.1	–0.3	WGI

	Food safety capacity (index 0–100, higher = stronger)	80.0	20.0	FSD
	Open Budget Index (score)	63.0	—	IBP-OBI
	Civil society participation index (0–1)	0.5	0.3	V-Dem
	V-Dem accountability index (–1 to +1)	–0.1	–0.6	V-Dem
5. Resilience & buffers	Food price volatility (index)	0.7	0.4	FAOSTAT
	Food supply variability (kcal/person/day)	62	41	FAOSTAT
	Social capital index (0–1)	0.5	0.5	FSD / WVS
	Mobile subscriptions (per 100 people)	130.4	103.1	WDI
	Agricultural land with species diversity (%)	19	12	FSD
	Severe coping strategies prevalence (%)	—	0.5	FSD / WFP

Note. Latest available values by series (years vary). Units/definitions: Safely managed drinking water per WHO/UNICEF JMP; Water stress = SDG 6.4.2 (may exceed 100% by definition); Food safety capacity index (0–100, higher = stronger); Food supply variability (kcal/person/day). Cereal yield shown in t/ha (WDI/FAO kg/ha converted ÷1,000). “—” denotes unavailable. Values are rounded to one decimal (percentages) and whole numbers (counts/indices) for readability. Vegetable and cow-milk yield rows are omitted here pending unit/coverage verification across sources.

Source key. FSD = Food Systems Dashboard; FAOSTAT = FAO Statistics; WDI = World Bank World Development Indicators; JMP = WHO/UNICEF Joint Monitoring Programme; FIES = FAO Food Insecurity Experience Scale; MICS = UNICEF Multiple Indicator Cluster Surveys; WHO = Global Health Observatory; ILOSTAT = ILO Statistics; ASPIRE = World Bank Social Protection & Jobs; OBI = International Budget Partnership—Open Budget Index; WGI = Worldwide Governance Indicators; V-Dem = Varieties of Democracy; WVS = World Values Survey; WFP = World Food Programme.

Appendix C - Interview Questions

This guide was used with all expert respondents; probes were adapted by role.

1. Could you briefly describe your current or past role, and how it relates to food systems or agricultural policy in Kazakhstan or Central Asia more broadly?
2. Have you or your organization worked on food systems or supply chain projects in Kazakhstan or other Central Asian countries? If so, could you share a few examples?
3. Based on your experience, what are the biggest challenges currently facing food supply chains in Kazakhstan? Do you see similar issues elsewhere in the region?
4. What recent events (e.g. COVID-19, droughts, trade disruptions, or geopolitical tensions) have most affected food systems in Kazakhstan or neighbouring countries in your view?
5. What kinds of programmes, tools, or partnerships have helped food systems or supply chains become more resilient in Kazakhstan or elsewhere in Central Asia? What do you see as the key enablers of resilience in the region?
6. Are there any policy, institutional, or governance-related barriers that make it harder to strengthen food supply chains in Kazakhstan or the wider region?
7. Are there any examples of successful regional cooperation (e.g. trade agreements, joint initiatives, cross-border coordination) that have helped address food system challenges in Central Asia?
8. In your work, how have farmers, women, or other underrepresented groups been included in efforts to build food system resilience, if at all? Have women been represented in leadership or decision-making roles within these initiatives?
9. What would you recommend as top priorities—at both national and regional levels—to improve food system and supply chain resilience in Kazakhstan and the broader Central Asian context? Are there particular enablers or success factors to focus on?

Appendix D - Source Documents Used in Analysis

Table D-1. Policy and strategy documents are mapped to short codes.

	Short Name	Full Title	Type	Country	Year	Language
1	KZ1	Concept for the Development of the Agro-Industrial Complex of the Republic of Kazakhstan for 2021–2030	National strategy	Kazakhstan	2021	Russian
2	KZ2	Food Security Plan of the Republic of Kazakhstan for 2022–2024	National action plan	Kazakhstan	2022	Russian
3	KZ3	Food Security Report of the Ministry of Agriculture of Kazakhstan	Ministerial report	Kazakhstan	2024	Russian
4	KZ4	Strategic Plan of 'Food Corporation' JSC, Kazakhstan	Institutional strategy	Kazakhstan	2021	Russian
5	KZ5	FAO Technical Report: Support to Agro-Industrial Policy 2022–2026	FAO Technical assistance report	Kazakhstan	2022	English
6	UZ1	Uzbekistan Country Programming Framework (CPF) 2021–2025 (FAO)	FAO strategic framework	Uzbekistan	2021	English
7	UZ2	Uzbekistan Strategy for Agricultural Development 2020–2030 (Presidential Decree No. UP-5853)	National strategy	Uzbekistan	2019	Russian
8	UZ3	Presidential Decree of the Republic of Uzbekistan No. UP-36 "On Additional Measures to Ensure Food Security"	Presidential Decree	Uzbekistan	2024	Russian

Note. Short codes (e.g., KZ1, UZ2) are used in the Discussion; full bibliographic details appear in the reference list where relevant.

Appendix E - Analytical theme coverage across the three research questions.

Table E-1. Summary of how each thematic subcode contributes to answering RQ1–RQ3, based on coding frequencies from the policy and interview datasets; numbers in parentheses show total references per theme.

Legend: ●=1, ○=0.5, –=0

No	Theme (coded segments, n)	Subcodes	RQ1: Risks & Institutional Response	RQ2: Barriers & Enablers	RQ3: Regional Cooperation
1	Governance & Institutions (226)	Policy instruments	●	●	○
		International collaboration	○	○	●
		Inter-ministerial coordination	○	●	○
		Monitoring & Evaluation	○	●	—
		Other governance & institutional issues	○	●	○
		Multi-stakeholder coordination	○	○	○
		Policy inefficiency	○	●	○
		State support	○	●	○
2	Market & Trade (127)	Agri-food value chain development	○	●	○
		Private sector role	○	●	○
		Export strategy	○	●	○
		Other market & trade issues	○	●	○
3	Sustainability, Environment & Innovations (109)	Digitalisation & AgTech	○	●	○
		Sustainability initiatives	○	●	○
		Natural resource management	●	●	○
		Biodiversity & ecosystems	○	●	○
		Climate-smart agriculture	○	○	○
4	Human Capital, Inclusion & Knowledge (102)	Capacity & skills/knowledge	○	●	○
		Smallholder, youth & gender inclusion	○	●	○
		Science, education & R&D	○	●	○
5	Infrastructure & Resources (99)	Rural infrastructure & development	○	●	○
		Storage & logistics	○	●	—
		Irrigation & water	●	●	○
		Financial resources	○	●	—
6	Risk & Vulnerability (71)	Price regulation	●	○	○
		Weaknesses & threats	●	○	—
		External shocks	●	●	—
		Environmental crises	●	○	—

Appendix F - Additional Analysis Outputs

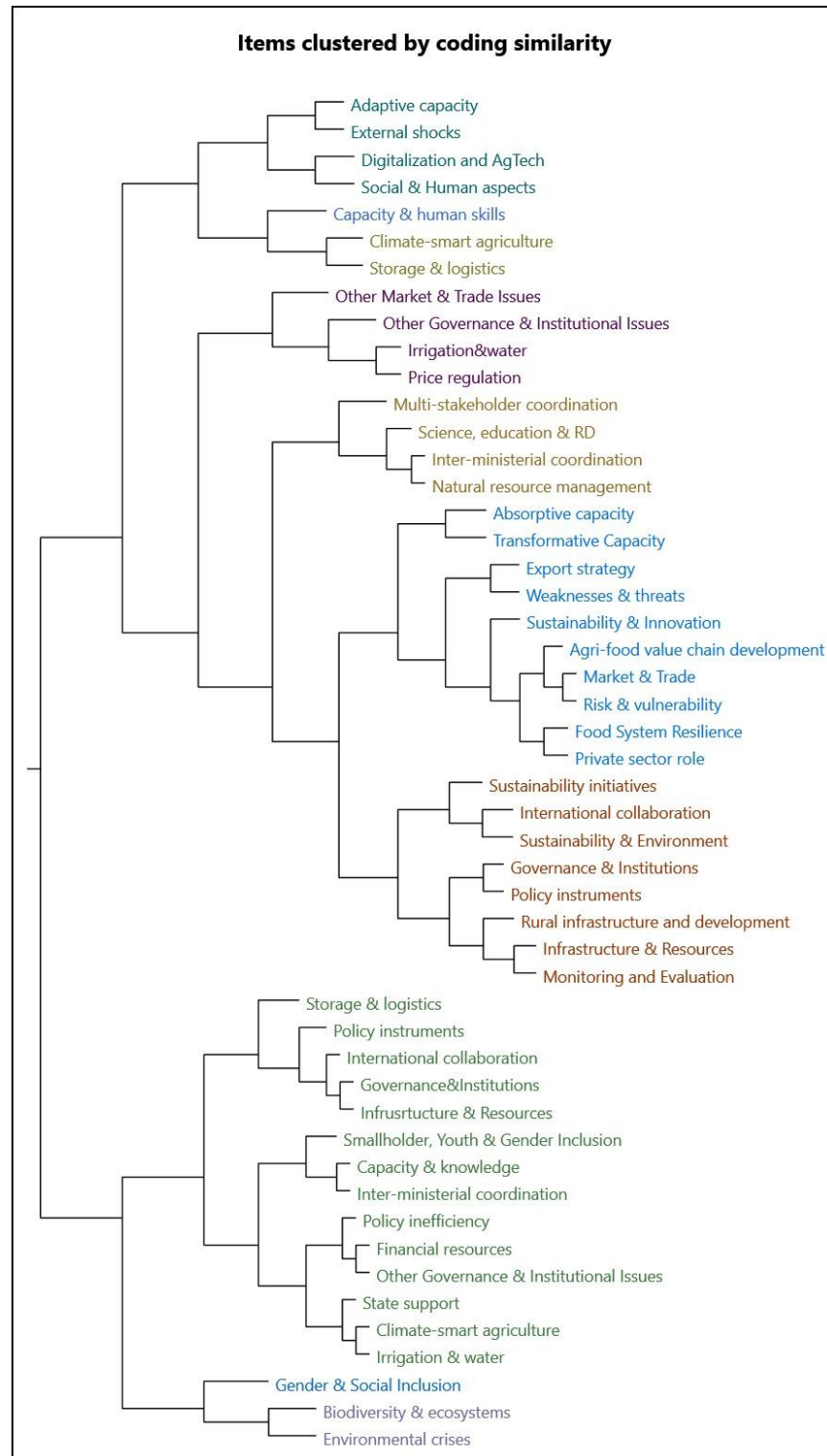


Figure F-1. NVivo dendrogram of thematic co-occurrence.

Note. Hierarchical clustering of node similarity on the combined policy + interview corpus; used as a validity check on the code structure.