CENTRAL ASIAN JOURNAL OF WATER RESEARCH (2025) 11(1): 59-85

https://doi.org/10.29258/CAJWR/2025-R1.v11-1/59-85.eng

Central Asian Journal of Water Research

Exploring the interlinkages between water and energy use in the lift irrigated agriculture of Uzbekistan

Asliddin Bobocholov [a], Ahmad Hamidov [a,b], Sonoko Dorothea Bellingrath-Kimura [a]

[a] Leibniz Centre for Agricultural Landscape Research, Eberswalder Str. 84, Müncheberg, 15374, Germany
[b] "Tashkent Institute of Irrigation and Agricultural Mechanization Engineers" National Research University ("TIIAME" NRU), Kary-Niyaziy 39, Tashkent, 100000, Uzbekistan

ABSTRACT

The water, energy, and food (WEF) nexus is being promoted as a conceptual idea for achieving sustainable development, that describes the interconnections and interdependencies between those three sectors. The main objective of this article is to operationalize the WEF nexus concept in lift-irrigated areas of Uzbekistan through involving local stakeholders, to investigate the WEF nexus within the lift-irrigated agriculture of the Kashkadarya region, an area heavily reliant on the Karshi Canal system. The study is grounded in the urgent need for sustainable development, with a focus on enhancing intersectoral cooperation between water, energy, and food sectors. A case study methodology was employed, incorporating semi-structured interviews with experts, alongside local farmers and scientists. Data were analysed using the qualitative analysis software, Atlas.ti.

The results indicate significant challenges to intersectoral cooperation in the WEF nexus, including lack of trust, communication barriers, differing priorities, and insufficient political will. However, the findings also highlight the potential benefits of improved cooperation, such as enhanced resource efficiency, reduced operational costs, and mitigated risks from environmental stressors like drought. The study concludes that, according to stakeholders' opinions, while the WEF nexus presents critical opportunities for advancing sustainable development in Uzbekistan, substantial barriers must be addressed to realize these benefits. Recommendations include promoting sustainable agriculture to reduce water dependency, improving energy security by diversifying energy sources, and raising awareness of the WEF nexus's importance. Furthermore, fostering stronger stakeholder cooperation is crucial for achieving Uzbekistan's Sustainable Development Goals (SDGs) by 2030.

ARTICLE HISTORY

Received: September 17, 2024
Accepted: February 25, 2024
Published: March 11, 2025

KEYWORDS

cooperation, irrigated agriculture, lift irrigation, sustainability, SDGs, nexus

CONTACT Asliddin Bobocholov asliddin.bobocholov@zalf.de, Leibniz Centre for Agricultural Landscape Research, Eberswalder Str. 84, Müncheberg, 15374, Germany

Published by Kazakh German University, Almaty/Kazakhstan

1. Introduction

The three fundamental components that sustain human life and socioeconomic development are water, energy, and food (WEF) (Mohtar et al., 2015). Water and energy are very important for producing agricultural food, securing a sustainable economy, including improving human well-being (McCarl et al., 2017). The challenge of how to sustainably manage limited natural resources has become more complicated due to the increase in global population. Water is essential for producing both energy and food, thus managing water resources, mostly through irrigation systems, is as important as it is difficult (Hamidov et al., 2016). Water scarcity is becoming more widespread internationally since the demand for water increases to produce food and energy. Hence, sustainable water use is crucial to preventing disputes between the parties involved; nevertheless, it is particularly difficult in developing countries (Chathuranika et al., 2022). Such discussions frequently revolve on the scarcity of natural resources (Yapiyev et al., 2017). The World Economic Forum annual meeting 2011 identified a "nexus" among water, energy, and food, and originally proposed the WEF nexus as a concept in 2011. The WEF nexus was defined as a Global Risk in 2011 (Allouche et al., 2015). The Bonn Conference (2011), which focused on "Initiating Integrated Solutions for the Green Economy" was significant because it proposed for the integration of water, energy, and food security (Mohtar et al., 2015).

The interaction between water and energy often leads to conflicts. For example, energy is required to pump and transport water for irrigation, especially in lift-irrigated areas, while water is essential for energy generation, particularly in hydropower and thermal power plants (Djumaboev et al., 2019). In water-scarce regions like Central Asia (CA), including Uzbekistan, this interdependence becomes a source of tension as limited water resources must be shared among competing demands for energy production and agricultural irrigation (Hamidov et al., 2020). In analyzing and resolving the conflict between food and energy for water, the WEF nexus is crucial (Hua et al., 2021). The nexus refers to the interactions and interdependencies between the sectors of food, energy, and water. Global projections indicate that demand for water, energy and food will increase significantly over the next decades due to the pressure of population growth, economic development, international trade, urbanization, diversifying diets, cultural and technological changes, and climate change (Hoff, 2011).

Rhouma et al. (2024) provides a comprehensive bibliometric analysis of the scientific evolution and research trends related to the WEF nexus, highlighting the significant growth in publications, particularly between 2017 and 2023. The study identifies critical gaps, such as the underdeveloped WEF nexus in agriculture and its integration with Sustainable Development Goals and emphasizes the need to incorporate health considerations and practical applications into this research area.

The main objective of this study was to operationalize the WEF nexus concept in lift-irrigated areas of Uzbekistan through involving local stakeholders. This study investigated the water and energy related challenges on the lift irrigated agriculture in the Kashkadarya Region of Uzbekistan. Specifically, the study investigated the following research questions:

• What are the determinants for explaining cooperation among WEF sectors in the lift-irrigated agriculture in Uzbekistan?

• To what extent can the WEF nexus approach facilitate to attain the SDGs in Uzbekistan?

In this study, our hypothesizes include that the dividing WEF sectors in different disciplinary institution is one of the biggest obstacles, and that institutional barriers such as trust, and communication hinder better cooperation within WEF sectors in Uzbekistan. Furthermore, achieving better cooperation in the WEF nexus sectors helps to achieve the number of SDGs, mainly SDG 2, 6 and 7 in Uzbekistan. Additionally, based on the literature review, we hypothesized that the fragmented nature of WEF sectors, particularly in post-socialist countries like Uzbekistan, hinders effective cooperation.

The contribution of this research is the following: (1) contribution to WEF nexus concept discourse through analyzing interconnectedness of individual sectors; (2) improvement of understanding in linkages between WEF nexus sectors and SDGs in lift-irrigated area of post-socialist transition country; (3) contribution to WEF nexus concept operationalization in lift-irrigated areas; (4) improvement of knowledge in the Kashkadarya region from a WEF nexus context.

2. Literature review and analytical framework

2.1. Literature review

The literature review of this study aims to provide an overview of the key concepts, approaches, and findings related to the WEF nexus, highlighting its relevance for sustainable development and policy-making international organizations, scholars, policy analysts, and other stakeholders are increasingly acknowledging the WEF nexus concept as a conceptual framework.

For the concept to be operationalized, several obstacles still exist. Kalvani and Celico (2023) investigate the WEF nexus in Europe, revealing a focus on water-stressed countries like Spain and Italy, an emphasis on energy production and water quantity, and highlights the need for a more holistic, cross-sectoral framework that includes climate and circular economy considerations. The WEF challenges are still primarily dealt with within sectorial boundaries, especially in terms of projects, investments, and policy decisions, despite the growing attention the WEF nexus

has received from international institutions, development agencies, academics, policymakers, and other stakeholders (Glassman et al., 2011).

The overwhelming majority of the WEF nexus concepts and research to date are around water. Accordingly, even though energy and water security are intricately linked, water security has received more emphasis in mainstream discussions of the nexus. The importance of these sectors for humanity, as well as the complexity and scope of the difficulties they face, make the nexus a vital topic for research and practice. Even if the concept of the nexus is not yet fully developed or tested in practice, it has already generated a few methods in a variety of circumstances (Allouche et al., 2015).

The role that renewable energies can play in addressing trade-offs and achieving synergies has been given relatively little attention, despite the WEF nexus obtaining increasing attention (Turner et al., 2017). Up to now, national, or global levels, macro-level drivers, material flows, and significant infrastructure projects have been the major topics of WEF nexus debates and applications (Terrapon-Pfaff et al., 2018). This omits the fact that significant nexus challenges are encountered locally. The WEF nexus has grown in popularity in the international development community's discourse regarding sustainable development since 2008. As Allouche et al. (2015) state, it is tough to dispute with the idea that by recognizing the connections between the three sectors, synergies can be formed and trade-offs avoided, leading to the acceleration of sustainable development. Understanding WEF can contribute to human well-being, poverty reduction and sustainable development. The conceptual approach to achieve sustainable development is the WEF nexus.

Water, energy, and food security are crucial for Sustainable Development. The 17 Sustainable Development Goals (SDGs) of Agenda 2030 for Sustainable Development were adopted by 193 nations in 2015 (Katila et al., 2019). A conceptual framework that could also really promote the effective implementation of the SDGs is the WEF nexus. The WEF nexus concept can be applied focusing on three main SDGs: SDG 2 “zero hunger”, SDG 6 “clean water and sanitation”, and SDG 7 “affordable and clean energy”. However, it can be difficult to integrate and optimize the WEF nexus’s components to consider the SDGs. The systematic literature review revealed that it is necessary to develop new theoretical frameworks that can, to the highest extent possible, account for both the dynamics of each WEF component and their nexus.

Over the past ten years, scientific research has developed and applied a wide variety of tools and methodologies for this aim. For instance, Bazzana et al. (2022) investigated an overview of several analytical tools to model the WEF nexus and linked to the SDGs. They found out the insufficiency of the WEF nexus research on direct interactions with the associated SDGs. Furthermore, Hamidov and Helming (2020) investigated a systematic review of 194 publications from 2011- 2019. The

review focused on the WEF nexus on irrigated agriculture and its relevance to SDGs. The review findings indicated that most publications revealed a single-sector strategy, while the WEF nexus research emphasizes cross-sectoral cooperation. Additionally, they criticized that little amount of research was conducted in the field of irrigated agriculture and there are ample rooms for research contributions for different regions, namely in such areas of CA (which caught our attention) and southern America.

Djumaboev et al. (2019) investigated the WEF nexus by assessing water and energy use in the Kashkadarya region of Uzbekistan. Using field experimental methods (such as physical and chemical analysis of water) they identified the necessary amount of water and energy use in farmlands. However, the study omitted stakeholders' involvement, the notion of cross-sectoral cooperation in the WEF and the relevance of WEF nexus to the SDGs. Djumaboev et al. (2019) applied WEF nexus in CA and founded out that the nexus was received some attention. However, little or no international research has been conducted in the region thus far. In their paper the example of proper irrigation planning as a tool for water and energy savings and consequent reduction was described.

2.2. Analytical framework: WEF Nexus

This WEF nexus framework facilitates a comprehensive analysis of the interconnections among water, energy, and food systems, with a focus on their interdependencies, trade-offs, and implications for sustainable resource management. Figure 1 highlights the interactions for addressing WEF challenges in the study area.

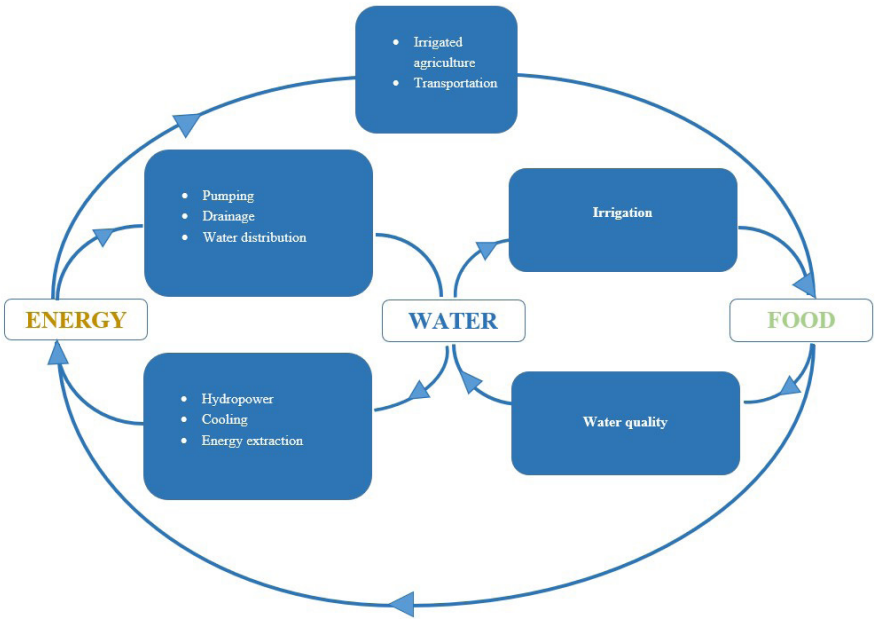

Figure 1. WEF interdependencies in the study (Stephan et al., 2018)

Energy for Food: Energy is used extensively in agriculture. Therefore, it is either directly or indirectly consumed in agricultural fields, relying on energy for irrigated agriculture and transportation. At the moment, the food system consumes approximately 30% of the world's energy. It is important to remember that livestock and fish farming account for 6.6% of the energy used to produce products (Taguta et al., 2022). These processes underscore the critical role of energy in ensuring food security, particularly in regions with extensive irrigated farming systems (Khamidov et al., 2023).

Water for Energy: Water plays a vital role in energy production, including hydropower generation, cooling of thermal power plants, and energy extraction processes in the region (Djumaboev et al., 2019). Bearing in mind that water is needed for the extraction, transfer, production, hydropower and consumption of energy. Increasing energy demands, driven by population growth and economic development, heighten competition for limited water resources, presenting a significant challenge for sustainable management (Molefe and Inglesi-Lotz, 2023).

Energy for Water: Energy is integral for water pumping, treatment, and distribution, especially in water-scarce regions. Consequently, the value of energy constraints related to the human and agriculture sector need for water has increased substantially. The direct use of water for mechanical energy has changed to more complicated uses of energy. For instance, dams provide both irrigation water for agriculture and hydroelectricity (Yillia, 2016). Advanced irrigation technologies, such as pressurized systems, demand considerable energy inputs to ensure effective water management. This highlights the energy intensity of modern water management systems and their implications for sustainable development (Zhiltsov et al., 2018, Hamidov and Helming, 2020).

Water for Food: Water is indispensable for agriculture, serving both as a direct input for irrigation and indirectly through food processing and virtual water trade. Crop yields and agricultural land productivity decline as a result of growing drought conditions and water scarcity (Chathuranika et al., 2023). Agriculture, as the largest global consumer of freshwater, necessitates efficient water-use strategies to meet growing food demands sustainably (Hamidov et al., 2024). Currently, agriculture accounts for 1.5 billion hectares of the world's total land area, which is equivalent to 12% of it, used for global food production. Approximately 1.1 billion hectares are irrigated using rainwater. Agriculture uses a substantial amount of water in the world The trade in agricultural and food products usually includes the trade in water, crucial for their production. Because, food trading also involves the trade of water, which is used to produce the product called virtual water, from the perspective of the consumption of water resources. (Salem et al., 2022).

Food for Water: The agricultural sector is heavily reliant on chemical fertilizers and pesticides to maintain crop yields. This dependency, especially for water-

intensive crops, contributes to significant runoff into irrigation canals, reservoirs, and groundwater systems (Kulmatov, 2014, Schmidt et al., 2024). The resultant water pollution degrades water quality, limiting its suitability for drinking, domestic use, and sustaining ecosystems. This highlights the critical need for integrated strategies to manage agrochemical use and its impact on water resources (Stephan et al., 2018).

Food for Energy: The study did not identify significant interconnections between food production and energy systems in the region, suggesting potential gaps or opportunities for future research and integration.

By employing this WEF nexus analytical framework, the study identifies both challenges and opportunities for improved sectoral cooperation. It provides valuable insights into leveraging these interconnections to support Uzbekistan's sustainable development agenda, emphasizing the importance of integrated strategies for resource management in addressing complex regional WEF nexus issues.

3. Materials and Methods

3.1. Case study area description

In response to massive and irrational water and land development during the Soviet era, which resulted in significant deterioration of water and land resources and the Aral Sea catastrophe, the Aral Sea Basin (ASB), which includes five nations (Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan) in CA, is well recognized across the world. The economic development of the ASB countries, particularly Uzbekistan in many respects, is connected to the availability of water and land resources and their sustainable use (Kulmatov, 2014). Intensive irrigation initiatives focused on steppes and desert areas, with the objective of cultivating cotton in the Amu Darya and Syr Darya river basins (Koriyev et al., 2024). Uzbekistan has the largest territory of irrigated agriculture in CA, and agriculture is an important sector of the Uzbek economy, accounting for 20.3% of gross domestic product (GDP) and providing the livelihood for almost half of the population. More than 45% of the population in CA live in Uzbekistan, making it the region's most populous country in the region (Roßner and Zikos, 2018).

The water management system operates irrigation and drainage, including 28,400 canals, 54,432 hydraulic structures, 70 reservoirs and mudflow reservoirs with a total capacity of 19.4 billion cubic meters. Due to disproportionate distribution of water resources in the country and difficult topography of the irrigated areas, around 60% of the irrigated lands have to be irrigated with 1687 pumping stations, the annual electricity consumption of which makes 8 billion kWh (Gofurov et al., 2023). Besides, Water Consumer Associations (WCA), farmers and clusters operate 155.2 km of irrigation networks and more than 10,280 pumping stations. More than 12.4%

of irrigation wells are operated in the country, including 4153 in the water sector (Khamidov et al., 2023). Since 2019, a new system of state support for water-saving irrigation technologies has been launched. As a result, drip irrigation technology was installed on the area of 77,470 ha, sprinkler irrigation - 1123 ha, and discrete irrigation - 2000 hectares. At the same time, the share of areas covered with such modern irrigation technologies remains low, namely about 6% (Djumaboev et al., 2019). As a result, the volume of water consumption per hectare is 10,690 cubic meters, which is high as compared to the developed countries. Improving irrigation management is a critical issue.

Over 60% of irrigated land in Uzbekistan receives at least part of the water from pump irrigation. The most part of pump irrigated land of Uzbekistan is in Kashkadarya region. The region plays major part in the economy of Uzbekistan (Djumaboev et al., 2017). Over 60% of irrigated land in Uzbekistan receives at least part of the water from pump irrigation and the most part of pump irrigated land of Uzbekistan is located in the Kashkadarya region. Therefore, we explored the interlinkages between WEF sectors in the lift irrigated agriculture and selected the Kashkadarya region as case study area for this research.

The Kashkadarya region is rich in production of natural gas, agricultural products (cotton, wheat, fodder crops, fruits, and vegetables), and raw materials for construction. The region is important for the Uzbek economy. The total area of the Kashkadarya region is 28,400 km². It is situated in the southwestern part of Uzbekistan and borders with Bukhara, Surkhandarya, and Samarkand regions in Uzbekistan as well as with Tajikistan and Turkmenistan (Figure 2).

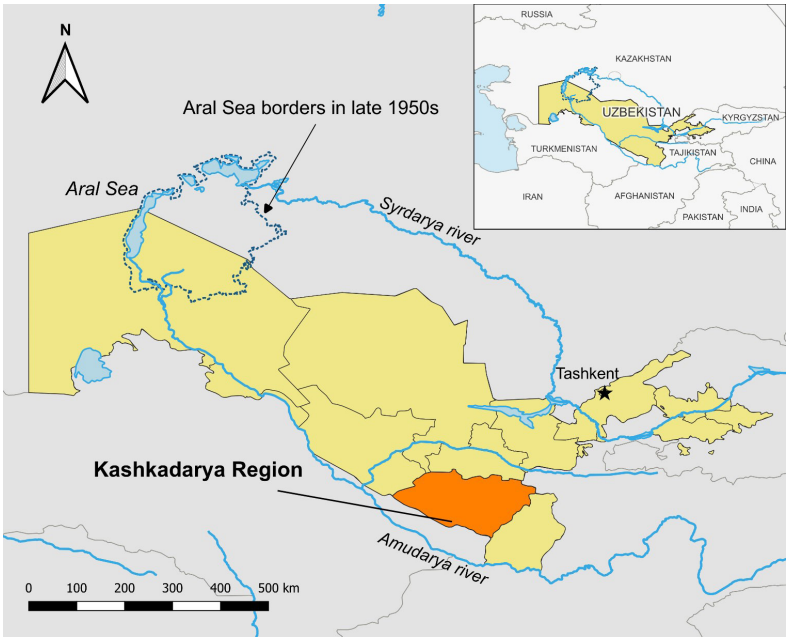

Figure 2. Map of study area

Irrigated agriculture plays a major economic role for the region and human life of rural population. There are about 0.5 million hectares of irrigated land, or 17% of the total area of the region. The most part of pump irrigated land of Uzbekistan is in the Kashkadarya region. Aksuv, Katta Uradarya, Yakkabagdarya, Kashkadarya, Tanhozdarya, and Djinddarya internal rivers are the main water source for the irrigated land in the region. Approximately 75% of water is lifted from Amu Darya River through a cascade of pumping stations. The remaining water comes from the Zarafshan River (5%) as well as from Kashkadarya River and other mentioned internal rivers (20%). Water from Amu Darya River is typically lifted over 130 m by seven pumping stations into Karshi Main Canal (KMC) and discharged into the Tallimarzhan water reservoir. It implies that this region has been using a huge amount of energy for irrigated agriculture (Djumaboev et al., 2017). The Kashkadarya region includes about one million hectares of land suitable for irrigation, due to the water scarcity in the region, which is only around 0.5 million hectares of cultivated land. Every year, the region's lack of water resources increases the hazard to agricultural production (Djumaboev et al., 2019).

The irrigation system in the Kashkadarya region is heavily reliant on energy-intensive lift irrigation methods, necessitating significant amounts of energy to pump water to higher elevations (Hamidov and Helming, 2020). This infrastructure, while vital for sustaining agricultural production, faces several technical challenges, including outdated equipment, high energy consumption, and inefficiencies in water distribution. These issues not only strain the region's energy resources but also exacerbate water scarcity, which is a critical factor for achieving water and food security. These technical improvements, although not the primary focus of this study, are closely linked to the broader WEF nexus (Djumaboev et al., 2019). Without addressing these underlying technical challenges, achieving sustainable intersectoral cooperation and leveraging the WEF nexus to support the SDGs would remain insufficient.

Figure 3 illustrates the most part 85.8% of water in the region used in irrigation sector, 8.6% for the energy sector and 4.6% is for communal service, industry, fishery, and 1% of water in the region gets lost.

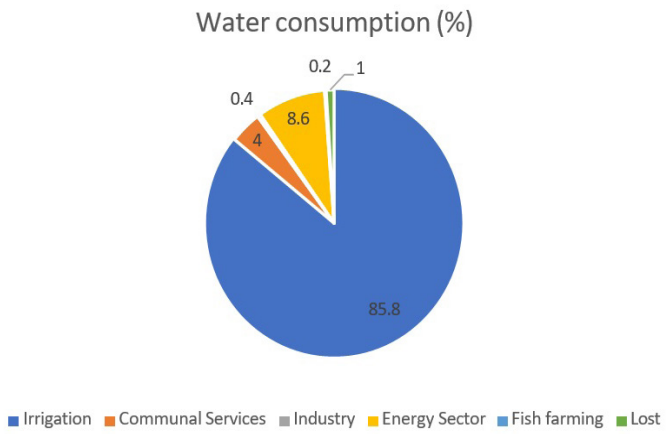

Figure 3. Water consumption by sectors in Kashkadarya

The interactions between water, energy, and food sectors in Uzbekistan's lift-irrigated agriculture are characterized by both conflict and cooperation. The water sector's high dependency on energy for pumping irrigation water, coupled with energy demands for electricity generation, often leads to competition for resources, especially during drought periods (Khamidov et al., 2023). The Ministry of Water Resources (MWR) and the Ministry of Energy (ME) sometimes prioritize their sector-specific objectives, resulting in reduced cooperation. Additionally, conflicting goals between water usage for irrigation and energy production exacerbate tensions. However, cooperation does occur in structured environments, such as annual planning meetings for water allocation and shared infrastructure projects. Existing platforms, like social media groups and formal agreements, facilitate some collaboration between water and agriculture sectors. Nonetheless, significant gaps remain in aligning the priorities of the ME and the Ministry of Agriculture (MA), highlighting the need for enhanced institutional mechanisms to support cross-sectoral synergy. Strengthening this cooperation is vital for addressing resource inefficiencies, reducing costs, and promoting sustainable development (Khamidov et al., 2023).

Over the past 10–15 years, Uzbekistan has made notable strides in aligning its national priorities with the SDGs. Specific to SDG 6, SDG 7, and SDG 2, the country has undertaken significant reforms in water, energy, and agricultural sectors, which are pivotal to the WEF nexus (Hamidov and Helming, 2020, Karimov et al., 2021).

In the Kashkadarya region, efforts to improve water resource management have been visible through the adoption of modern irrigation technologies such as drip irrigation and discrete irrigation systems, although their coverage remains limited to approximately 6% of irrigated areas (Djumaboev et al., 2019). These measures directly contribute to water-use efficiency and support SDG 6, while also addressing

energy demands SDG 7 associated with lift irrigation systems, which consume around 8 billion kWh annually (Gofurov et al., 2023).

On SDG 7, Uzbekistan has focused on diversifying its energy mix, emphasizing renewable sources such as solar and wind. In regions like Kashkadarya, where irrigation heavily relies on energy-intensive pumping, improving energy efficiency remains a critical goal (Kulmatov, 2014). The region's reliance on Amu Darya River water, lifted through cascades of pumping stations, exemplifies the interplay between water and energy sectors and underscores the importance of enhanced cooperation within the WEF nexus.

Regarding SDG 2, the region has witnessed shifts in agricultural practices, including crop diversification. While staple crops like cotton and wheat dominate, there has been an increase in cultivating high-value crops such as vegetables and fruits. These changes aim to enhance food security and reduce water dependency, aligning with both SDG 2 and broader WEF nexus objectives (Hamidov and Helming, 2020).

Despite these achievements, challenges persist. Limited intersectoral cooperation, inefficient resource use, and institutional silos continue to hinder the integration of WEF nexus approaches into sustainable development strategies. Strengthening cooperation among water, energy, and food sectors, promoting technological innovation, and fostering stakeholder engagement are crucial for accelerating progress toward SDGs by 2030.

As a result, the cost of irrigation water in the Kashkadarya region is high. Therefore, a case study approach appeared most appropriate for research into the problems of cross-sectoral challenges among water users, energy producers, and agriculture food producers in the Kashkadarya region.

3.2. Data collection and analysis

In this study the primary data collection technique was used. Primary data analysis refers to the process of collecting and analyzing data directly from its source. This can be done through various methods such as interviews, surveys, experiments, or observations (Guillaume et al., 2015). For our research analysis, we used semi-structured expert interview with 22 WEF experts from six of representatives of five Ministries, including MWR, ME, MA, Ministry of Innovational Development (MID) and Ministry of Finance (MF) of Uzbekistan who are involved in decision making in WEF sectors in Uzbekistan. Furthermore, expert interviews were conducted with key WEF academic experts from “Tashkent Institute of Irrigation and Agricultural Mechanization Engineers” National Research University (“TIIAME” NRU), Scientific Research Institute of Irrigation and Water Problems (SRIIWP) under “TIIAME” NRU. Besides that, we interviewed two international organizations working on WEF issues

in the country, namely, International Water Management Institute (IWMI) Central Asia office in Tashkent and World Bank. Accordingly, a total of five local farmers in the Kashkadarya region were interviewed. The selection of participants for the interviews was conducted with careful consideration to ensure a diverse and representative sample of stakeholders in the lift-irrigated agriculture sector of the Kashkadarya Region. The study specifically aimed to include farmers from a range of socioeconomic backgrounds to capture varied perspectives on water and energy use in agriculture. In addition, we contacted different private consulting firms – such as the Tunser Irrigation Engineering (TIE) and Nazar Business and Technology, LLC (NBT) who were also involved in agriculture and irrigation management, water, and energy technology infrastructure in Uzbekistan. Furthermore, we initially conducted an in-depth expert interview with two regional WCA members and four local farmers. Data on the views of knowledgeable people from the case study region was collected using Zoom platform.

A qualitative data analysis tool Atlas.ti was employed for analyzing the collected data. Atlas.ti is a comprehensive qualitative data analysis tool developed to assist researchers analyze and understand complicated data (Friese, 2012, Silver and Lewins, 2014). Atlas.ti is a qualitative data analysis program providing tools for text analysis, coding, and data organization. It enables systematic and orderly analysis and exploration of vast amounts of textual data by researchers (Friese, 2012). Audio recording was used to record all interviews with WEF experts when respondents consented to record and use for this study. National, regional, and local interviews were conducted in the local Uzbek language. Afterwards, all recorded interviews were translated into English and transcribed. In order to address the potential biases in translating interviews from Uzbek to English, a bilingual expert familiar with both Uzbek and English agricultural terminology reviewed the transcriptions to ensure accuracy and consistency. To avoid interpretative distortions, we maintained direct translations for technical terms while providing the necessary context for clarity. These steps aimed to preserve the integrity of the responses and minimize potential biases in translation. The transcriptions were then imported into Atlas.ti 6.2, which assisted in the analysis of the qualitative text data. The entire transcribed document was subject to coding scheme using a deductive strategy established based on the conceptual frameworks implemented in this research. Codes were developed based on post-empirical data. The codes were also incorporated during the design and after implementation of semi-structured interviews (Table I). This table outlines the thematic categories derived from the semi-structured expert interviews, which were analyzed using the Atlas.ti software. These categories provide insight into the core aspects of cooperation and challenges within the WEF nexus in Uzbekistan's lift-irrigated agriculture. The themes include cooperation mechanisms, food security

conditions, water security challenges, energy security issues, and the WEF nexus's relevance to achieving SDGs. Each theme is supported by definitions and code themes that emerged during the analysis, illustrating the interconnected nature of the WEF sectors.

Table I. List of categories extrapolated using Atlas.ti software

Code Definition	Code Theme	Interview Examples
WEF nexus cooperation	Cooperation|Trust| Collaboration| Meetings|Interlinkages| Knowledge sharing	"There are regular meetings between water and agriculture ministries to plan..," "Farmers lack modern irrigation knowledge, requiring more training from experts."
Food security condition	Logistic|Food Wasting |Export potential| Hunger |Satisfaction	"Crop yield is insufficient due to unreliable water supply during peak seasons."
Water security	Water shortage| Water scarcity|Water problem	"The Karshi Canal cannot meet irrigation demand during summer due to limited flow."
Energy security	Energy shortage|Energy crisis	"Pumping stations often fail due to energy shortages during peak irrigation times."
WEF relevance to SDGs	SDG|Sustainability| Economic|Social|Environmental	"By improving energy efficiency, we can better align with SDG7 goals."

4. Results and Discussion

The findings confirm the significant energy demands of irrigated agriculture in the Kashkadarya region, particularly for pumping. Similar to Djumaboev et al. (2017) who emphasized high energy inputs in lift-irrigated systems, this study identified electricity costs as a primary barrier to agricultural productivity. However, diverging from Djumaboev et al. (2017), the stakeholder interviews revealed that farmers often lack awareness of energy-efficient practices, highlighting a gap in capacity building and technology dissemination.

Expert interviews were conducted with 22 WEF experts that have some experience and role in WEF sector decisions in Uzbekistan. These experts represent diverse levels of decision-making agencies influencing the cooperation in the lift irrigated areas. Wagner et al. (2012) propose that in the social science strategy, observation plays a significant role in collecting data about interview participants, their background, and behaviors. Therefore, we started our interviews with basic and academic background questions. Figure 4 indicates that the majority of the

interviewees are highly qualified, namely nine of them have doctoral degrees (DR.), six of them have Master of Science (MSc.), six of them have Bachelor of Science (BSc.) and one has a secondary school degree (SD).

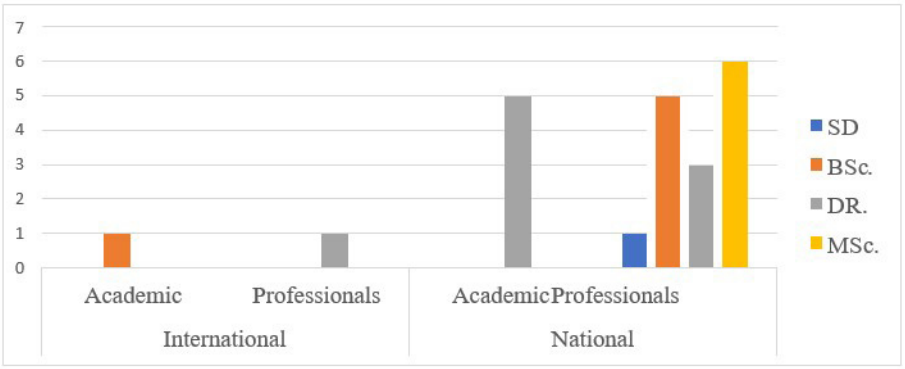

Figure 4. Number of interviews by organizations and academic qualifications

A total of five local farmers in the Kashkadarya Region were interviewed. Four farmers finished higher education, whereas one farmer did not continue with the higher education (Figure 5). Nevertheless, the latter had sufficient knowledge and experience regarding the discussion of WEF and other local organizations.

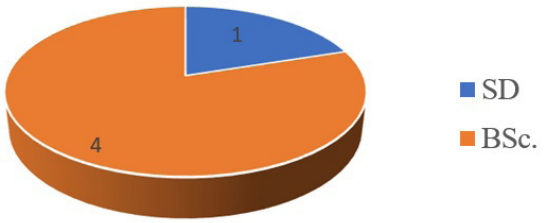

Figure 5. Number of farmers by academic qualifications

Figure 6 shows the number of experts discussing intersectoral cooperation agreements among the WEF sectors in Uzbekistan. The data highlights that more experts observed cooperation between the water and food sectors (15) compared to water and energy (7) or energy and food (2).

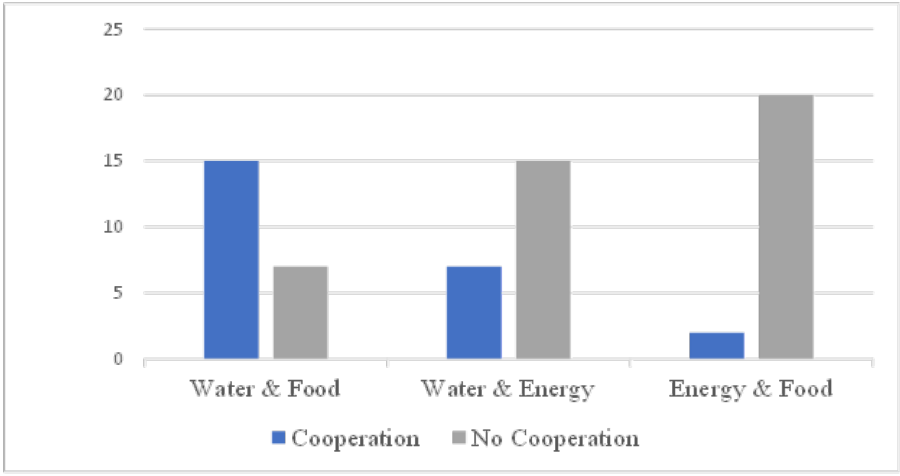

Figure 6. Intersectoral cooperation among WEF sectors in Uzbekistan

More than 80% of the interviewed experts stated that cooperation is the most significant factor in the lift irrigated agriculture in Uzbekistan. In the context of decision-making structures, good cooperation among the three sectors can lead to increased agricultural productivity and avoid water and energy wasting. However, academics claimed that the lack of knowledge of farmers and having limited ability of WCA chairman can also cause lack of cooperation because most of the farmers are old and have limited up-to-date knowledge about the agriculture and irrigation practices. Therefore, the number of complaints from farmers about decision-making institutes is increasing. A significant barrier identified is the limited integration of renewable energy sources, such as solar power, into water-pumping operations. Despite policy-level initiatives promoting renewable energy adoption, stakeholders reported a lack of financial incentives and technical expertise as key constraints. These findings echo the broader global discussions by Hoff (2011) on the importance of clean energy integration in water management systems. After analysing the interviewswe argue that conditions for effective intersectoral cooperation that might have impact in lift irrigated areas: effective communication, clear goals, and the shared commitment to the desired outcomes.

Water for Energy: Water plays a crucial role in energy production in the region, particularly for hydropower and thermal plant cooling. This aligns with findings by Kalvani and Celico (2023) , who highlighted water scarcity challenges in energy systems across water-stressed regions. However, unique to this study is the competition between agricultural and energy sectors for limited water resources. Interviewees identified weak cross-sectoral coordination as a persistent issue, echoing Turner et al. (2017), who cited institutional silos as a barrier in nexus implementation.

Energy for Water: The energy sector's role in water management is pivotal, especially for ensuring consistent water supply in lift-irrigated agriculture. However, energy shortages, especially during peak irrigation periods, exacerbate water scarcity challenges. Interviews with Ministry of Energy representatives revealed that the lack of prioritization for agricultural energy needs, compounded by bureaucratic delays, leads to inefficiencies in water distribution. Hamidov and Helming (2020) similarly identified energy insecurity as a critical bottleneck for irrigation-dependent agriculture in CA. To address these gaps, stakeholders recommended targeted investments in energy-efficient pumping systems and the exploration of decentralized solar-based energy solutions. Such interventions could alleviate the burden on national grids while ensuring a reliable energy supply for irrigation.

Water for Food: Agricultural water use, particularly for water-intensive crops such as cotton and wheat, remains the largest contributor to water consumption in Kashkadarya. Similar to findings by Hamidov et al. (2016), inefficiencies in irrigation practices exacerbate resource stress. Stakeholders pointed out the urgent need for water-saving technologies and better planning, consistent with Hoff (2011), who emphasized the potential of innovative water management to enhance food security. The study uncovered significant inefficiencies, such as over-irrigation and improper crop selection, which exacerbate water stress. Local farmers expressed concerns about water allocation during summer months, often citing delays and inadequate distribution by WCAs. These findings are consistent with those of Karimov et al. (2021) who noted the inefficiencies in water use and the pressing need for improved irrigation practices in Uzbekistan.

Despite ongoing efforts to introduce water-saving technologies, adoption rates remain low, with only 6% of irrigated land utilizing modern methods like drip and sprinkler systems (Gofurov et al., 2023). The lack of financial incentives and technical training for farmers were cited as primary barriers. Addressing these challenges requires a multifaceted approach, including capacity-building programs, subsidies for water-saving technologies, and enforcement of water-use regulations to optimize resource utilization.

Energy for Food: The agricultural sector in Kashkadarya heavily depends on energy for mechanization, transportation, and fertilizer production. Interviewees noted that energy inefficiencies, coupled with high dependency on subsidized electricity, deter investments in innovative energy-saving technologies. These findings align with Hoff (2011) analysis of the energy demands in agriculture, particularly in regions reliant on intensive irrigation systems.

Food for Water: Excessive use of agrochemicals, particularly fertilizers and pesticides, has led to significant water quality degradation in irrigation canals and groundwater. This finding complements the observations by Kulmatov (2014) on

environmental pollution in Uzbekistan's irrigated agriculture. The study extends this understanding by linking pollution issues directly to poor regulatory enforcement and limited farmer education. Furthermore, the competing demands between bioenergy production and food security present a growing challenge. While stakeholders acknowledged the potential of biomass as an alternative energy source, they cautioned against policies that could divert critical resources away from food production. This aligns with the global discourse by Terrapon-Pfaff et al. (2018) who highlighted the socio-economic trade-offs of biofuel expansion in agriculture-dependent regions.

Food for Energy: Unlike other linkages, this study did not find significant interactions between food production and energy sectors in the region. This result aligns with the observations of Terrapon-Pfaff et al. (2018), who noted that food-energy linkages often remain underexplored in localized nexus studies. It highlights an opportunity for future research to investigate potential synergies or overlooked connections. The role of agriculture in contributing to energy production, particularly through bioenergy, remains an underexplored area in the region. While the interviews provided limited data on this dimension, the integration of biomass energy from agricultural residues could offer a dual solution for managing waste and generating energy. Future research should investigate the feasibility of such initiatives in Uzbekistan, drawing lessons from global best practices.

The study identified significant barriers to intersectoral cooperation, with stakeholders repeatedly citing a lack of trust, communication gaps, and conflicting priorities among water, energy, and food sectors.

These findings are consistent with Hamidov and Helming (2020), who criticized the single-sector strategies prevalent in WEF nexus research. Stakeholders emphasized the need for institutional frameworks that foster collaboration through joint planning, shared resources, and regular communication channels. For instance, establishing inter-ministerial committees could facilitate the alignment of sectoral priorities and reduce operational silos.

The interviews revealed notable discrepancies between the perceptions of academics and farmers regarding intersectoral cooperation and resource use in the WEF nexus. Academics often emphasized the importance of implementing advanced water- and energy-saving technologies and highlighted systemic barriers, such as institutional silos and lack of strategic alignment among WEF sectors. In contrast, farmers predominantly focused on immediate, practical challenges, such as insufficient water delivery during peak demand periods and the perceived inefficiency of WCAs. While academics pointed to a lack of policy coherence as a root cause of inefficiencies, farmers frequently attributed issues to mismanagement or lack of transparency at the local level. Moreover, farmers expressed frustration over limited access to training and knowledge-sharing platforms, whereas academics

often assumed that such mechanisms were sufficiently available. These contrasting perspectives underscore the need for targeted interventions to bridge the gap between theoretical recommendations and on-the-ground realities.

One of our main objectives was to analyze how the water and agriculture sectors cooperate. According to fifteen interviewees, cooperation between two sectors is sufficient. They emphasize that they participate in formal meetings with the representatives of MA and MWRs on a weekly basis, and a representative of the MWRs indicates that they have established social media groups on platforms like WhatsApp and Telegram, where farmers, stakeholders, and WCA members may contact them or post with their daily problems or requests. MWR representatives stated that they meet annually at the beginning of the year to review potential water availability, precipitation forecasts, and make planning on water distribution.

Approximately 70% of interviewees claim there is a lack of cooperation between the ME and MWR sectors. As they argue that it is a very problematic issue for these two sectors to cooperate and collaborate. There can be different priorities and goals between the sectors and there can be a lack of resources and capacity to support cooperation. Both of the two sectors need water. Water is needed for the ME to produce electrical power in the country, and the MWR also needs massive amounts of water for irrigated agriculture. However, the MWR always tries to make a deal, as they need electricity for the lift irrigated agriculture in Uzbekistan. The remaining 30% of experts assume that lack of cooperation between water and energy sectors causes water waste and food security issues. Thus, based on their assumptions, in reality the cooperation between the two sectors works regularly. They also believe that the energy and water sectors cooperate adequately. In this scenario, the representatives of the two Ministries argue that they are developing their cooperation every year, however the lack of cooperation is still occurring adequately. But the ME demonstrates lack of cooperation between two sectors, and it sometimes causes energy-waste issues. The electricity is the most critical part for the lift irrigated agriculture in Uzbekistan. While conducting these interviews, We also noted additional conditions that might have an impact on the cooperation, which are summarized in Figure 7. As can be seen from Figure 7, the most commonly discussed topic among the various WEF experts were cooperation and the current water security issues under different contextual conditions. As local farmers state, there are a number of challenges that exist for successful cooperation in the WEF nexus. First, there is often a lack of trust and communication between the farmers and WCAs members. Second, there can be different priorities and goals between the sectors. Third, there can be a lack of resources and capacity to support cooperation.

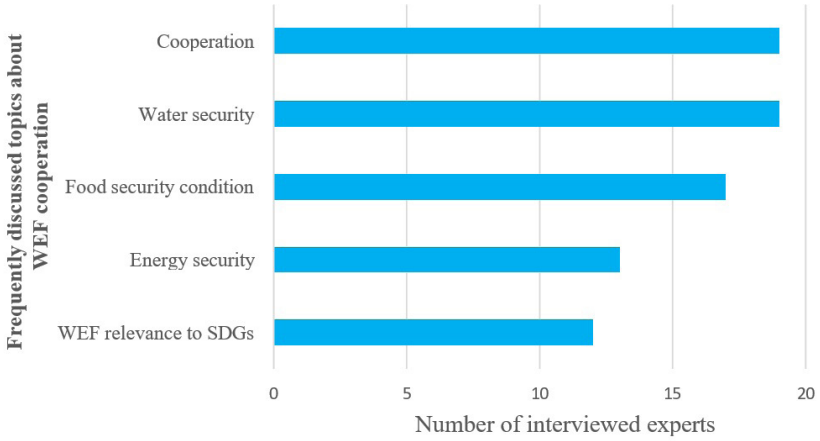

Figure 7. Analysis of expert views regarding WEF nexus in Uzbekistan, derived from Atlas.ti software analysis

According to the interview results, local farmers do not receive water in a required amount in due time, because the local WCA members pretend that the water is always wasted by farmers. For instance, the Karshi and Zarafshan BISA representatives assume that one of the main reasons for lack of cooperation between them is farmers' knowledge and willingness to save the limited amount of water. Even though decision-making organization WEF specialists advise against planting high water-demanding crops for the following year due to a lack of perception and water reservoir potential, farmers want to plant high water-demanding crops and complain about water scarcity. Both two sectors assume that unless any legal mechanism (e.g., rules or fines) is enforced against rule-breaking individuals, it is difficult to achieve stable cooperation among all three sectors.

Based on the results of the semi-structured interviews, this research hypothesizes that improving our understanding of how the water, energy, and food sectors are interconnected in lift-irrigated areas in Uzbekistan, and how they relate to the SDGs, will demonstrate the importance of intersectoral cooperation between these sectors. The SDGs that are most relevant to the WEF nexus in Uzbekistan are SDG 2, SDG 6, and SDG 7. As Allouche et al. (2015) state, it is difficult to dispute the idea that by recognizing the cooperation between the three sectors, synergies can be formed and trade-offs avoided, leading to the acceleration of sustainable development. This research provided a good overview of the challenges and opportunities for the intersectoral cooperation within the WEF sectors in Uzbekistan. Thus, during the semi-structured expert interviews, particular key phrases such as sustainable, irrigation, water, energy, and food were discussed numerous times (Figure 8). And it indicates the challenges to cooperation and conditions that might have an impact on the cooperation among the three sectors.

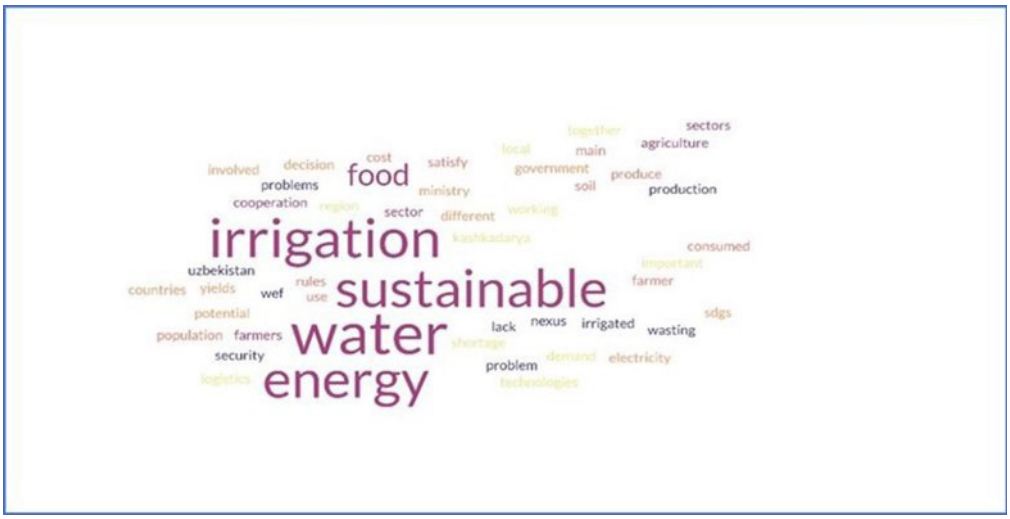

Figure 8. Illustration of mostly discussed phrases during the interviews

This research finds that there is a lack of cooperation between the water and energy sectors in Uzbekistan. There is a growing recognition of the importance of intersectoral cooperation in the WEF nexus in Uzbekistan; this is reflected in the increasing number of cooperation agreements between different sectors. The result of this study shows that the number of cooperation agreements in the WEF sectors in Uzbekistan and illustrates that there are more cooperation agreements between water and food than between water and energy or energy and food sectors. In this matter, Hamidov and Helming (2020) comment that previous research studies lacked a specific cross-sectoral approach in the WEF nexus. Thus, this paper discusses the importance of cross- sectoral cooperation between WEF sectors in Uzbekistan to fill in the gap which was specified earlier in this research. The result of the expert interview revealed that there are a number of benefits to intersectoral cooperation in the WEF nexus. First, it can help to improve efficiency and reduce costs. For example, by cooperating, the water and food sectors can share resources and infrastructure. Second, it can help to mitigate risks and vulnerabilities. For example, by cooperating, the water and energy sectors can develop contingency plans for droughts and other water shortages. Third, it can help to promote sustainable development. By cooperating, the three sectors can develop solutions that meet the needs of the present without compromising the ability of future generations to meet their own needs.

Among all challenges, experts particularly highlighted three main hindrances to intersectoral cooperation. First, there is often a lack of trust and communication between the different sectors. Experts were reasoning this by claiming that there are no proper communication methods that could inform farmers during abnormal weather conditions. Furthermore, they added that they never have a chance to

communicate or meet together with the representatives of either MWR or MA, which further discourages them from performing their duties with care. Second, there can be different priorities and goals between the sectors. This challenge was particularly striking in areas where the water and energy relationship is high. Experts in these areas state that the energy sector is highly dependent on water to produce electricity and the water sector, in turn, same as energy sector needs water for irrigated agriculture, but also energy in lift irrigated agriculture. Thus, because of dependency on the same resources for producing utilities in these two sectors, there will always be a doubt on improvement of successful cooperation between energy and water sectors in the country. Third, there can be a lack of resources and capacity to support cooperation. There were also additional obstacles that experts mentioned during the interview which are self-explanatory and highlighted below:

- Lack of knowledge and willingness of farmers to cooperate.
- Lack of trust and communication between the different sectors.
- Lack of qualified specialists.
- Financial constraints.
- Water scarcity.

Yet, this research could not explicitly discover the cooperation between the energy and food sectors in Uzbekistan. This is due to the fact that the two sectors are not seen as being linked in the country by the majority of interviewed experts. The majority of international and academic experts argue that despite the challenges, there are a number of things that can be done to promote intersectoral cooperation in the WEF nexus. First, it is important to build trust and communication between the different sectors. This can be done through dialogue and cooperation on shared projects. Second, it is important to align the priorities and goals of the different sectors. This can be done through strategic planning and coordination. Third, it is important to provide the resources and capacity needed to support cooperation. This is achieved through funding, training, and technical assistance. However, the increasing number of cooperation agreements is a positive sign. With continued effort, Uzbekistan can make considerable progress in promoting intersectoral cooperation in the WEF nexus and achieve sustainable development.

In addition to the challenges mentioned above, there are a number of other factors that can hinder intersectoral cooperation in the WEF nexus. These include:

- Lack of political will: Governments must be willing to invest in intersectoral cooperation and create a supportive policy environment.
- Institutional barriers: There may be institutional silos that prevent different sectors from working together effectively.
- Cultural differences: There may be diverse cultural norms and values that make it difficult for the different sectors to communicate and collaborate.

The WEF nexus in lift-irrigated agriculture in Uzbekistan faces challenges, but there is growing recognition of the importance of cross-sectoral cooperation. Continued effort is needed to improve cooperation and achieve sustainable development in Uzbekistan's WEF nexus.

The nexus is a complex system that involves the interconnection of water, energy, and food resources. It is a critical issue for sustainable development in Uzbekistan, as the country faces challenges in all three areas. A conceptual framework that could also really promote the effective implementation of the SDGs is the WEF nexus. The review findings indicated that most publications revealed a single-sector strategy, while the WEF nexus research emphasizes cross-sectoral cooperation. Therefore, the WEF nexus approach and relevance to SDGs are studied and analyzed in this study.

The interviewed experts agreed that the WEF nexus is relevant to the SDGs in Uzbekistan. They reiterated that these goals are all interconnected, and progress in one area can help to achieve progress in another. For example, improving water management can help to increase agricultural productivity, which can lead to food security. Similarly, investing in renewable energy can help to reduce pollution and improve air quality, which can benefit human health. The interviewed experts also identified a number of challenges that the country faces in these areas. Most experts claim that one of the most pressing challenges is water scarcity. Uzbekistan is a landlocked country with a hot and dry climate, and its water resources are limited. This is a major constraint on agricultural production, and it also affects the availability of water for drinking, sanitation, and industrial use. The agricultural sector is highly dependent on water, which can be challenging in current situations where it encounters water insecurity challenges. International experts also complained that Uzbekistan is not using its water and energy up to high efficiency possible. Consequently, this is leading to waste and pollution, which can be a major obstacle to sustainable development.

On top of that, experts mentioned another challenge as the energy security. They demonstrated that Uzbekistan is heavily dependent on imported energy, and this makes it vulnerable to price fluctuations and supply disruptions. The country is also facing increasing demand for energy as its economy grows. Energy security is a complex issue, and there is no unique and simple solution to it. However, academics suggests that by implementing the right policies and investing in modern technologies, Uzbekistan can achieve energy security and contribute to the achievement of the SDGs by 2030.

Overall, the literature review and results of the study provide important insights into the challenges on cooperation of the WEF nexus in lift-irrigated agriculture. The experts' recommendations are relevant and timely, and they could help to improve

cooperation between WEF sectors, and to achieve the three SDGs in Uzbekistan by 2030. Furthermore, the findings show that the WEF nexus is a critical issue for sustainable development in lift-irrigated areas in Uzbekistan and by taking steps to improve the WEF nexus, the country can achieve its development goals and improve the quality of life of its citizens. The empirical results of the expert interviews and Atlas.ti analysis showed that there are challenges to intersectoral cooperation in the WEF nexus in Uzbekistan. These include:

- Lack of trust and communication between the different sectors.
- Different priorities and goals between the sectors.
- Lack of resources and capacity to support cooperation.
- Lack of political will.
- Institutional barriers.
- Cultural differences.

The result of this research also illustrates that there is a growing recognition of the importance of intersectoral cooperation in the WEF nexus in Uzbekistan. With continued effort, Uzbekistan can make considerable progress in promoting intersectoral cooperation and achieving sustainable development. The WEF nexus in lift-irrigated agriculture in Uzbekistan faces challenges, but there is growing recognition of the importance of cross-sectoral cooperation. Continued effort is needed to improve cooperation and achieve sustainable development in Uzbekistan's WEF nexus.

5. Conclusion

The WEF nexus is a critical aspect for sustainable development in Uzbekistan, as the country faces challenges in the lift irrigated areas. The results of this study indicate that there is a lack of intersectoral cooperation among water, energy, and food sectors in Uzbekistan. This is a major challenge to sustainable development in the country.

Key challenges identified include a lack of trust and communication between sectors, differing priorities and goals, and inadequate resources and capacity for cooperation. Institutional silos and limited political will further exacerbate these issues, alongside cultural differences that hinder effective collaboration. Additionally, specific challenges such as water scarcity, inefficient energy use, and financial constraints complicate the operationalization of the WEF nexus in Uzbekistan.

The findings underscore several institutional barriers, including lack of trust, and communication gaps, which hinder effective cooperation among the WEF sectors in Uzbekistan's lift-irrigated agriculture. To address these, this study proposes the following solutions:

• Establishing Intersectoral Coordination Platforms: A formalized coordination body comprising representatives from the Ministries of Water Resources, Energy, and Agriculture is essential. This body should meet regularly to discuss integrated planning and resolve conflicts.

• Capacity-Building Programs: Training workshops focusing on the principles of the WEF nexus and integrated resource management should be organized for policymakers and local stakeholders to build mutual understanding and technical expertise.

• Policy Alignment and Joint Funding Mechanisms: Developing harmonized policies that recognize interdependencies among the sectors will minimize overlaps. Additionally, joint funding initiatives for projects such as water-saving technologies can foster collaboration.

• Stakeholder Engagement and Trust-Building: Regular stakeholder forums involving local farmers, energy providers, and water user associations can provide a platform for dialogue, thereby improving trust and communication.

By implementing these solutions, Uzbekistan can overcome the barriers to intersectoral cooperation and fully realize the benefits of the WEF nexus framework. Improved collaboration will not only enhance water, energy, and food security but also contribute to achieving SDG 2, SDG 6, and SDG 7 by 2030. This integrated approach will ensure sustainable development and improve the livelihoods of communities reliant on lift-irrigated agriculture.

This study faced several limitations, which highlight areas for future research.

Methodology: Atlas.ti was employed for qualitative analysis, providing structured insights from expert interviews. However, the tool was unable to fully analyze the complexities of cross-sectoral cooperation among WEF sectors. This limits the depth of findings regarding interdependencies between water, energy, and food.

Energy Focus: Energy plays a critical role in agriculture, powering irrigation and food production processes. While this study acknowledged these linkages, it did not comprehensively assess energy's contribution to intersectoral dynamics within the WEF nexus in the region.

Gender Balance: Achieving gender balance in interviews was challenging. Although 13 female WEF experts were contacted, only four participated, limiting the representation of diverse perspectives. Gender-inclusive insights remain an area for improvement in future research.

Despite these constraints, the data collected provides valuable insights into the WEF nexus and its relevance to SDGs, particularly in lift-irrigated areas. Further studies could deepen understanding of intersectoral cooperation, enhance the operationalization of the WEF nexus, and explore additional scenarios that connect water, energy, and food to SDGs.

Acknowledgements

First and foremost, we would like to express our appreciation and sincere thanks to the IWMI Central Asia team who supported Asliddin Bobocholov during the research over the internship of six months. In particular, our special gratitude goes to Kakhramon Djumaboev from the IWMI for his constant advice and encouragement, and valuable feedback. Unfortunately, he passed away at the time this study was drafted. We also would like to show our gratitude to the Arbeitsgemeinschaft Tropische und Subtropische Agrarforschung (ATSAF) e.V. who financially supported Asliddin Bobocholov's internship period of six-month at IWMI. Ahmad Hamidov's research for this paper benefited from the German Federal Ministry of Education and Research (BMBF) through the SusWEF project (FKZ: 01DK22002) and from the German Research Foundation (DFG) through the RebUZ project (GZ: HA 8522/2-2).

Furthermore, our special gratitude goes to the twenty participants in the expert interview and to those people who not only warmly agreed to the interview but made the research possible through their constant support

References

Allouche, J., C. Middleton, and D. Gyawali (2015). "Technical veil, hidden politics: Interrogating the power linkages behind the nexus." *Water Alternatives* 8(1)

Bazzana, D., J. Foltz, and Y. Zhang (2022). "Impact of climate smart agriculture on food security: An agent-based analysis." *Food Policy* 111: 102304. https://doi.org/10.1016/j.foodpol.2022.102304

Chathuranika, I., B. Khaniya, K. Neupane, K. M. Rustamjonovich, and U. Rathnayake (2022). "Implementation of water-saving agro-technologies and irrigation methods in agriculture of Uzbekistan on a large scale as an urgent issue." *Sustainable Water Resources Management* 8(5): 155. https://doi.org/10.1007/s40899-022-00744-8

Chathuranika, I. M., M. R. Koriyev, E. M. Wimalasiri, K. B. Asamovich, N. Muttil, and U. Rathnayake (2023). "Investigation of Rain-Fed Horticulture Productivity in the Namangan Region, Uzbekistan." *Water* 15(13): 2399. https://doi.org/10.3390/w15132399

Djumaboev, K., A. Hamidov, O. Anarbekov, Z. Gafurov, and K. Tussupova (2017). "Impact of institutional change on irrigation management: A case study from southern Uzbekistan." *Water* 9(6): 419. https://doi.org/10.3390/w9060419

Djumaboev, K., T. Yuldashev, B. Holmatov, and Z. Gafurov (2019). "Assessing Water Use, Energy Use And Carbon Emissions In Lift-Irrigated Areas: A Case Study From Karshi Steppe In Uzbekistan." *Irrigation and Drainage* 68(3): 409-419. https://doi.org/10.1002/ird.2345

Friese, S. (2012). "Atlas.ti 7 Quick tour." Atlas.ti Scientific Software, Berlin

Glassman, D., M. Wucker, T. Isaacman, and C. Champilou (2011). "The water-energy nexus." Adding Water to the Energy Agenda, A *World Policy Paper,* EBG Capital, Environmental Investments

Gofurov, A.-S., Z. Juraev, and Y.-J. Ahn (2023). "Regional Water Crisis: A Case Study of Uzbekistan and its Neighboring Countries."

Guillaume, J. H., M. Kummu, S. Eisner, and O. Varis (2015). "Transferable principles for managing the nexus: Lessons from historical global water modelling of central Asia." *Water* 7(8): 4200-4231. https://doi.org/10.3390/w7084200

Hamidov, A., and K. Helming (2020). "Sustainability considerations in water–energy–food nexus research in irrigated agriculture." *Sustainability* 12(15): 6274. https://doi.org/10.3390/su12156274

Hamidov, A., K. Helming, and D. Balla (2016). "Impact of agricultural land use in Central Asia: a review." *Agronomy for Sustainable Development* 36: 1-23. https://doi.org/10.1007/s13593-015-0337-7

Hamidov, A., U. Kasymov, N. Allahverdiyeva, and C. Schleyer (2024). "Governance of technological innovations in water and energy use in Uzbekistan." *International Journal of Water Resources Development* 40(1): 123-139. https://doi.org/10.1080/07900627.2023.2245589

Hamidov, A., U. Kasymov, A. Salokhiddinov, and M. Khamidov (2020). "How can intentionality and path dependence explain change in water-management institutions in Uzbekistan?" *International Journal of the Commons* 14(1): 16-29. https://doi.org/10.5334/ijc.1001

Hoff, H. (2011). Understanding the nexus. Stockholm Environment Institute

Hua, E., X. Wang, B. A. Engel, H. Qian, S. Sun, and Y. Wang (2021). "Water competition mechanism of food and energy industries in WEF Nexus: A case study in China." *Agricultural Water Management* 254: 106941. https://doi.org/10.1016/j.agwat.2021.106941

Kalvani, S., and F. Celico (2023). "The water–energy–food nexus in European countries: A review and future perspectives." *Sustainability* 15(6): 4960. https://doi.org/10.3390/su15064960

Karimov, A. K., R. H. Toshev, R. Karshiev, and A. A. Karimov (2021). "Water–energy nexus in Central Asia's lift irrigation schemes: Multi-level linkages." *Renewable and Sustainable Energy Reviews* 147: 111148. https://doi.org/10.1016/j.rser.2021.111148

Katila, P., C. J. P. Colfer, W. De Jong, G. Galloway, P. Pacheco, and G. Winkel (2019). Sustainable Development Goals, *Cambridge University Press*. DOI not available

Khamidov, M., J. Ishchanov, A. Hamidov, E. Shermatov, and Z. Gafurov (2023). "Impact of soil surface temperature on changes in the groundwater level." *Water* 15(21): 3865. https://doi.org/10.3390/w15213865

Koriyev, M. R., P. U. Fonseka, U. N. Umurzakova, K. U. Rozumbetov, S. Arachchi, V. O. Erkudov, D. Mehta, and U. Rathnayake (2024). "Soil salinity status in Namangan region, Uzbekistan." *Suranaree Journal of Science & Technology* 31(5)

Kulmatov, R. (2014). "Problems of sustainable use and management of water and land resources in Uzbekistan." *Journal of Water Resource and Protection* 2014

McCarl, B. A., Y. Yang, K. Schwabe, B. A. Engel, A. H. Mondal, C. Ringler, and E. N. Pistikopoulos (2017). "Model use in WEF nexus analysis: A review of issues." *Current Sustainable/Renewable Energy Reports* 4: 144-152. https://doi.org/10.1007/s40518-017-0078-0

Mohtar, R. H., A. T. Assi, and B. Daher (2015). Bridging the water and food gap: The role of the water-energy-food nexus, United Nations University Institute for Integrated Management of Material

Molefe, T., and R. Inglesi-Lotz (2023). "Examining the water–energy–food (WEF) nexus through an SDG lens for the big 5 African countries." *Environment, Development and Sustainability* 25(12): 14083-14100. https://doi.org/10.1007/s10668-023-03182-4

Rhouma, A., J. El Jeitany, R. Mohtar, and J. M. Gil (2024). "Trends in the Water–Energy–Food Nexus Research." *Sustainability* 16(3): 1162. https://doi.org/10.3390/su16031162

Roßner, R., and D. Zikos (2018). "The role of homogeneity and heterogeneity among resource users on Water Governance: Lessons learnt from an economic field experiment on irrigation in Uzbekistan." *Water Economics and Policy* 4(03): 1850008. https://doi.org/10.1142/S2382624X18500082

Salem, H. S., M. Y. Pudza, and Y. Yihdego (2022). "Water strategies and water–food Nexus: challenges and opportunities towards sustainable development in various regions of the World." *Sustainable Water Resources Management* 8(4): 114. https://doi.org/10.1007/s40899-022-00609-0

Schmidt, S., A. Hamidov, and U. Kasymov (2024). "Analysing groundwater governance in Uzbekistan through the lenses of social-ecological systems and informational governance." *International Journal of the Commons* 18(1)

Silver, C., and A. Lewins (2014). Using software in qualitative research: A step-by-step guide

Stephan, R. M., R. H. Mohtar, B. Daher, A. Embid Irujo, A. Hillers, J. C. Ganter, L. Karlberg, L. Martin, S. Nairizi, and D. J. Rodriguez (2018). "Water–energy–food nexus: a platform for implementing the Sustainable Development Goals." *Water International* 43(3): 472-479. https://doi.org/10.1080/02508060.2018.1446580

Taguta, C., A. Senzanje, Z. Kiala, M. Malota, and T. Mabhaudhi (2022). "Water-energy-food nexus tools in theory and practice: a systematic review." *Frontiers in Water* 4: 837316. https://doi.org/10.3389/frwa.2022.837316

Terrapon-Pfaff, J., W. Ortiz, C. Dienst, and M.-C. Gröne (2018). "Energising the WEF nexus to enhance sustainable development at local level." *Journal of Environmental Management* 223: 409-416. https://doi.org/10.1016/j.jenvman.2018.06.037

Turner, S. W., J. Y. Ng, and S. Galelli (2017). "Examining global electricity supply vulnerability to climate change using a high-fidelity hydropower dam model." *Science of the Total Environment* 590: 663-675. https://doi.org/10.1016/j.scitotenv.2017.03.022

Wagner, C., B. Kawulich, and M. Garner (2012). EBOOK: Doing social research: A global context, McGraw Hill

Yapiyev, V., Z. Sagintayev, V. J. Inglezakis, K. Samarkhanov, and A. Verhoef (2017). "Essentials of endorheic basins and lakes: A review in the context of current and future water resource management and mitigation activities in Central Asia." *Water* 9(10): 798. https://doi.org/10.3390/w9100798

Yillia, P. T. (2016). "Water-Energy-Food nexus: framing the opportunities, challenges and synergies for implementing the SDGs." *Österreichische Wasser-und Abfallwirtschaft* 68(3): 86-98. https://doi.org/10.1007/s00506-016-0297-4

Zhiltsov, S., Parkhomchik L., Slisovskiy, D., and Medvedev, N. (2018). "Central Asia Today: A New Wave of Water and Energy Cooperation and Pipeline Architecture." *Central Asia & the Caucasus* 19(2)