Energy Dialogue
Germany – Central Asia

The Role of Water for Sustainable Hydrogen Production in Kazakhstan

Part I: Water management for the production of sustainable hydrogen

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Key take-aways

Green hydrogen has the potential to set Kazakhstan's economy on a green trajectory. The production and use of green hydrogen in the energy-intensive industry sector as well as in transport can contribute the country's net-zero goals for the year 2060. Kazakhstan has favourable conditions for producing electricity from renewable energy sources including solar and wind energy. In addition, the country is the ninth largest country in the world with vast amounts of land available.

The production of green hydrogen in Kazakhstan will be an additional challenge for the country's water management system. The production of 1 kg of hydrogen requires between 15 and 30 litres of water. Establishing hydrogen production in Kazakhstan therefore demands careful consideration of the use of water for producing hydrogen or other essential needs, as the country already faces challenges in limiting transport losses and inefficient use of water. Rising temperatures and precipitation shifts caused by climate change add additional pressure on Kazakhstan's water resources in the future.

An environmental impact assessment of green hydrogen production in Kazakhstan is essential and needs to specify the use of water along the whole hydrogen production value chain. This requires a granular approach that takes into account the unique local characteristics of a region (see figure below). In addition, the transition to a hydrogen economy requires effective policies regarding water resources. Furthermore, green hydrogen certification should require specification of the origin, use, volumes and reclamation of suitable sources of water. To ensure the responsible and sustainable use of existing water resources, cooperation between governmental actors is essential for streamlining policies to address potential conflicts over water use, particularly in applications involving water-intensive processes.

Addressing the threat of water scarcity in Kazakhstan requires a comprehensive water stewardship model for the entire Central Asian region as well as international attention and concerted efforts. Cooperation among Central Asian countries, as well as an integrated and unified approach by the entire region, is essential to address water challenges. This cooperation should focus on improving the efficiency of water use, modernising irrigation systems and introducing advanced technologies under the umbrella of a water management initiative. Beyond recognising the severity of the problem, a commitment to building capacity and streamlining global initiatives is paramount. This could include the strengthening of the World Bank's multilateral Central Asia Water and Energy Program.

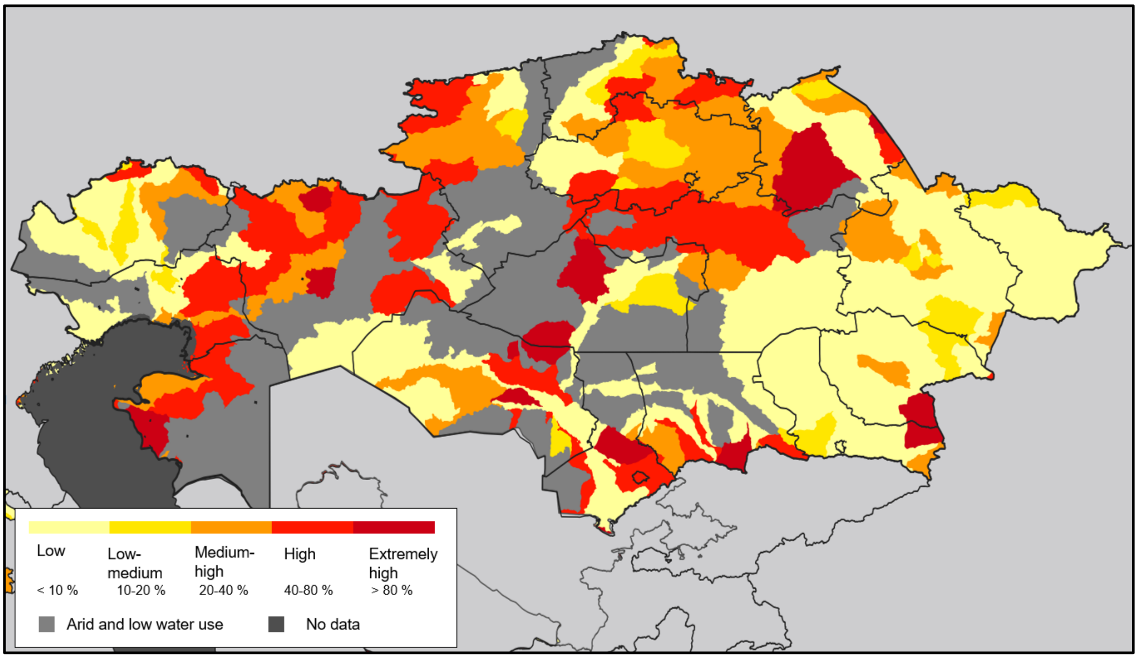

Figure: A key factor in assessing hydrogen production in Kazakhstan is the distribution of water at local level. Water availability varies widely among the regions. Own illustration based on (https://www.wri.org/data/aqueduct-global-maps-30-data)

1 Introduction

Kazakhstan is the world's ninth largest country and is located in Central Asia. It has abundant resources of raw materials, including the fossil fuels crude oil, natural gas and hard coal. The country's economy is heavily reliant on crude oil exports and therefore dependent on oil price developments. In recent years, the former president Nursultan Nasarbajew endeavoured to modernise the economy and bring the whole country onto a green trajectory. In February 2023, Kazakhstan's president, Kassym-Jomart Tokayev, approved the Strategy on Achieving Carbon Neutrality by 2060, which sets ambitious net-zero carbon goals for the country's decarbonisation. To achieve these goals, Kazakhstan must transform its energy-intensive industry away from fossil fuels by encouraging the development of renewable energy sources and introducing energy efficiency measures to industry and local authorities.

Kazakhstan has favourable conditions for producing electricity from renewable energy sources including solar and wind energy. The theoretical production potential amounts to 2.5 terawatt hours (TWh) for solar energy and 920 TWh for wind energy, which is about nine times more than the total generation of electricity in 2020 (IEA, 2022). The use of green hydrogen and its derivatives is being considered by Kazakhstan's decision-makers. In recent years, efforts have been made to create a framework for establishing green hydrogen production, transport and consumption in Kazakhstan. Low carbon hydrogen is expected to be used mainly in industrial sectors such as steel and chemical industries, where direct electrification is not always an option, as well as in the transport sector.

Apart from renewable electricity, water is the other essential component needed to produce green hydrogen. In general, the water demand can be met from all available water bodies, including groundwater, surface water, seawater and tap water from the existing network. The additional demand caused by the production of hydrogen can lead to competition for water at a local or even a regional level (Heinemann and Mendelevitch, 2021). Kazakhstan is a very arid country with scant water resources. Water resources, mostly surface water, are very unevenly distributed across the country and subject to seasonal fluctuations. Furthermore, Kazakhstan's water resources are also highly dependent on water inflows from the neighbouring countries, which add up to about 44% of the surface water inflow (MENR RK, 2023a). In coming years, climate change impacts are expected to exacerbate Kazakhstan's water situation. Temperature shifts as well as precipitation shifts have already been observed and have resulted in the desertification and degradation of croplands and pastures. Estimates assume that 66% of the irrigated land is already subject to some form of degradation (World Bank, 2022). Taking all these factors into account, it is important to assess the viability of green hydrogen production in Kazakhstan. The following question arises: *what are the challenges of producing green hydrogen in an arid region and how can sustainable green hydrogen production be achieved in Kazakhstan?*

To address this question, this study explores the water consumption of the three common electrolyser technologies and takes a close look at the technical aspects of water treatment in water electrolysis (see section 2). Section 3 assesses how sustainable use of water in hydrogen production can be embedded in certification schemes. Sections 4 and 5 provide insights into Kazakhstan's water resource management and examine how hydrogen production could affect the country's water resources. This study is the first part of a two-part publication on the role of water in sustainable hydrogen production in Kazakhstan. The second part provides an initial assessment of hydrogen production and use in Kazakhstan, for further information see dena (2023).

2 Technical assessment of the use of water for the production of green hyrdrogen[1]

In the pursuit of a cleaner and more sustainable energy future, green hydrogen has emerged as a promising alternative. Green hydrogen is produced through electrolysis, a process whereby water is split into hydrogen and oxygen using renewable electricity. The potential of green hydrogen to decarbonise various sectors is undeniable, however its production process requires a significant amount of water.

2.1 Water demand and management for hyrdrogen production

Green hydrogen production involves electrolysis, which requires ultrapure water as a feedstock. Ultrapure water (UPW) is the term for high-quality water that is free of contaminants such as microbes, minerals, and dissolved gases (Onissiphorou, 2022). It consists entirely of H_2O molecules and has a degree of purity of near or equal to 100%. The process takes place in an electrolyser where an electric current is passed through water to separate hydrogen and oxygen gases. The basic reaction is as follows:

$$2H_2O\ (l) \rightarrow 2H_2\ (g) + O_2\ (g).$$

This electrolysis process consumes water, and the volume of water required depends on several factors, including the type of electrolyser, efficiency, and the scale of production. Current estimates suggest that producing one kilogram of hydrogen requires around 9 to 15 litres of UPW, depending on the quality of the input water and the amount of treatment equipment required (see Figure 1).

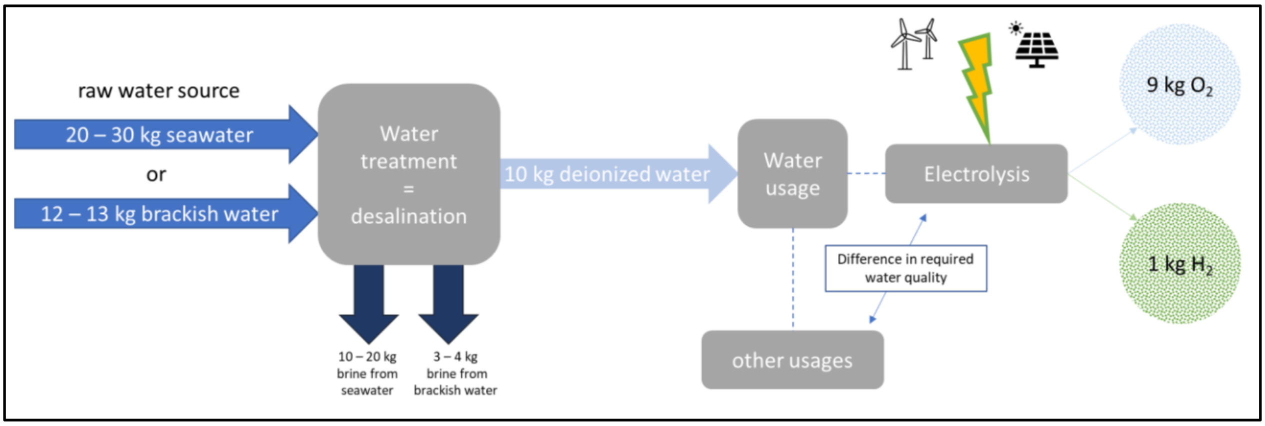

Figure 1: To produce 1 kg of hydrogen, water electrolysis requires between 12 and 30 kg of water depending on the water source. Source: Schmidt and Frank (2023)

Electrolysers are the core components in the production of hydrogen through water electrolysis. Different types of electrolysers have emerged over the years, each with their own characteristics, advantages and specific requirements. Among these requirements, water conductivity plays a crucial role in ensuring the efficiency and longevity of the electrolysis process. The electrolyser technologies with the highest current market shares and their water consumption are examined below.

Alkaline electrolysers

Alkaline electrolysers have been used for decades and are among the earliest technologies developed. They operate in an alkaline electrolyte solution (typically potassium hydroxide) and require relatively high water conductivity. The electrolyte's conductivity should be maintained to ensure the efficient transport of ions and to prevent energy loss. Alkaline electrolysers often have strict requirements for purity and low levels of impurities could interfere with the electrolyte's conductivity. As shown in Figure 2, the water withdrawal intensity is about 32.2 litres H_2O/kg H_2 and the water consumption intensity is

[1] Section 2 was written by Dr. Daniel Frank (DECHEMA)

about 22.3 litres H_2O/kg H_2. The water withdrawal and consumption intensities refer here to the volumes of water withdrawn or consumed for the generation of 1 kg hydrogen (IRENA and Bluerisk, 2023).

Proton Exchange Membrane (PEM) electrolysers
PEM electrolysers operate at lower temperatures and are suitable for on-site hydrogen production due to their compact size. These electrolysers utilise a proton-conducting polymer membrane as the electrolyte. The water fed into the PEM electrolyser should have a certain level of conductivity in order to facilitate proton transfer through the membrane. However, excessive impurities or high ion concentrations can lead to membrane degradation, reduced performance, and shorter lifespans. As shown in Figure 2, the water withdrawal intensity is about 25.7 litres H_2O/kg H_2 and the water consumption intensity is about 17.5 litres H_2O/kg H_2. The water withdrawal and consumption intensities refer here to the water volumes withdrawn or consumed for the generation of 1 kg hydrogen (IRENA and Bluerisk, 2023).

Solid Oxide Electrolysis Cells (SOEC)
SOEC electrolysers are high-temperature electrolysers that operate above 700 °C. They utilise a solid oxide ceramic material as the electrolyte, which conducts oxygen ions. While water conductivity is less of a concern in SOECs compared to alkaline or PEM electrolysers, maintaining proper water vapour content and preventing excessive carbon dioxide in the feedstock gases are crucial to avoiding carbonate formation on the electrolyte surface.

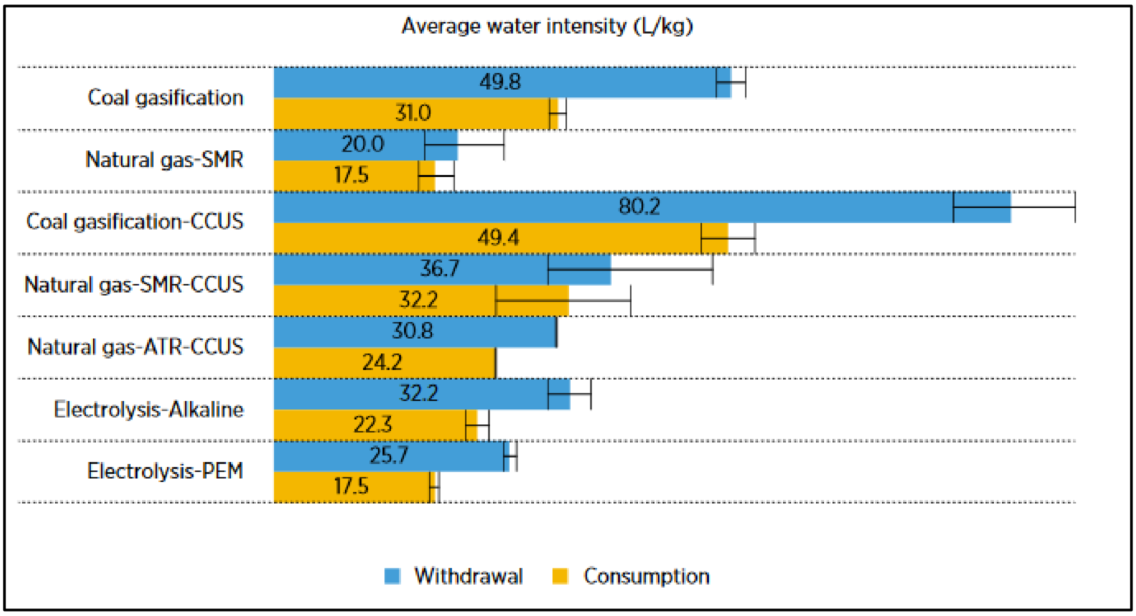

Figure 2: The average water withdrawal intensity of PEM and alkaline electrolysis is about 25.7 litres H_2O/kg H_2 and 32.2 litres H_2O/kg H_2, respectively. Source: IRENA and Bluerisk (2023)

Addressing the water demand for green hydrogen production requires a multifaceted approach. Firstly, advancements in electrolyser technology can lead to higher efficiency and lower water consumption. Research and development efforts are focused on improving the efficiency of PEM and alkaline electrolysers, for example, with SOEC electrolysers being developed for initial large-scale applications in the near future. Secondly, selecting production sites in regions with abundant water resources can help alleviate the strain on water-stressed areas. However, this approach must be balanced with other environmental considerations. Thirdly, in coastal areas, desalination of seawater can provide a sustainable source of water for hydrogen production, albeit with its own energy and environmental considerations. In addition, governments and regulatory bodies can play a pivotal role in incentivising water-efficient technologies and promoting responsible water management practices in the hydrogen sector.

2.2 Water treatment requirements for hyrdrogen production

The quality of water used in the electrolysis process plays a critical role in ensuring the efficiency, durability, and environmental sustainability of electrolysers. To achieve the required purity, the raw water must be treated accordingly, even if groundwater or drinking water is used. The effort required varies according to the type of raw water to be used. If seawater is used, the yield is 40 to 50% (in terms of reverse osmosis, higher for thermal approaches), and for other raw water sources, for example groundwater, 75 to 80% (Saravia et al., 2023). The missing percentages to 100% are brine, which is waste or concentrate that can either be further processed or disposed of.

Water conductivity, measured in micro siemens per centimetre (μS/cm), is a key parameter for water electrolysis. The appropriate level of conductivity varies depending on the type of electrolyser:

- *Alkaline electrolysers*: these typically require water conductivity in the range of 1000 to 3000 μS/cm, achieved by adding alkaline agents to ultra-pure water. Ensuring the proper concentration of the alkaline electrolyte solution is essential for efficient ion conduction.

- *PEM electrolysers:* the recommended water conductivity for PEM electrolysers falls between 1-10 μS/cm. This range balances the need for efficient ion transport while preventing excessive impurities that can harm the polymer membrane.

- *SOEC:* as SOECs operate at high temperatures, water vapour is often provided in the form of steam. While conductivity is less of a concern, maintaining appropriate water vapour levels is essential for maintaining electrolyte stability.

Maintaining proper conductivity ensures effective ion transport and minimises energy loss. While each type of electrolyser has specific conductivity requirements, the overall goal is to strike a balance between providing an environment conducive to ion conduction while minimising impurities that could harm the electrolysis process. For an overall assessment of potential impurities, see Becker et al. (2023).

Water treatment equipment

Typically, water treatment is carried out by reverse osmosis (RO), a common process for removing salt loads. This system employs a semi-permeable membrane to remove dissolved salts, minerals and impurities from the water. RO systems ensure a high level of purity and reduce the risk of scaling, corrosion and fouling in the electrolyser. By producing "deionised" water, an RO system enhances the efficiency and longevity of the electrolysis process (Dokhani et al., 2023).

The higher the pressure applied on the membrane, the higher the permeate flow rate increases proportionally. The aim of this treatment stage is to obtain a permeate with a conductivity of between 5-10 μS/cm, which is suitable for the operation of electro deionisation. The permeate produced by reverse osmosis should have a salt load reduced by 99%, but this means that a second reverse osmosis step may be necessary depending on the conductivity of the raw water.

It must be remembered, however, that RO is not sufficient for producing ultra-pure water, and depending on the initial medium, pre-treatment must be carried out (Becker et al., 2023). A whole range of possible pre-treatment technologies exist which can also be combined in various ways (Herco, n.d.):

- *Particle filtration:* filtration units, including activated carbon filters, are used to remove particulate matter and sediment from the water. These filters prevent the clogging of electrolyser components and protect against the adverse effects of chlorine on electrode materials

- *Disinfection via Ultraviolet (UV) for pathogen removal*: UV or ozone disinfection systems are employed to eliminate microorganisms and bacteria from the water. While hydrogen production typically operates at elevated temperatures, these disinfection methods provide an extra layer of protection against potential biofilm formation and microbial contamination

- *Granulated activated carbon filters (GAC)* are an organic carbon filtration substrate, based on e.g. wood, coconut shells, coal or other organic materials used for water purification. A GAC filter is able to remove organic contaminants from water, including substances that produce odors such as hydrogen sulfide. Depending on the level of chemicals present, the GAC filter should be changed frequently

- *Antiscalant dosing* to prevent salt precipitation on the RO membrane or a decalcification system to remove water hardness (calcium and magnesium salts)

- *Degassing systems* (especially relevant if an EDI is installed) to remove any present dissolved gases like oxygen, carbon dioxide.

The pre-treatment processes required are determined by the amount of dissolved solids (TDS), organic matter (TOC), and chlorine and carbon. Downstream of the RO, further purification can be carried out with mixed-bed ion exchangers or electrodeionidation (EDI), a so-called "polishing" stage. Water softening systems use ion exchange resin to remove calcium and magnesium ions responsible for water hardness. By preventing scaling and reducing the potential for scaling-related issues, water softeners contribute to the smooth operation of electrolysers. As an alternative to RO, thermal processes such as vacuum evaporation can also be used, especially if the waste heat from the electrolyser can also be utilised.

2.3 Desalination techniques for hydrogen production

Desalination is the process of removing salt and other impurities from seawater or brackish water, rendering it suitable for various applications. When it comes to hydrogen production, desalination offers an alternative water source that is abundant, although energy-intensive. Two primary desalination techniques are considered:

- *Reverse osmosis (RO):* RO involves forcing water through a semi-permeable membrane to remove salts, minerals, and impurities. The purified water that emerges from the other side can be used in hydrogen production. While RO is energy-efficient compared to other desalination methods, it still requires a considerable amount of energy.

- *Multi-Stage Flash (MSF) distillation:* MSF distillation is a more energy-intensive process where seawater is heated and evaporated in multiple stages, leaving salt and impurities behind. The vapour is then condensed to produce fresh water. This method is often used in large-scale desalination plants.

On the one hand, desalination for hydrogen production has several advantages. For example, desalination provides a reliable source of water in areas where freshwater resources are scarce or unreliable, ensuring a consistent supply for green hydrogen production. In addition, using desalinated water for hydrogen production can reduce competition with other water-intensive industries such as agriculture and municipal use. Finally, in coastal areas, using seawater for desalination reduces the environmental impact associated with freshwater extraction and preserves local ecosystems.

On the other hand, desalination presents several challenges. Firstly, desalination is energy intensive, which can raise concerns about the carbon footprint and cost effectiveness of hydrogen production. The use of renewable energy sources for desalination can help mitigate this challenge. Secondly, desalination produces brine as a by-product, which must be properly disposed of to prevent damage to marine environments or, in the case of landlocked countries, to inland environments. Innovative brine management solutions are being explored. Thirdly, desalination equipment can scale due to the high mineral content of seawater. Effective maintenance and cleaning strategies are necessary to prevent efficiency loss.

Desalination for hydrogen production holds promise, especially in regions where freshwater resources are limited. To make this approach more sustainable, research is ongoing to develop energy-efficient desalination technologies, integrate renewable energy sources, and optimise the overall process. As the hydrogen industry expands, strategic planning and collaboration between hydrogen producers and desalination experts will be essential to ensure responsible water use and minimise environmental impacts.

Outlook: seawater electrolysis

Seawater electrolysis involves the direct utilisation of seawater as the feedstock for electrolysis and has a TRL level of 3-4 (Service, 2023). It is assumed that for an investment decision in the next couple of years, this technology is not yet market-available. Among the actual topics of ongoing research are:

1. *Corrosion and fouling:* the corrosive nature of seawater and the presence of marine organisms can pose challenges to electrolyser materials and performance. Electrolyser designs must account for these factors to ensure longevity.

2. *Mineral content:* seawater contains a higher concentration of minerals compared to freshwater. Proper management is needed to prevent scaling and fouling on electrodes and other components.

3. *Energy intensity:* seawater electrolysis typically requires greater energy input due to its higher ionic content compared to freshwater. Efficient electrolyser designs and renewable energy sources can help mitigate this challenge.

4. *Brine disposal:* seawater electrolysis generates a concentrated brine byproduct, which requires responsible disposal in order to avoid environmental harm.

2.4 Cooling water and wastewater treatment

When considering the total water-related process streams in a hydrogen production unit, the cooling water streams and the potentially generated wastewater from so-called Power-to-X (PtX) processes must be included.

In order to minimise scaling and biofouling in the cooling water circuit, it is advised to use water of the same quality as for the electrolysis process, therefore the same treatment processes could be used, to achieve ultra-pure water quality.

Although cooling water must be replaced from time to time, the total amount is negligible compared to the amount of water used for electrolysis, assuming there is a closed cooling water circuit.

Wastewater treatment for PtX processes involves various technologies to remove contaminants and pollutants from the wastewater generated during these processes. PtX refers to technologies that convert power, typically from renewable sources, into other forms of energy or products, such as the production of methanol or sustainable aviation fuels by Fischer-Tropsch reactors. When implementing wastewater treatment for PtX processes, the choice of technology depends on factors such as the type and concentration of contaminants, the scale of the operation, and the desired water quality standards. In general, technologies to be used for PtX wastewater are no different than for industrial/municipal wastewater purposes. Additionally, regulatory requirements and environmental considerations play a crucial role in the selection of appropriate technologies.

3 Sustainability standards for hydrogen production using local water resources

Water is an increasingly scarce resource in many regions of the world. Reaching the Paris Agreement's central aim of limiting global warming to well below 2 °C above pre-industrial levels not only requires lowering GHG emissions. To ensure a sustainable energy transition, it is also important to understand and manage the water intensity involved in generating electricity as well as energy carriers, such as hydrogen, on a global and local scale (Terrapon-Pfaff et al., 2020).

To develop meaningful sustainability assessments, it is imperative to examine the entire value chain both up-stream and down-stream (PtX-Hub, 2022). To make sure that the production of green hydrogen is compliant with set Sustainable Development Goals, it is vital to set up standards and certification schemes. Standards and certification provide clarity for investors and managers as well as for customers. Sustainability criteria can be incorporated in different ways. Heinemann and Mendelevitch (2021) suggest different options for the placement of criteria for hydrogen production projects e.g. into financing guidelines, voluntary certification schemes, procurement initiatives for hydrogen, trade regulations as well as technology support and standards.

3.1 Criteria for sustainable water use in hydrogen certification

Certification schemes play a crucial role in validating specific requirements defined for products or services. In general, certification schemes include two main elements: the criteria that outline the specific requirements and the framework that ensures compliance with the established criteria (GIZ, 2021). These schemes offer proof that prescribed standards and specific requirements are followed, providing credibility and transparency to consumers. Either mandatory or voluntary, certification schemes are issued by independent bodies to verify compliance by market actors with criteria outlined in policies, regulations or contractual obligations, for example. Key elements of a successful certification system include governance in establishing roles and responsibilities, application of standards, evaluation of compliance, and enforcement and verification of ongoing compliance (IEA, 2023).

Currently, the certification of hydrogen is in an early stage globally, and multiple standards are being developed. According to GIZ (2021), it is important to note that most hydrogen certification schemes currently lack coverage of essential sustainability criteria, including aspects such as water supply and use, social impact and community development. When considering criteria for water as a resource in hydrogen production, various publications, such as Heinemann and Mendelevitch (2021), GIZ (2021), Bracker (2017), TÜV Nord (2023), NWR (2021), Global Alliance Powerfuels (2021) outline a number of aspects that are relevant for the sustainable production of hydrogen.

Firstly, it is crucial that hydrogen production does not add extra pressure to local water availability in the short-term, seasonally, or in the long-term. To achieve this, hydrogen production should comply with existing water rights and align with water management plans, aiming to minimise conflicts with other water use cases, e.g., irrigation. An ideal scenario would involve the local population benefiting from increased access to the water supply and infrastructure resulting from the hydrogen project. Secondly, the production of hydrogen must not impact the quality of the water source used. As discussed in section 2, water electrolysis requires ultrapure water. Whether the water source is groundwater or surface water, it is essential to ensure that the wastewater from hydrogen production, such as brine or wastewater from the production of PtX materials, does not negatively impact the quality of the source. In regions where seawater desalination is an option, it is vital to ensure that desalination plants adhere to high ecological standards, particularly regarding brine disposal. Thirdly, water is also used as a coolant or for cleaning photovoltaic plants[2]. For these applications, efforts can and should be made to maximise efficiency in water use and minimise the additional water required aside from the volumes used as a feedstock. In summary, as a first step in achieving a sustainable hydrogen product, basic water management practices to increase transparency and comparability should be incorporated into hydrogen certification schemes. This would include the specification of the origin, use, volumes and reclamation of suitable sources of water, surface water or groundwater, or in the case of seawater, details on the operation of desalination plants should be specified. Going one step further, in an ideal case, hydrogen certification schemes would also include additional requirements, e.g., benefits to local communities through increased access to water and improved supply infrastructure.

[2] According to ETC (2023) 1 GW of installed solar capacity requires 45,000–230,000 m^3 of water for cleaning each year.

3.2 Hydrogen schemes and regulations for the sustainable use of water

In the future, it is unlikely that an universial approach will be adopted to incorporate sustainable criteria into a governance structure. Apart from regulation, criteria can be integrated in private sector schemes. This section examines three examples of different kinds of options for addressing sustainability criteria for the use of water. The three examples stand out due to their explicit mention of water as a resource, namely the EU Taxonomy (regulation for classification of investments as sustainable), the H2Global mechanism (public PtX funding instrument) and the Roundtable on Sustainable Biomaterials (private sector scheme). There have been extensive research efforts into comparing existing hydrogen certification schemes and regulations. For further information, see the following publications: IEA (2023), TÜV Nord (2023), dena and World Energy Council (2022), GIZ (2021).

EU Taxonomy

The EU Taxonomy Regulation outlines criteria for identifying environmentally sustainable economic activities, and promotes private investment in green and sustainable projects in support of the European Green Deal (EU, 2021). It aims to provide a classification system for a consistent and transparent understanding of activities that are considered environmentally sustainable. It also imposes sustainability reporting obligations on companies. The six EU environmental objectives under the EU Taxonomy include climate change mitigation, climate change adaptation, sustainable use and protection of water and marine resources, transition to a circular economy, pollution prevention and control, and protection and restoration of biodiversity and ecosystems.

The Taxonomy Regulation tasked the Commission with establishing technical screening criteria through Delegated Acts to define activities that contribute substantially to the aforementioned environmental objectives. In the EU Taxonomy Climate Delegated Act adopted in 2021, hydrogen is mentioned in the manufacturing sector and in the energy sector (sections 3 and 4) and included in the following activities qualify as contributing substantially to climate change mitigation under certain conditions:

- Manufacture of equipment for the production and use of hydrogen (p. 41)
- Manufacture of hydrogen (p. 53)
- Manufacture of anhydrous ammonia (p. 59)
- Storage of electricity (p. 75)
- Storage of hydrogen (p. 77).

Criteria for further economic activities, including the sustainable use and protection of water and marine resources, are specified in the Taxonomy Environmental Delegated Act adopted in 2023. The criteria include the management of environmental degradation risks relate to the maintenance of water quality and the prevention of water stress. They must be identified and addressed with the aim of achieving good water status and good ecological potential, and a water use and protection management plan must be developed for the potentially affected water body or bodies in consultation with relevant stakeholders. If an environmental impact assessment is carried out that includes an assessment of the impact on water in accordance with the Water Framework Directive, no additional assessment of the impact on water bodies is required if the identified risks have been eliminated.

H2Global

The H2Global instrument promotes the deployment and use of PtX products through a market-driven approach (H2Global Stiftung, n.d.). H2Global functions as a competition-based instrument designed to facilitate the rapid and efficient scale-up of the PtX market at industrial level. Following a Contracts for Difference (CfD) aligned approach, the difference between supply (production and transport) and demand prices is compensated by grants from a funding agency. An intermediary, the Hydrogen Intermediary Company GmbH (HINT.CO), enters into long-term purchase contracts on the supply side and short-term sales contracts on the demand side. Pricing for both procurement and sales is determined through seperate competitive bidding within a tailored funding window. Targeted green products in the first tender round with the German Ministry of Economic Affairs and Climate Action as the grant authority include renewable hydrogen-based ammonia, methanol and jet fuel. The geographic scope of the financing instrument can be adapted for each funding window, and may be regional (e.g. Europe) or country-specific, and the procurement process may be global or also geographically restricted. Stringent product requirements and sustainability criteria for production, transportation, and off-take are integral to the initiative but will also be determined for each window.

Regarding sustainability criteria for water use, the first production-side tender requires a comprehensive environmental and social impact assessment that considers the entire supply chain in addition to production sites. Both assessments must comply with an internationally recognised Environmental Impact Assessment (EIA) standard, which must be defined and carried out by the bidder (BMWK, 2022). Sustainable water procurement for eligible projects is considered essential to avoid any foreseeable degradation in quality or scarcity over the life of the project. In arid regions, the use of fossil water resources and potable water is prohibited. Applicants must disclose the source of their sustainable water supply which meets these criteria. If desalination is used, evidence of sustainable management of desalination residues is required. Applicants are encouraged to explore other uses for the residues, such as raw material extraction, and provide an implementation concept. Desalination processes must use renewable energy only, and the technical definition of "sustainable management" of residues is clarified through the competitive dialogue process. The award procedure for the first tender round started in December 2022 and deadline for participation in the bidding process was February 2023. However, selected projects for the production of ammonia, methanol and jet fuel have not been announced publicly yet.

RSB Standard For Advanced Fuel

Initially focused on certifying products based on biogenic materials, the Roundtable on Sustainable Biomaterials (RSB) has expanded the scope of its certification schemes to include Renewable Fuels of Non-Biological Origin (RFNBOs). These RFNBOs now fall into the category of Advanced Fuels and are governed by the "RSB Standard for Advanced Fuels". The current version of the standard (2.6) is effective as of December 1, 2023, and specifically addresses hydrogen, syngas, and synthetic liquid fuels as outlined in Annex II (RSB, 2023a). The primary audience for this standard includes producers, traders, processors and transporters in any region of the world excluding the EU. For companies within the EU or seeking to trade with it, the RSB EU RED Fuel Standard applies. The transportation sector is specifically excluded.

The RSB certification process for RFNBOs is guided by the 12 principles embedded in the "RSB Standard for Advanced Fuels" (RSB, 2023b). These principles cover a range of issues including human and labour rights, rural and social development, local food security, land rights and water. In particular, the RSB standard provides comprehensive criteria for the use of water, with four key points: 1. Operations must respect the existing water rights of local and indigenous communities.
2. Operations should include a water management plan to ensure efficient water use and to maintain or improve the quality of water resources. 3. Operations should not contribute to the depletion of surface or groundwater resources beyond their replenishment capacities. 4. Operations should actively contribute to enhancing or maintaining the quality of surface and groundwater resources.

4 Kazakhstan’s water resource management

Kazakhstan is an arid and water-dependent country. In fact, within the Eurasian continent, it is one of the most water-scarce countries (Rivotti et al., 2019). By 2030, freshwater volumes are set to decrease by 5 times to 23 km^3 which corresponds to the current annual consumption rate (Chynybaeva, 2023). Several parts of the country, including its capital, Astana, have been facing acute water shortages. Against this backdrop, this section provides an overview of Kazakhstan’s water resources, water management policies and the challenges occurring in the region.

4.1 Water resources and water usage

Kazakhstan’s total renewable water resources are about 108 km^3/year (FAO, n.d.). The main volume of water resources in Kazakhstan is provided by surface water, with an average annual volume of 101 km^3 (MENR RK, 2023a). Of these, 56% are formed locally, the remaining 44% are formed by the inflow of transboundary rivers from China, Uzbekistan, Russia and Kyrgyzstan. There are eight major water-economic basins (WEB) in Kazakhstan, as can be seen in Figure 3, namely Aral-Syrdarya, Balkash-Alakol, Ertis, Zhaiyk-Caspian, Esil, Nura-Sarysu, Shu-Talas and Tobyl-Torgai basins (Issanova et al., 2018). The availability of water resources across the eight river basins is unevenly distributed, where 75% of all the water resources generated is accounted for by the three largest river basins, namely Aral-Syrdarya, Irtysh and Balkhash-Alakol (Karatayev et al, 2017). Over the past two decades, Kazakhstan has experienced increasing transboundary water management problems. Water abstraction occurs all along the river flow and is utilised in industry and for domestic use (Yunussova and Mosiej, 2016).

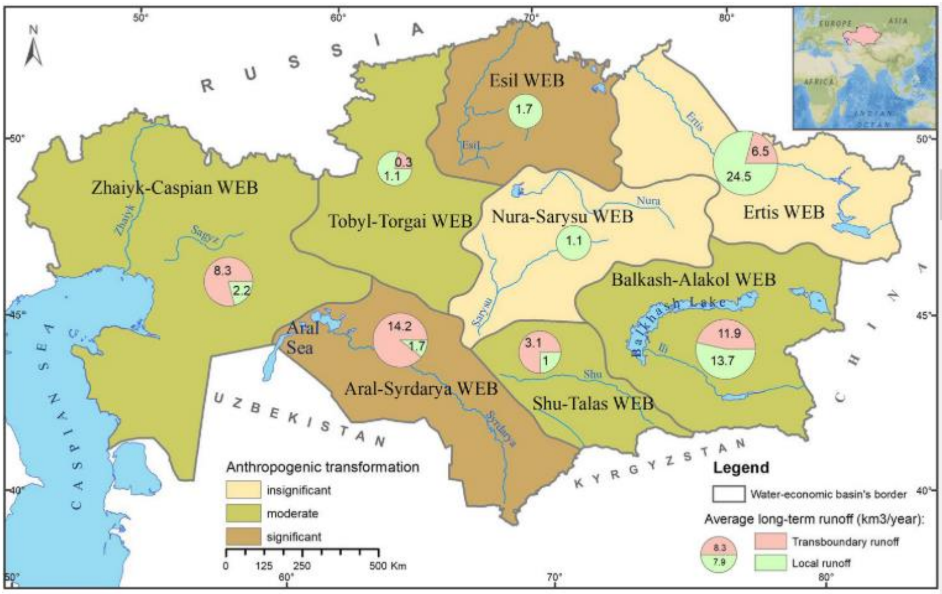

Figure 3: Water-economic basins (WEB) of Kazakhstan with available water resources where over 40% is generated through transboundary water inflow. Source: Issanova et al. (2018)

Kazakhstan’s water resources are scarce, at 6,000 m^3 per capita per year, which is significantly lower compared to regions such as Northern Europe (43,000 m^3 per capita per year) (Issanova et al., 2018). In 2022, the volume of water withdrawal as a whole for the economy and population amounted to 24.96 km^3 (MENR RK, 2023a). Agriculture, industry and public supply account for the three major water demand sectors in Kazakhstan. The agricultural sector, including regular irrigation, withdraws a total of 14.2 km^3 (11.3 km^3) per year, industrial users withdraw a total of 5.99 km^3 per year, and public users withdraw a total of 1.28 km^3 per year. The rest is for other uses. In terms of water usage, the total withdrawal consists of 96% from surface water, 4% from groundwater and small percentages from desalinated water, treated wastewater and agricultural drainage (own calculations based on FAO (n.d.)). The main reason for the low use of groundwater in Kazakhstan is attributed to the non-use of authorised groundwater reserves. A significant part of groundwater extraction takes place in subsoil areas without approved groundwater reserves or by uncontrolled extraction (MENR RK, 2023a).

4.2 Water governance and management

Kazakhstan plays a pioneering role in Central Asia in implementing the basin management approach in the post-Soviet area (Zhupankhan et al., 2018). The Water Code of Kazakhstan was implemented in 1993 as the basis of water legislation in Kazakhstan. Several governmental acts also exist which regulate water resource management (Genina, 2007). Water resources in Kazakhstan are managed along the lines of the basin management principle of the Integrated Water Resources Management (IWRM)[3]. Stressing the importance of water resources in the country, president Kassym-Jomart Tokayev established the Ministry of Water Resources and Irrigation of the Republic of Kazakhstan (CAREC, 2023). Compared to other Central Asian countries, Kazakhstan has made significant progress in implementing IWRM at all levels by adapting its institutional and legal framework (Sharipova and Chemayeva, 2022).

Due to the high level of natural irregularities in the distribution of water resources across Kazakhstan as well as the high dependency on water resources formed outside the country's borders, policymakers in Kazakhstan pay significant attention to water management policy. The outline for policy direction is decided at a top political level and is formulated into strategic documents and water-related regulations. Targets of the policy framework on water include the increase in water efficiency, water reuse and recycling as well as the increase in the capacity to accumulate water through the construction of new reservoirs. Furthermore, the policy framework aims to increase the provision of water supply and sanitation systems for the population. (UNECE, 2019).

Article 34 of the Water Code of the Republic of Kazkahstan[4] underlines the significance of basin management in the management of water resources. Departments for basin management have been established in all major water basins and are located within their respective basins. By the end of 2006, advisory bodies were set up in the form of councils for all eight basins as required by Article 43 of the Water Code, and with the support of the UNDP (UNECE, 2016). The main source of funding for the councils is the government budget. However, the government's financial support only just about covers funds to organise annual meetings of all eight basin councils. Most councils still lack the financial resources required to implement concrete actions beyond regular meetings (UNECE, 2019). Here, the reinforcement of multilateral and multi-donor formats such as the Central Asia Water and Energy Program (CAWEP)[5], which is jointly organised by the World Bank, the EU, Switzerland and the United Kingdom, will be key. CAWEP would benefit from stronger political backing. Support for pilot projects and activities in the water-energy nexus should include financial and regulatory incentives for sustainable water use in green hydrogen production.

Since its first publication in 1993, the Water Code has been amended a number of times. In 2014, for example, amendments regarding the safety of hydrotechnical installations were implemented in the Water Code. As of October 2023, the Ministry of Water Resources and Irrigation is developing a new version of the Water Code (Shashkina, 2023). This was announced by the head of the department Nurzhan Nurzhigitov. The draft Water Code plans, among other things, to transfer supervisory functions to river basin inspectorates in order to increase the speed of monitoring compliance with water use limits and to establish surface and groundwater quality management. In drafting the document, experts studied international practice in the field of national legislation and water resources in countries such as Australia, Canada, Germany, Israel and Uzbekistan.

The objective of the Water Resources Committee is to coordinate the implementation of state policy into water management as well as to regulate and control the field of water management (MWRI RK, n.d.). The Committee faces problems such as an inherent conflict of interest due to the close ties to the agricultural sector as a key water user, as well as a reduction in actual staff members of the Committee since 2014. The territorial bodies of the Committee include eight inspectorates in their respective basins. The basin inspectorates have control over the use and protection of the water resources and are in charge of an integrated water resources management system. Furthermore, the basin inspectorates coordinate the use of water within a basin by implementing basin agreements as well as supporting the activities of basin councils. However, to a certain extent, the basin inspectorates lack expertise on specific topics, such as the safety of hydrotechnical facilities, and are heavily understaffed. For instance, the Nura-Sarysu basin with an approx. area of 139,000 km^2 only has four inspectors to supervise the entire territory (UNECE, 2019).

There is also the Department of Transboundary Rivers, as a separate structure within the Ministry of Agriculture, which is in charge of Kazakhstan's bilateral water corporations with Kyrgyzstan, China and the Russian Federation. The Department is also in charge of multilateral cooperation such as the IFAS and its ICWC (UNECE, 2019). The main elements of water management within the basins are territorial boards which communicate with local authorities as well as the Water Resource Committee. The instated bodies play a significant role in privatisation and legislative processes within the basins.

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[3] https://www.gwp.org/en/gwp-SAS/ABOUT-GWP-SAS/WHY/About-IWRM/
[4] https://online.zakon.kz/Document/?doc_id=1042116&pos=6;-106#pos=6;-106
[5] https://www.worldbank.org/en/region/eca/brief/cawep

For the operation of water structures, solely state enterprises are responsible, including hydro-units, water-intakes, and pumping stations, etc. (Sarsenbekov and Ahmetov, n.d.).

4.3 Water management challenges

One of the challenges that Kazakhstan faces is water loss during transport. Water transport loss or leakages account for 13% of the total water withdrawals in 2022. The largest share of water withdrawals is for agriculture, especially for regular irrigation, where losses account for 65% of the water consumed by the sector. (MENR RK, 2023a) Kazakhstan also struggles with water quality due to primary pollutants from industry, which poses a serious environmental threat (Issanova et al., 2018). Fossil fuel extraction, particularly coal mining, exacts an environmental toll with issues such as drainage, emissions, and dust. Surface mining exacerbates challenges such as land use, tailings, and acid drainage (UNECE, 2019).

Another challenge for Kazakhstan and the Central Asian region is the expected growth in the population. As the population grows, the challenge of water scarcity in Central Asia will become more acute. Currently, 100 to 120 million people live in the region, and by 2050 this number could increase to 150 million (PAN, 2021). By 2040, Kazakhstan's population will grow by about 15% to 22 million people (World Bank, 2016). Combined with migration from rural to urban areas, this is expected to put additional pressure on the use of water and water supply infrastructure in Kazakhstan (Zhupankhan et al., 2018).

Climate projections indicate a rise in mean temperatures in Kazakhstan, with an increase of 3 to 4 °C anticipated by 2050. Central Asia, including Kazakhstan, has experienced temperature increases twice as rapidly as the global average since the 1970s. The Intergovernmental Panel on Climate Change (IPCC) forecasts a further temperature rise of 2 to 4 °C by 2050 and 3 to 5 °C by 2080 for the region (Lioubimtseva and Henebry, 2009; Lutz et al., 2013). Due to the reduction of transboundary runoff, the Republic's available water resources are expected to decrease to 77 km^3/year by 2040 (MENR RK, 2023a). An assessment of vulnerability to climate change identified the Almaty, Turkistan, North Kazakhstan, and Jambyl regions as the most vulnerable of the eight major water basins (FAO, 2017). With regard to precipitation, Kazakhstan faces a projected decrease in precipitation during the summer season and an increase in winter and spring (Chepelianskaia and Sarkar-Swaisgood, 2022). This will increase the risk of floods, landslides, mudslides and debris flows, especially in mountainous regions, as well as summer droughts. Increased glacier melt is also affecting water resources, particularly the Amu Darya and Syr Darya, major rivers that supply water to the Central Asia region (Gafurov et al., 2022). Attention is also focused on the Caspian Sea, where sea levels are projected to fall significantly in the coming decades, due to increased evaporation that is not balanced by increased river discharge or precipitation (Kaleji, 2023). Climate change adaptation measures are on Kazakhstan's agenda as the country is implementing comprehensive water management strategies. These include the construction of water reservoirs and emergency reservoirs to capture excess rainfall, the modernisation and reconstruction of water canals and hydraulic structures, wastewater treatment projects and the promotion of modern irrigation methods, as well as plans to provide incentives for the use of water-saving technologies in the industrial, agricultural and residential sectors (MENR RK, 2023b).

5 The influences of hydrogen production on Kazakhstan's water resources

The current backbone of Kazakhstan's energy sector is oil, hard coal and natural gas, which the country both produces and exports. The power sector is based on coal-fired thermal power plants – the share of electricity generation reached 70% in 2019, the share of gas-fired thermal power plants was almost 20%, and the remaining 10% came from large hydropower plants and emerging renewables (UNECE, 2023). Kazakhstan's energy landscape is undergoing significant changes, driven by key policy decisions and initiatives. One of the most important goals shaping the country's energy trajectory is its firm commitment to achieving carbon neutrality by 2060. This commitment was formalised in September 2021 with the adoption of the Strategy on Achieving Carbon Neutrality by 2060, signalling a greater awareness of climate change in Kazakhstan. On 2 February 2023, Kazakhstan's current president, Kassym-Jomart Tokayev, approved the Strategy on Achieving Carbon Neutrality by 2060, which sets ambitious net-zero carbon targets for the country's decarbonisation[6]. Furthermore, in line with its international commitments under the Paris Agreement, Kazakhstan has also outlined its Nationally Determined Contribution (NDC). The revised NDC of June 2023 includes a target to reduce GHG emissions by 15-25% by 2030 compared to 1990 levels, and prioritises water resource management, among others (MENR RK, 2023b). In line with Kazakhstan's NDC, on 29 July 2020, the government adopted the Action Plan for the implementation of the Concept for the transition of the Republic of Kazakhstan to a "Green Economy" for 2021-2030 (the 2021-2030 Action Plan). The 2021-2030 Action Plan contains several measures related to climate change adaptation[7]. These include reducing water use intensity, transforming agriculture, improving energy efficiency, modernising housing and municipal services, promoting sustainable transportation, preserving ecosystems and increasing forest cover.

As of December 2023, Kazakhstan is actively working on a National Hydrogen Strategy. While the exact timeline for approval has not yet been announced, this initiative demonstrates the country's intent to transition its economy to a sustainable trajectory. This section focuses on the impact of hydrogen production on water resources in Kazakhstan and conducts an analysis of green hydrogen production under two scenarios for the year 2040.

5.1 Production scenarios for green hydrogen

The Strategy on Achieving Carbon Neutrality by 2060, the primary energy policy, describes two contrasting scenarios: the Baseline Scenario and the Carbon Neutrality Scenario. In the Baseline Scenario, renewable electricity generation, including hydropower, is expected to increase by a factor of 2.2 (15.6 TWh) from 2017 to 2040. In contrast, the Carbon Neutrality Scenario projects a nearly fifteen-fold increase in renewable electricity generation (161 TWh) over the same period.

Following a methodology similar to UNECE (2023), this study adopts two scenarios – a conservative and an optimistic outlook. The conservative scenario assumes that approximately 3.12 TWh of renewable electricity, or 20% of solar and wind energy growth through 2040, will be used for green hydrogen production. Assuming full operation of 4,000 hours, this would correspond to an installed electrolyser capacity of 780 MW. Conversely, in the optimistic scenario, approximately 96.6 TWh of renewable electricity, or 60% of the solar and wind energy growth up to 2040, is used for green hydrogen production. This would also correspond to an installed electrolyser capacity of about 24 GW. In both scenarios, hydrogen production by electrolysis is assumed to require about 52 kWh/kg.

The results of these scenarios are shown in Figure 4. According to the conservative scenario, the analysis shows a hydrogen production volume of about 0.6 Mt, while the optimistic scenario shows a volume of about 1.8 Mt in the year 2040.

[6] https://adilet.zan.kz/rus/docs/U2300000121

[7] https://policy.asiapacificenergy.org/sites/default/files/Government%20Decree%20No%20479%20of%202020%20%28RU%29.pdf

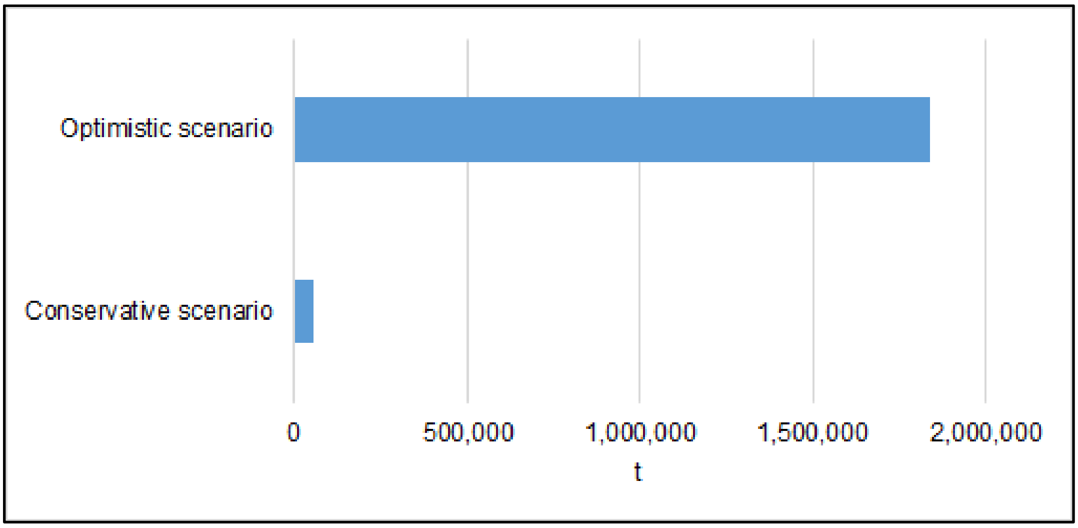

Figure 4: According to the carbon neutral scenario, a hydrogen volume of about 1.8 Mt would be possible in Kazakhstan in the year 2040.

5.2 Water volumes required for hydrogen production

This section takes a closer look at the withdrawal intensities of PEM and alkaline electrolysers to produce the hydrogen quantities required by the two scenarios in the previous section, in order to make an assumption about the impacts on Kazakhstan's water resources. As shown in section 2.2, the average water withdrawal intensities for PEM and alkaline electrolysers are about 25.7 litres H_2O/kg H_2 and 32.2 litres H_2O/kg H_2, respectively. Considering these withdrawal intensities, for the conservative scenario, the amount of water required for hydrogen production is 1.5 million m^3 for PEM electrolysis and 1.9 million m^3 for alkaline electrolysis, which is 0.006% and 0.008% of Kazakhstan's total water withdrawal in 2022. For the optimistic scenario, the water withdrawal for PEM electrolysis is 47.2 million m^3 and for alkaline electrolysis, 59.1 million m^3, making a share of 0.19% and 0.24% of Kazakhstan's total water withdrawal in 2022. A comparison of the optimistic scenario with the current water withdrawal per sector described in section 4.1 is shown in a logarithmic scale in Figure 5.

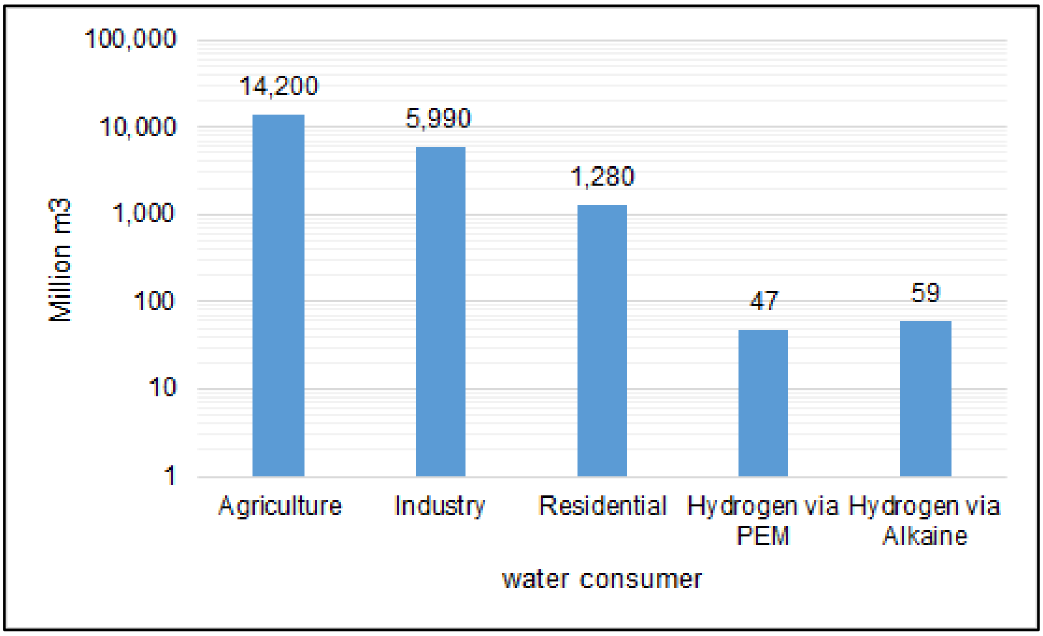

Figure 5: Compared to other water users (shown in a logarithmic scale), the impact on water resources is relatively small, but needs to be assessed on a case-by-case basis, as water resources are highly dependent on local availability.

The analysis shows that, while the overall impact of hydrogen production on water resources in Kazakhstan may seem relatively small compared to other water users, a more nuanced analysis is essential. This is a key factor is the regional distribution of water resources in Kazakhstan, where there are significant disparities. WRI's Aqueduct Water Risk Atlas, shown in Figure 6, gives a good first impression of where water availability is most scarce in Kazakhstan. This regional variation requires a thorough assessment of locally available water resources in order to make informed decisions about the feasibility and sustainability of hydrogen production in specific areas.

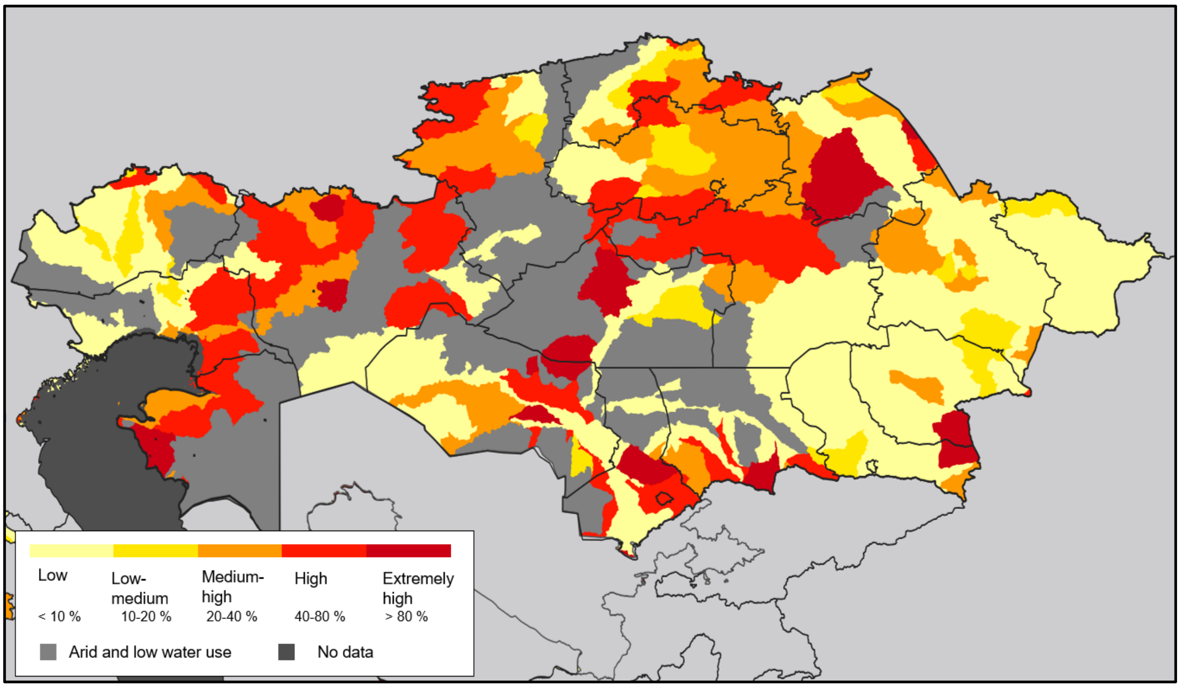

Figure 6: A key factor in assessing hydrogen production in Kazakhstan is the distribution of water at local level. Without sufficient water resources, there is no way of producing green hydrogen sustainably. Own illustration based on (https://www.wri.org/data/aqueduct-global-maps-30-data)

In areas with abundant water resources, hydrogen production could proceed with minimal impact on local water systems. However, in regions facing water scarcity or other challenges, it is essential that strategic water management practices are implemented in order to ensure sustainable hydrogen production without exacerbating existing water-related problems. Therefore, understanding the local context is critical to establishing a solid foundation for hydrogen production plans in Kazakhstan.

5.3 Discussion about the influences of hydrogen production

The analysis conducted in the previous section emphasizes the relatively modest impact of hydrogen production on the total water withdrawal, even in the optimistic scenario. However, it is critical to recognise that Kazakhstan's water resources exhibit significant regional disparities. Therefore, a more detailed assessment is imperative, focusing on water consumption specifically along the hydrogen production value chain and quantifying the water balance at the water basin and water body levels, including lakes and rivers. This requires a more detailed and granular approach that takes into account the unique local characteristics of a region.

The transition to a hydrogen economy offers Kazakhstan the opportunity to reduce water consumption and water scarcity compared to water-intensive energy production via coal. As Kazakhstan contemplates this transition, it is important to recognise regional variations in water availability and consumption. Therefore, this calls for proactive policies to protect existing water resources. Effective policies are essential to ensuring the responsible and sustainable use of existing water resources. Therefore, all actors on a governmental level involved in implementing hydrogen policies such as the Ministry of Energy (energy sector), the Ministry of Water Resources and Irrigation (water resource management), the Ministry of Industry and Construction (industrial development), the Ministry of Ecology and Natural Resources (environmental protection), and the Ministry of National Economy (strategic planning for the economy) must actively work together.

In addition, regional cooperation with neighbouring countries should be strengthened in order to address Kazakhstan's dependence on transboundary water inflows. Therefore, existing policies such as the 2021-2030 Action Plan, which already incorporates Central Asian cooperation, should be implemented consistently. The Action Plan includes support for a Central Asian regional programme on climate change adaptation, the implementation of agreements on the protection of water quality and the joint use and protection of transboundary rivers.

6 Conclusion

In conclusion, the sustainable use of water plays an important role in the production of green hydrogen. Hydrogen has the potential to set Kazakhstan's economy on a green trajectory. However, water demand for hydrogen production poses certain challenges and concerns. The production of 1 kg of hydrogen requires between 15 and 30 litres of water, depending on the water source and electrolyser technology. Striking a balance between using water to produce hydrogen and other essential needs will be crucial for establishing green hydrogen production in Kazakhstan. This underlines the importance of good governance, water management and regulation. As a first step in achieving a sustainable hydrogen product, green hydrogen certification should require the specification of the origin, use, volumes and reclamation of suitable water sources, surface water or groundwater, or in the case of seawater, the operation of desalination plants should be specified. Going one step further, in an ideal case, hydrogen certification schemes would also include benefits to local communities through increased access to water and improved supply infrastructure.

In the coming years, Kazakhstan will need to prepare its water management system for future challenges. One of the main challenges for Kazakhstan's water resource management is water loss during water transport due to infrastructure degradation as well as inefficient water use such as in the agricultural sector for irrigation purposes. Projected increases in temperature and precipitation shifts caused by climate change are another challenge for Kazakhstan. Due to the reduction of transboundary runoff, the country's available water resources are expected to decrease by about 30% by 2040. Furthermore, the sea level of the Caspian Sea is projected to fall significantly in the coming decades, due to increased evaporation. Climate change adaptation measures are thus on Kazakhstan's agenda as the country is implementing comprehensive water management strategies. In addition, the expected population growth poses another challenge for Kazakhstan and the Central Asian region.

In the context of Kazakhstan's pursuit of a hydrogen economy, an environmental impact assessment of green hydrogen production in the country is imperative. Sourcing unsustainable water or withdrawing excessive volumes of water could harm aquatic ecosystems and compromise biodiversity. A comprehensive assessment needs to specify the use of water along the whole hydrogen production value chain and to quantify the water balance at the level of water basin as well as water bodies, including lakes and rivers. This requires a granular approach that takes into account the unique local characteristics of a region. The envisioned transition to a hydrogen economy provides opportunities for Kazakhstan, but requires effective policies regarding water resources. To ensure the responsible and sustainable use of existing water resources, cooperation between governmental actors such as the Ministry of Energy, the Ministry of Water Resources and Irrigation, the Ministry of Ecology and Natural Resources, the Ministry of Industry and Construction, and the Ministry of National Economy is essential. This cooperation should extend to streamlining policies to address potential conflicts over water use, particularly in applications with water-intensive processes.

Addressing the threat of water scarcity in Kazakhstan requires a comprehensive water stewardship model for the entire Central Asian region. Recognising that reliance on water supplies from neighbouring countries may not be sufficient in the future, there is a need for an integrated and unified approach by the entire Central Asian region. Cooperation among Central Asian countries is essential to address the water challenges. This cooperation should focus on improving the efficiency of water use, modernising irrigation systems and introducing advanced technologies under the umbrella of a water management initiative. Existing policies, such as the 2021-2030 Action Plan, which already includes cooperation with other Central Asian countries, should therefore be implemented consistently. Addressing water scarcity on a global scale requires collective international focus and joint action. Beyond recognising the severity of the problem, a commitment to building capacity and streamlining global initiatives is paramount. Collaborative efforts and shared responsibility among the nations are required in order to empower local communities, implement sustainable water management practices and build resilience to the impacts of water scarcity. One such international effort is the multilateral Central Asia Water and Energy Program (CAWEP), which is organised by the World Bank, the EU, Switzerland and the United Kingdom. It would deserve more high-level political backing from the EU and Germany including financial and regulatory incentives for sustainable water use in green hydrogen production.

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Table of figures

List of abbreviations

GHG	Greenhouse gases
IWRM	Integrated Water Resources Management
MSF	Multi-Stage Flesh
NDC	Nationally Determined Contribution
PEM	Proton exchange membrane
PtX	Power-to-X
RFNBO	Renewable Fuels of Non-Biological Origin
RO	Reverse osmosis
RSB	Roundtable on Sustainable Biomaterials
SOEC	Solid Oxide Electrolysis Cells
TWh	Terrawatt hours
UPW	Ultrapure water
UV	Ultraviolet
WEB	Water-economic basin

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