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## The water-energy-food nexus in Kazakhstan: challenges and opportunities

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### Abstract

The concept of the water, energy, food nexus is extremely relevant to Kazakhstan as the country faces population growth, economic progress and environmental challenges such as water scarcity, desertification, and climate change. Furthermore, poor sectoral coordination and inadequate infrastructure have caused unsustainable resource use and threaten the long-term water, energy and food security in Kazakhstan. This study presents the key elements required to implement a nexus-based resource management approach in Kazakhstan, by identifying linkages between water resources, energy production and agriculture. A case study illustrates how this methodology can be applied to quantify linkages between the water and energy sectors.

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### 1. Background

Kazakhstan is one of the most water scarce countries on the Eurasian continent [1]. Global climate change has made water resources in Kazakhstan even scarcer. The mean annual precipitation has decreased by 0.5 mm per

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decade [2]. Meanwhile, future projections suggest a temperature increase of 1.4°C by 2030 and 2.7°C by 2050 [2]. Water resources in Kazakhstan are unevenly distributed geographically by river basin - for example, to meet water demand in the industrial area near Karaganda, in the Nura-Sarysu river basin, an irrigation canal transfers water from the Irtysh river basin. Moreover, around 45% of the renewable water resources are transboundary flows from Central Asia, China and Russia. The cross-border Irtysh, Ili, Chu, Talas, Ural and Syr Darya and some others rivers bring nearly 44.64 km<sup>3</sup> of water to Kazakhstan [3]. It is estimated that these inflows could decrease to 31.6 km<sup>3</sup> per year by 2030 [4].

The major water demand sectors are agriculture, industry and the energy sector, with agriculture accounting for almost 70% of total water demand [4]. Future population growth and urbanization together with fast GDP growth is likely to result in increased demand for energy, food and water. This notwithstanding, efficiency in the water sector is very low, with losses accounting for 45% of total water use [3].

Kazakhstan is a resource-rich country with vast reserves of coal, oil, gas and uranium [5]. The energy system is mostly based on fossil fuels, with coal power plants accounting for 68% of total electricity generation in 2014, with significant implications for water withdrawals for extraction and cooling purposes. Moreover, the energy intensity of the economy is among the highest in the world with electricity production responsible for 80% of the country's total GHG emissions [5]. While there is significant renewable energy potential, the current national low carbon policies fail to adequately address energy use issues [6]. Similarly, current water policies do not consider the impact of energy consumption, greenhouse gas emissions and climate change.

In this context, it is vital for the country to adopt an integrated approach in resource management, which accounts for co-benefits and trade-offs in policies related to energy, agricultural and water sectors. Identifying these key elements and the main interactions between different sectors and natural resources will contribute to a more sustainable and coordinated management of natural resources in the future. In this paper, we identify elements required for a nexus methodology to be successfully applied in Kazakhstan (sections 2 to 3) and show through a case study how this could be applied to quantify water use in the energy sector, specifically in extraction of primary energy resources, electricity generation and oil refining (section 4).

## 2. Water

The average perennial renewable freshwater resource that flows in rivers across Kazakhstan is estimated at 100.6 km<sup>3</sup> per year [3], out of which 42% is technically accessible [4]. This translates to a relatively low per capita water availability of around 3650 m<sup>3</sup> annually, which is lower than the global average (around 6000 m<sup>3</sup>) [7]. Water resource governance in Kazakhstan is based on eight major river basins (Fig. 1), with average water availability per square kilometre estimated of 37000 m<sup>3</sup> [7]. Water resource availability across these major basins is unevenly distributed, with the three largest river basins, Aral-Syrdarya, Irtysh and Balkhash-Alakol, accounting for almost 75% of all the water resource generated within the country. Access to water in Kazakhstan is disproportionate among urban and rural dwellers, both in terms of quantity and quality [8]. Whilst the overall average potable water access is estimated at over 85% coverage of the country's population, only 47% of rural dwellers are covered compared to 86% in urban areas [9]. The three major water demand sectors in Kazakhstan are agriculture (~69%), industry (~26%) and public supply (~5%) [9]. Water demand in agriculture is high as crop choice is sub-optimal frequently relying on inefficient historical practices [4]. Water availability for agriculture does not always match crop pattern requirements, i.e. rivers flow in winter due to hydro releases. There are also higher demands for water especially in the Ural-Caspian and Aral-Syrdarya river basins due to the need to get rid of salt in the soil. With over 45% of water resources in Kazakhstan being inflows from neighbouring countries, high demands and inefficiencies in agricultural water use, and growing population and climate change, water resource availability in Kazakhstan in the near future could be significantly hampered. This could be further complicated by future energy sector water demands. The remainder of this section aims to highlight current issues regarding transboundary water resources, agricultural water use and water for energy.

### 2.1. Water for agriculture

The current volume of agricultural production in Kazakhstan is estimated at approximately 7 million tonnes per

year [10], with an average annual growth in food production of 7% [11]. This steady growth follows a significant decline of the sector post the Soviet Union era. As a result of institutional change following independence in 1991, the country experienced a serious decline in agricultural output [12] and a decrease in food security at the household level [13]. However, since 2000 agricultural production has shown steady growth, with an overall increase of about 62% [14]. Kazakhstan is currently one of the largest producers and exporters of wheat globally [3].

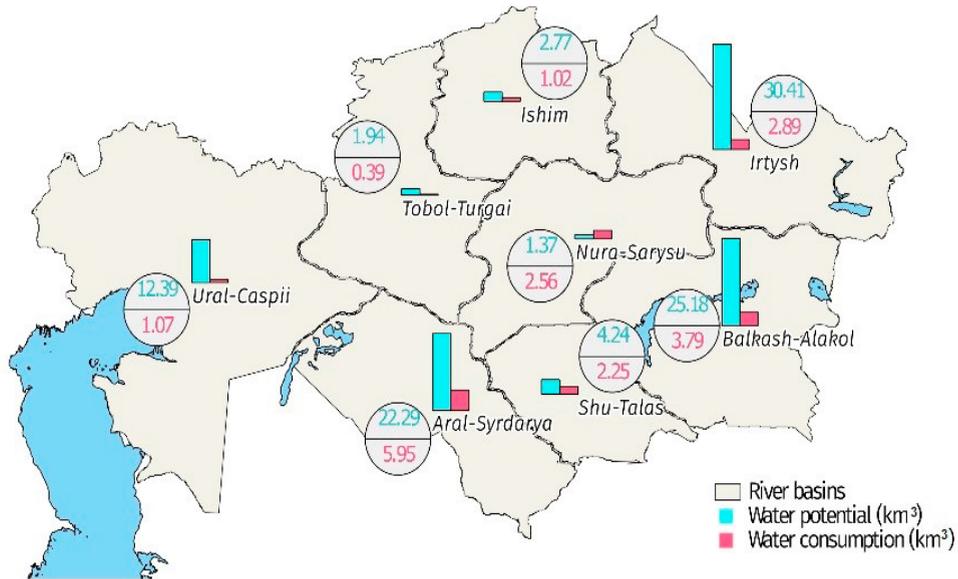


Fig. 1: Water consumption and potential by river basin, km<sup>3</sup>

Agricultural output in Kazakhstan is hugely dependent on water availability (including precipitation) and land-use changes [15]. In the past, climatic conditions such as summer droughts have drastically affected the agricultural productivity in the country [16]. Additionally, agricultural fields in the Aral Sea basin, Ili-Balkhash and Ural-Caspian are largely affected by the process of extensive desertification, and have led to food scarcity in the past. In the early 90s, irrigated lands occupied more than 2.1 million ha or 6.7% of the country's arable land and produced more than 30% of the gross output of the crop sector in the country. Over the years the area of irrigated land has sharply decreased in some regions. For example, in the Akmola province there is 95% decline in irrigated land, Kostanai province fell by 80%, East Kazakhstan province by 60%, Almaty province by 11%, Zhambyl province by 32.7%, Kyzylorda province by 23.7% and South Kazakhstan region by 16.8%. At present, the total irrigated area of land is estimated at less than 1.5 million ha, and produces only 5.3% of the gross crop production [17].

The water resource demand associated with this level of production is estimated at 13.4 km<sup>3</sup> annually, and constitutes about 69% of total water demand of the country [4]. As a result of high water use inefficiencies, about two-thirds of the water withdrawals for the agricultural sector is lost during transport, with only 3.8 km<sup>3</sup> per year effectively used for irrigating crops [4]. According to FAO data, an average of 3 500 m<sup>3</sup> of water is used to produce 1 tonne of crops in Kazakhstan, and to produce the same amount of food, it took 1 300 m<sup>3</sup> of water in Poland, 1 000 m<sup>3</sup> in the United States, 790 m<sup>3</sup> in the United Kingdom and 660 m<sup>3</sup> in France [18].

Water leakage in the irrigation networks is one of the major sources of inefficiencies of the water resource sector in Kazakhstan. It is estimated that losses during water transport reaches about 50% for utilities, 70% in agricultural and 40% in industrial sectors [4]. Furthermore, there is a substantial level of wastage in the water that eventually reaches the agricultural field. The large losses in the water system are mainly attributable to deteriorating infrastructure and lack of modern irrigation practices. For example, 382 of 1645 hydraulic structures in the country are in poor technical condition [19]. The application of sprinkler and drip irrigation is almost negligible, while other more efficient and yet less capital and energy-intensive water-saving methods such as canal lining, border irrigation, hose water conveyance, water quantity and timing control, and plastic mulch, are also not widely used.

Water tariffs in agriculture sector are still relatively low [4], as water is perceived as a free resource, hence consumers do not use water sparingly. As a result, the water sector is not attractive to new investments, both from the public and private sector. Recently, the Government announced plans to create two national companies to manage irrigation infrastructure, with the aim of building and managing new water facilities according to international water standard; however, bureaucratic complexities and ongoing government reforms slow down this process [20].

In order improve water use efficiency, the Government of Kazakhstan has developed and applied National Water Programme Ak Bulak 2010-2020 (№ 1176 of 09.11.2010) [21], National Green Economy Concept (№ 577 of 30.05.2013) [21], and State program on Water Resources Management (№ 786 of 04.04.2014) [21] which aim to reduce water consumption per unit of GDP by 33% by 2020 compared to the level of 2012, increase access in both urban (to 100%) and rural (to 80%) areas and improve water resource quality. To achieve these targets, the government intends to develop effective water resources management system in accordance with the best world practices and principles of integrated water resources management by 2020 [21]. The first step in this direction has been the passage of the Water Code (№ 481-II with amendments of 20.02.2017) and the Law on Green Economy (№ 506-V of 28.04.2016) [21]. In the agricultural sector, the Government has also rolled-out the Agro Business 2020 Programme (№ 151 of 18.02.2013) [21] which aims to encourage diversification of crop production away from wheat to more feed grains and oilseeds, in order to support the livestock sector. However, the direct impact this may have on the overall agricultural water consumption is unknown.

## 2.2. Water for Energy

The water and energy systems have strong linkages [22, 23], with water being used in different stages of the energy system, from resource extraction, to cooling in power generation, processing of fossil fuels and the irrigation of biofuels feedstock crops. On the other hand, electricity is needed to pump water in transboundary transport, irrigation, distribution and treatment water resources.

In 2014, water used in the energy sector accounted for 8.5% of total resource use across different sectors of the economy. From this total, a significant share was used in the extraction of fossil fuels and uranium, with total water demand for oil and coal production estimated at 155.05 million m<sup>3</sup> in 2014 [5]. This takes into account that water produced during extraction is treated and then re-injected into the oil reservoir for pressure maintenance and recovery improvement. Coal remains the dominant fuel source for electricity production accounting for 68% of electricity production [5], which is commensurate with coal power stations being responsible for the majority of the water withdrawals in the energy sector. A significant amount of these withdrawals are not returned to their original sources, with an estimated consumption of 114.51 million m<sup>3</sup> for thermal electric generation in 2014. If the current energy mix, power plant locations and water cooling technologies remain unchanged, water use in the energy sector is expected to grow rapidly due to rising demand for electricity in the industrial, domestic and services sectors. This is an important issue especially in areas that already rely on water inflows from other regions to meet water demand (e.g. the Nura-Sarysu basin as shown in Fig. 1).

Hydro power supplies approximately 10% of electricity production in Kazakhstan, with over 50% of the generating capacity located in areas with high or extremely high baseline water stress. Given future plans to increase current hydro power capacity by 15-20% by 2050, the stress would likely be exacerbated, as most of this would be added in the basins where current capacity is located. In this context, expected climate change impacts resulting in reduced precipitation and temperature increase could lead to increased risk of shortages of water resources for all sectors, and the energy system in particular. However, there are currently no studies dedicated to possible impacts of climate change on hydropower generation and the power sector in Kazakhstan.

## 2.3. Transboundary water issue

Kazakhstan has faced geopolitical tensions due to transboundary river use [24], as the example of Syr Darya and the Amu Darya has recently illustrated it [25]. Since almost half of the country's renewable freshwater resources are sourced outside its boundaries, with inflows via the Irtysh, Ili, Chu Talas, Ural and Syr Darya rivers, changes in withdrawals in any of the upstream countries are likely to have a very significant impact on the availability of water in Kazakhstan. In fact, some government projections [4] show that inflows are expected to decrease from 44.64 km<sup>3</sup>

per year to 31.6 km<sup>3</sup> per year by 2030 due to increased water withdrawals for hydro electricity generation and irrigation in countries in Central Asia and China. The Irtysh basin, where a substantial share of Kazakhstan's energy and industrial infrastructure is located, is likely to experience a major reduction in total available water, as withdrawals by China are projected to increase from 1.2 to 9.0 km<sup>3</sup> by 2040 as a result of construction of a series of drainage canals and reservoirs on the Irtysh river [4]. The largest inflow, of 19.2 km<sup>3</sup> (43% of total inflows), comes from China, yet the existing legal framework of cooperation with Kazakhstan has proven ineffective in regulating water resources shared by the two countries. This is illustrated by the limitations of the seven official bilateral agreements signed between 2001 and 2014, which did not include concrete actions or targets regarding transboundary water resources. In this context, improvement in international water relations is a key condition in providing national water, energy, and food security. In particular, issues which need to be addressed include: regulations on shared water resources, setting up an inter-state monitoring system of water resources, developing a system for collection of reliable information on the use of water, joint emergency alarm systems on transboundary waters, and a system of penalties for infringement of environmental regulations.

### 3. Energy

#### 3.1. Energy resource overview

The energy sector in Kazakhstan is largely shaped by the abundance of fossil fuel reserves in the country. In particular, its coal reserves are amongst the ten largest globally, and therefore around 90% of electricity is generated through fossil fuels, with coal accounting for 68% and gas 20% in 2014 [5]. The remaining generation is met by hydropower (around 10%), while renewables, such as wind and solar, currently have a minimal contribution to the energy system (less than 1%) [5].

The coal-fired power plants have a total installed capacity of 21 307 MW, and an available capacity is of 17 500 MW [26]. The majority of this capacity is located in the northern and eastern parts of the country, where there is heavy electricity demand from the industrial sector. Due to the overwhelming reliance on fossil fuels, the country produces high levels of carbon emissions. In 2014, total greenhouse gas emissions amounted to 315 Mt, of which 75% are due to coal [5].

Despite the abundance of solar and wind power potential in the country, these sources of energy are not widely used due to the lack of appropriate infrastructure and of an appropriate institutional and legislative framework [6]. There is also significant potential to produce electricity and heat from agricultural and forestry waste, with 12 to 14 Mt of waste being produced per year [6]. Apart from agricultural and forestry wastes, the cities and regional centres in Kazakhstan annually produce 3.4 million tonnes of municipal wastes which could partly be used for waste to electricity generation [27].

In rural areas, there is limited access to the electricity grid, and residents use solid fuels (wood, cowdung cakes, coal and kerosene) for cooking, heating and lighting. Using biomass and coal in simple stoves produces substantial indoor air pollution and contributes significantly to the total burden of ill health [28]. This is worsened as most rural households do not have adequate ventilation and access to modern energy technologies. Currently, there are not any policy initiatives which aims to replace old-fashioned stoves and provide installation of a chimney.

#### 3.2. Future energy outlook in Kazakhstan

In a context of significant population and GDP growth, domestic energy production and use are growing rapidly in Kazakhstan. Between 1999 and 2015, primary energy consumption grew from 26.92 to 91.08 Mtoe [26]. It is expected that by 2030 primary energy production will be approximately 140 to 160 Mtoe [5]. In 2014, the Ministry of Industry and New Technologies developed the Concept of developing the fossil fuel and power generation complex up to 2030 (Directive № 724 of 28.06.2014) [21]. According to the concept, the increase in volume of coal mining from 103.5 in 2014 to 113 million tons per year by 2030 is expected. Oil production is projected to increase from 84.2 in 2014 to 118.1 million tons per year by 2030, and natural gas production from 44.2 to 59.7 bln m<sup>3</sup> per year. Additionally, the government intends to increase the share of gas in the national energy mix by 25% by 2050 compared to the level of 2015.

One of the major future changes expected in the national energy system is the introduction of nuclear power

generation. According to the Nuclear Development Programme (Directive № 728 of 29.06.2011) [21], Kazakhstan plans the construction of a nuclear power plant with a capacity from 600 to 2000 MW by 2030. The period of implementation for this project is expected to be between 2020 and 2030.

Regarding renewable energy, the immediate target is to increase the share to 3% of the total energy mix by 2020 and to 6% by 2025. For 2050, there is a much more ambitious target of 50% of the total power generation from renewable energy sources (Directive № 577 of 30.05.2013) [21]. In order to move towards these targets, the government proposed a number of incentives and measures. Firstly, the country approved tariffs for energy produced from wind, solar, small hydro and biogas (Directive № 645 of 12.06.2014) [21]. According to the Roadmap for the Development of Alternative Energy for 2012-2030 (Directive № 068 of 24.02.2017) [21], the country intends to install 106 renewable energy projects with more than 3 000 MW of renewable energy capacity by 2020. In addition, different programs for electrification with small hydropower plants are currently running. The government intends to construct 11 small-scale hydropower stations with 205 MW by 2020 in Almaty, and Eastern and Southern Kazakhstan provinces. However, the future development of small-scale hydro power plants continues to face technical, economic, political, legal and regulatory challenges [6]. The Green Economy 2050 Strategy, which provides an overall framework for the low-carbon energy transition, also outlines an increase in biofuel production, with three biodiesel plants to be constructed in the North and South Kazakhstan. In 2010, Kazakhstan adopted specific Law of on regulation of production of biofuels № 351-IV [21] to support the biofuels production sector in Kazakhstan. However, bioenergy production still faces challenges in establishing adequate supply chains from the bioenergy crop production, storage and biorefineries.

#### **4. Case-study (current water use for energy)**

In this case study we illustrate how a nexus methodology can be applied to map the interactions between water and energy systems. Specifically we analysed water use in: the extraction of coal, oil, natural gas and uranium; oil refining; and thermal power generation. Since water resource impacts are best analysed at the river basin level, data for energy and water was collected and analysed at this scale.

For extraction, we estimated the water required for both underground and surface mined coal, for onshore oil and gas, and for extraction of uranium via in-situ leaching (ISL), based on annual production data and water use coefficients per unit of extracted resource [29]. For refining, we estimated the total water requirement associated with the production of petroleum products, using the same methodology. Water requirements for power generation were estimated by combining information about individual power generation technologies, primary fuel use and cooling technology with the annual electricity production data and the water use coefficients associated with these technologies [30]. The cooling technologies for each power station were identified using publicly available data and satellite imagery.

The above analysis and data collection was performed for the 8 major basins in Kazakhstan (Fig. 1). The outcome of this analysis is presented in Fig. 2, which shows the total national freshwater requirement for the energy sector disaggregated by key components (extraction, refining and power generation), and by river basin. The results show that power generation is the dominant freshwater user. This reflects the high share of coal power plants (Section 3.1) and the significant use of open loop cooling technology, which results in high water requirements per unit of generated electricity. The Irtysh and the Nura-Sarysu basins have the dominant water demand for energy in Kazakhstan. This is commensurate with the high concentration of coal power stations in these basins [5]. Even though water use is comparatively lower in the Nura-Sarysu basin, water for energy accounts for approximately 60% of total water potential in the basin. This is especially critical as the total water demand, including other sectors of the economy, is higher than the total potential in this basin.

This case study highlights the importance of integrated analysis as the results illustrate critical interdependence between the energy infrastructure and water resources in Kazakhstan. Future energy policies could exacerbate water stress issues given the current balance between availability and demand for water resources across different basins. This has implications on future energy infrastructure siting, electricity generation mix and choice of cooling technologies, considering that the two most important basins for energy and industry in Kazakhstan, Irtysh and Nura-Sarysu, are either under stress or depend on international inflows. Additionally, this also has important implications for other basins as the water system of the country is classified as generally under stress and highly

vulnerable to climate change [31]. Water inflows are also affected by hydro-generation in neighbouring countries – China and Central Asian countries. Thus changing water inflows is also a function of energy system dynamics. Further, this analysis shows that an integrated approach provides an opportunity to quantify water requirements associated with different technologies, which reiterates the benefits of efficiency improvements, such as the use of water-efficient cooling technologies, in electricity generation. Through a case-study we have shown that, if current practices are maintained, there is significant water security risk.

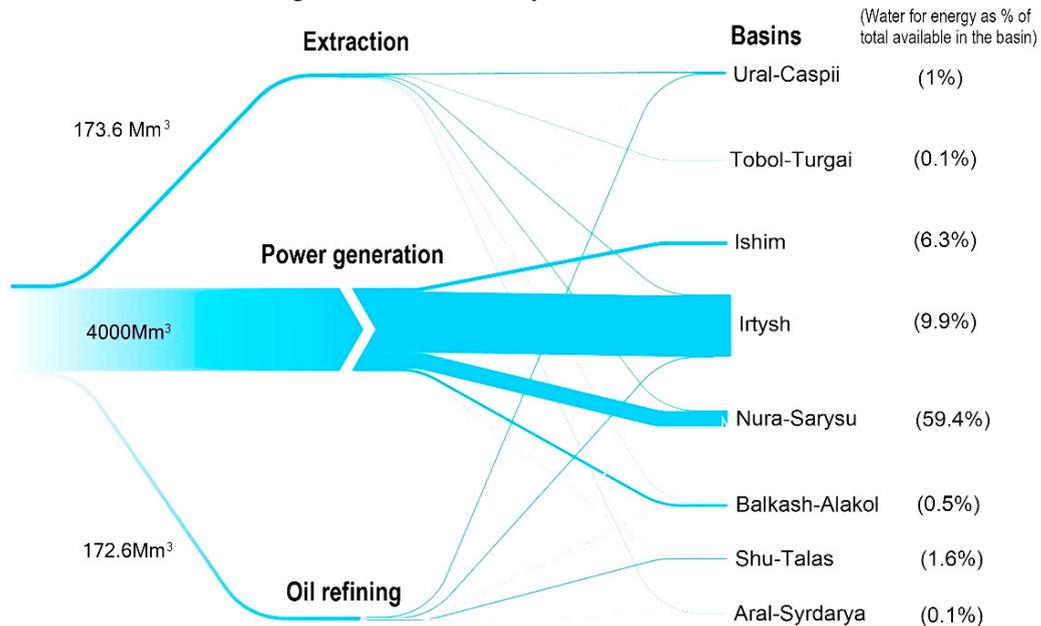


Fig. 2: Water requirements for extraction, refining and power generation per basin and as percentage of total available water in each individual basin

## 5. Key insights and research gaps

This paper highlights two key challenges in the future availability and sustainable use of water resources in Kazakhstan. Firstly, the country is going through a process of rapid economic and population growth, while also setting ambitious targets for carbon emissions reduction. Secondly, the current infrastructure and resource management are characterised by significant inefficiencies which have already resulted in high water losses and water scarcity. A combination of these circumstances makes it particularly important that future policy related to water, food and energy takes into account the linkages at the nexus between these systems. In this paper we collected and analysed data that is required for a nexus methodology to be successfully applied in decision-making in Kazakhstan. However, it is clear that more transparency and wider data availability would allow further studies to be carried out in order to showcase the critical importance of considering the water, food and energy systems concurrently.

Through a case-study we have shown that if current practices in the energy system are maintained, there is significant risk of increasing water stress if decisions on new energy infrastructure are taken without considering the availability and other uses of the water resources in the country. It is therefore important to carry out further studies that complement these results by also considering important factors such as future technology choices, climate change, availability of transboundary water inflows, or maintenance of minimum environmental flows. Another important research direction is to consider future scenarios for agricultural water use that relates to choice of crops and irrigation technologies; given the importance of the sector in the country's future economic strategy, it is likely that this will have major implications on the availability and use of water resources.

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