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Green Hydrogen and Decarbonization in Central Asia

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I. List of Abbreviations

APAEC	ASEAN Plan of Action for Energy Cooperation
ASEAN	Association of Southeast Asian Nations
CAPEX	Capital Expenditure
CELAC	Community of Latin American and Caribbean States
CENEF	Centre for Efficient Energy Use
CERTHILAC	Hydrogen certification system for Latin America and the Caribbean
CIS	Commonwealth of Independent States
COP	Conference of the Parties
DRI	Direct Reduced Iron
EEC	Eurasian Economic Commission
EEU	Eurasian Economic Union
EU	European Union
FCEV	Fuel Cell Electrical Vehicles
GCC	Gulf Cooperation Council
GDP	Gross Domestic Product
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
IEA	International Energy Agency
IEDB	Inter-American Development Bank
IDOS	Institute of Development Studies
IPHE	International Partnership for Hydrogen and Fuel Cells in the Economy
IRENA	International Renewable Energy Agency
ISO	International Organization for Standardization
ISO/TC 197	International Organization for Standardization / Technical Committee 197 on Hydrogen Technologies
KSTU	Kyrgyz State Technical University
KRSU	Kyrgyz-Russian Slavic University
LAC	Latin American and the Caribbean
MED	Multi-Effect Distillation
MENA	Middle East and North Africa
MOF	Metal-Organic Framework
Mtpa	Million Tons per Annum
NUUz	National University of Uzbekistan
OLADE	Latin American Energy Organization
OSCE	Organization for Security and Co-operation in Europe
PV	Photovoltaic
PtX	Power-to-X (technologies that convert power into different energy carriers)
RED II	Renewable Energy Directive II
RES	Renewable Energy Sources

RG-T3395	Regional Integration of the Green Hydrogen Value Chain
RMI	Rocky Mountain Institute
SCO	Shanghai Cooperation Organization
SIEM	Sistema de Interconexión Eléctrica de los Países de América Central (Electrical Interconnection System of the Central American Countries)
SPV	Special Purpose Vehicle
TALCO	Tajik Aluminum Company
TCGP	Trans-Caspian Gas Pipeline
THTI	Tashkent Chemical-Technological Institute
TITR	Trans-Caspian International Transport Route
TSTU	Tashkent State Technical University
TTU	Tajik Technical University named after M. Osimi
TNU	Tajik National University
UAE	United Arab Emirates
UNECE	United Nations Economic Commission for Europe
UNIDO	United Nations Industrial Development Organization
USAID	United States Agency for International Development
USSR	Union of Soviet Socialist Republics

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III. Executive Summary

The five Central Asian countries, Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan are located at the crossroads of Eurasia and share a long history of energy cooperation, industrial, agricultural and water management integration, as well as a common geopolitical and cultural heritage. These factors form a strong foundation for future collaboration in the development of green hydrogen, leveraging the region's vast renewable energy potential. Green hydrogen can play a transformative role in decarbonizing hard-to-abate sectors, advancing economic diversification, and fostering green industrial development across Central Asia. Regional cooperation would be essential for harmonizing hydrogen and derivative certification schemes, establishing green value chains, strengthening local content, advancing political and geopolitical dialogue, and enhancing human capital development and educational systems.

This report examines these aspects in the context of Central Asia's potential integration into the emerging global hydrogen economy, drawing comparisons to experiences from Latin America and the Caribbean, the Gulf Cooperation Council (GCC) countries, and Southeast Asia. Certification of green hydrogen and its derivatives is not only a cornerstone of future global trade but also a fundamental factor determining product value. By the end of 2024, at least 17 certification schemes were under development globally, with significant variations in criteria related to emissions accounting, production origin, temporal and geographical correlation, water and land use, and supply chain transparency. While global harmonization remains challenging, a modular approach - based on unified methodologies, digital product passports, mutual recognition, and transparent tracking systems - can enable regional cooperation to play a key role in ensuring compatibility and market access.

As of early 2025, Latin America and the Caribbean remains the only region actively developing a dedicated hydrogen certification system, CertHiLAC, established in 2023 through a ministerial declaration by 14 countries. CertHiLAC aims to ensure traceability by disclosing carbon intensity, production methods, and sustainability attributes, enabling green hydrogen exports while promoting sustainable practices. Key features of CertHiLAC include voluntary participation, technological neutrality, precision-focused classification beyond simple colour codes, and strong sustainability commitments. CertHiLAC offers two certification streams: one tailored to intra-regional trade within Latin America, and a stricter version aligned with EU standards, incorporating RED II requirements and stricter temporal and geographical correlation criteria.

Drawing on lessons from CertHiLAC, Central Asian countries could either develop their own regional certification system or join existing frameworks. Recommended steps include establishing a permanent intergovernmental dialogue platform on sustainable energy and hydrogen; securing external financing for joint activities; accelerating the adoption of national hydrogen strategies; and conducting a comprehensive assessment of global certification schemes. Such steps would help optimize existing frameworks, reduce costs, and accelerate decision-making on regional certification.

For green value chains to emerge at scale, the current export structure and economic complexity of Central Asian economies must also be considered. Central Asian countries rank relatively low in export diversification, with most exports concentrated in primary commodities such as oil, gas, coal, copper, iron, and ferroalloys. Primary export markets include Europe, China, and Russia. This commodity focus has led to the perception of green hydrogen and its derivatives primarily as future export commodities, shaping national hydrogen strategies and project pipelines. Notable initiatives include proposed energy corridors to the EU via the South Caucasus, Turkey, and the Black Sea, alongside flagship projects like Hyrasia One, which targets green ammonia exports. However, there is also untapped potential for integrating green hydrogen into domestic industrial value chains, particularly in refining, steelmaking, and ammonia and fertilizer production, which could support the region's important agricultural sectors.

Whether for export or domestic use, green hydrogen development will require extensive infrastructure investment. Despite Central Asia's vast renewable energy potential - estimated at up to 3,760 GW for solar and 354 GW for wind - renewable energy accounted for only 25% of total electricity generation in 2022, with wind and solar representing just over 2%. Scaling up renewable generation to enable large-scale hydrogen production will require transformative investment in power generation - with a manyfold increase in green electricity production compared to current levels - as well as major upgrades to electricity grids, water management infrastructure, and green industrial capacity. Balancing variable renewable electricity with water needs - critical given the region's dependence on hydropower - will require closer regional cooperation. Existing natural gas pipeline networks, developed over decades, could potentially be repurposed for hydrogen transport after appropriate upgrades. At the same time, green hydrogen export corridors will require the development of new hydrogen pipelines, port infrastructure, and expanded rail and logistics capacity, making regional cooperation essential.

Political cooperation in Central Asia is also evolving, shaped by state-building processes, leadership renewal, sustainability agendas, and the geopolitical impacts of the war in Ukraine. Central Asian governments are deepening regional political ties while diversifying external partnerships. Energy cooperation with Russia continues to focus heavily on fossil fuels and nuclear power, with very limited emphasis on renewables. In contrast, the EU, China, the Gulf states, and the United States - longstanding investors in the region's fossil fuel sector - are increasingly prioritizing renewable energy and green hydrogen investments. These include utility-scale renewable projects, early green hydrogen pilots (such as Chirchik in Uzbekistan), and educational and stakeholder engagement initiatives like the German-Kazakh Energy Dialogue and USAID Power Central Asia. New green initiatives enjoy strong political backing in countries committed to carbon neutrality, including Kazakhstan, Kyrgyzstan, and Uzbekistan.

To strengthen regional political cooperation in green energy, Central Asian countries could leverage existing intergovernmental and interministerial mechanisms, mobilizing key ministries, state-owned enterprises, development banks, and international agencies. Long-term development of hydrogen value chains will also require investment in human capital. Central Asian universities have significant potential to develop hydrogen-related programs, but current educational infrastructure, curricula, and faculty expertise remain limited. Kazakhstan leads the region in relevant programs and international partnerships, while Uzbekistan is adapting its curriculum, and Kyrgyzstan and Tajikistan face more acute challenges. Key gaps include weak industry links, low research funding, and insufficient integration of hydrogen into educational programs. Expanding international partnerships, academic exchanges, and industry collaborations, alongside establishing regional training centres and grant programs, can help close these gaps.

By learning from best practices in regional cooperation from Latin America and the Caribbean, the Gulf Cooperation Council, and ASEAN, Central Asian countries could pursue several key actions: establishing a dedicated regional platform for coordinating renewable energy and hydrogen projects; developing cross-border energy trade and a regional electricity market; launching joint education and research programs involving leading universities; enhancing partnerships with international organizations and development banks to access finance and technology; and hosting high-level regional forums to share experiences and showcase projects.

01. Introduction

This report was prepared by Mylonastars Ltd. on behalf of Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH under the framework of the “H2-diplo - Decarbonization Diplomacy” project. H2-diplo is part of the International Climate Initiative (IKI) under the Federal Foreign Office of Germany, designed to support the federal government’s foreign policy on energy and climate. Working in collaboration with partner countries, H2-diplo aims to explore ways to leverage green hydrogen for decarbonization and economic diversification. Green hydrogen, produced from water with renewable energy sources, holds the potential to play a pivotal role in decarbonizing so-called hard-to-abate sectors, such as chemical or steel production. Additionally, H2-diplo addresses geopolitical challenges related to the development of an international green hydrogen market, such as shifts in power dynamics on the path to a climate-neutral global economy.

The five Central Asian countries, Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan, share decades of collaboration in the energy sector, close industrial and agricultural ties, integrated water management systems, and a shared geopolitical and ethnocultural landscape. Recently, Central Asia has gained increasing attention for its green hydrogen potential, not only at the national level but also from a regional perspective. This report seeks to identify opportunities for regional cooperation on green hydrogen in Central Asia by analysing publicly available information on the following themes:

1. Regional Certification Schemes. *Objective:* Assess the potential for implementing regional certification standards for green hydrogen, for example drawing on best practices from Latin America and the Caribbean to ensure compliance and market credibility.
2. Green Value Chains. *Objective:* Investigate local production opportunities for green hydrogen end-products and the role of current infrastructure in supporting export opportunities.
3. Political Cooperation and Geopolitics. *Objective:* Explore the possibilities for regional political cooperation and negotiation on green hydrogen standards and regulations, facilitating a unified approach to policy and investment.
4. Water and Renewable Energy Potential. *Objective:* Evaluate prospects for harmonizing water resource management with the intermittent supply of renewable energy.
5. Human Capacities. *Objective:* Examine the education and training systems relevant to the development of a green hydrogen economy.
6. Technologies and Infrastructure. *Objective:* Analyse the availability and readiness of technologies and infrastructure for green hydrogen at a regional level.
7. Exporting Sectors and Regional Comparisons. *Objective:* Identify sectors with export potential beyond Central Asia and benchmark regional cooperation practices against global best practices.

The research methodology involves utilizing the most current publicly available sources and studies on these relevant themes.

02. Regional Certification Schemes

2.1 Landscape of Certification as of 2024

Certification of hydrogen and its derivatives, particularly in the context of verifying their carbon footprint, represents a fundamental element in enabling large-scale trade, including international markets. Such certification is no longer a mere desirable attribute of a product but has become a critical, and in some cases, essential component of its overall value.

The development of hydrogen certification schemes and systems involves the participation of dozens of countries, industry stakeholders, think tanks, international organizations and the private sector. As of December 2024, at least 17 such schemes were in advanced stages of development, targeting implementation at national and, much less frequently, regional levels across 11 countries and regions (IEA 2024a; IPHE 2024b; IRENA and RMI 2023).

An analysis of these diverse certification schemes generally highlights significant differences among them (see Figure 1) concerning product requirements (e.g., greenhouse gas emissions, sources of electricity, production technologies, temporal and geographical correlation, water and land use), operational procedures, and supply chain models (IPHE, 2024).

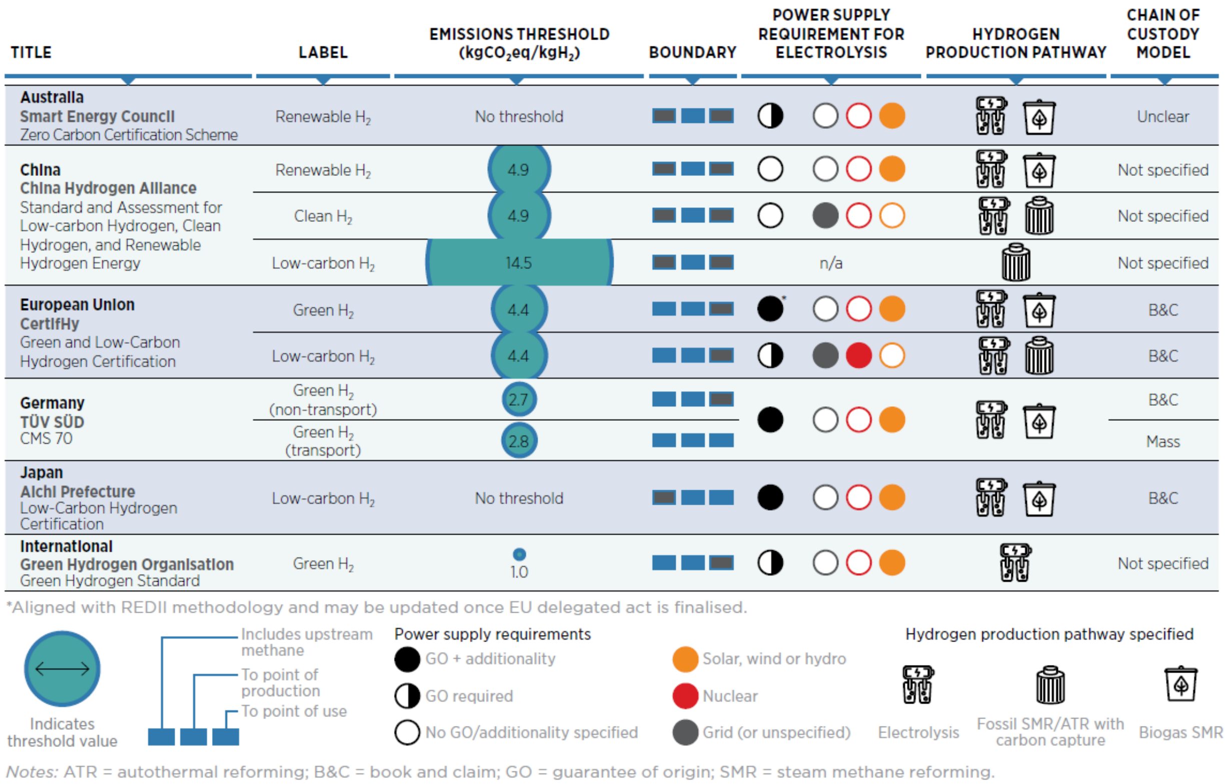

Figure 1: Summary of voluntary market hydrogen certification mechanisms with published technical criteria. Source: IRENA and RMI 2023

Existing certification systems are not suitable for cross-border trade due to significant differences in standards, eco-labelling practices, and certification criteria. Certificates often lack sufficient information about greenhouse gas emissions associated with the production and transportation of hydrogen, making it difficult to compare products from different countries. Moreover, the absence of a harmonized tracking system introduces the risk of double counting and creates barriers to ensuring compliance with market requirements (IRENA and RMI 2023).

Addressing these challenges, policymakers are working to implement a comprehensive and multifaceted approach toward harmonizing these diverse standards.

Key elements of this approach include:

- *Modularity:* The ability to select standard modules while maintaining unique national or regional requirements.
- *Unified Methodology*: Development of a consistent methodology for assessing carbon footprints.
- *Digital Product Passports*: Introduction of digital passports containing detailed information about the carbon footprint, origin, transportation emissions, and other relevant data.
- *Mutual Recognition*: Enabling the mutual recognition of various certification schemes or modules.
- *Transparent Tracking Systems*: Implementation of transparent tracking mechanisms modeled on postal parcel tracking systems.

Achieving these objectives requires enhanced dialogue among countries, collaboration between governments and businesses, and significant effort from all stakeholders involved in the process (IRENA and RMI 2023).

At the end of 2024, the COP29 Hydrogen Declaration was signed (COP29.AZ 2024), in which national governments and key stakeholders reaffirmed their commitments to accelerating the production, use, and trade of renewable, clean/zero-emission, and low-carbon hydrogen. The aim is to facilitate the global energy transition, achieve climate goals, and provide equitable and sustainable solutions. More than 50 countries (including all Central Asian countries except Turkmenistan) and over 40 companies and associations have already endorsed the Declaration. The document emphasizes the critical role of certification, highlighting the need for:

- Accelerating the development of global standards to support the process of mutual recognition of certification schemes through continued international cooperation on improving compatibility, consistency, transparency, sustainability and interoperability of relevant frameworks and instruments, including by consideration of the adoption of or consistency with globally recognised standards for evidencing carbon intensity.
- Advancing global trade through international collaboration and public-private partnerships to support the development of cross-border value chains, including enabling infrastructure and the wider supply chain, as well as pursuing a level-playing field to pave the way for an international market for renewable, clean/zero-emission and low-carbon hydrogen and its derivatives.
- Promoting climate and environmental stewardship and actively addressing the sustainability aspects of hydrogen through pursuing actions to help ensure hydrogen systems are maximally beneficial to the climate across the hydrogen value chain and conducted in an environmentally and socially responsible manner, including by minimising greenhouse gas emissions associated with hydrogen production and use, energy and hydrogen losses throughout the value chain, and mitigating potential impacts to air quality, water resources and land use.

2.2 Opportunities and Barriers for Regional Certification

An evident pathway for harmonizing certification systems is the development of supranational certification schemes that consider the positions of neighbouring countries with similar geographic characteristics, levels of economic and industrial development, potential for low-carbon and green hydrogen production, opportunities for establishing hydrogen value chains, natural resources, and geopolitical contexts. Aligning positions among such countries is likely to progress more rapidly and with fewer obstacles, laying the groundwork for the faster deployment of hydrogen value chains across the entire region.

The most well-known example is the development of hydrogen certification systems in the European Union. At the end of December, the EU officially recognized three voluntary certification schemes for renewable hydrogen: REDcert, ISCC, and CertifHY (S&P Global 2024). This recognition enables project developers to secure offtake agreements, access EU-specific support mechanisms (such as hydrogen auctions and contracts for difference), and significantly contributes to the expansion of hydrogen production and use across the continent.

While the European Union can be viewed as a regional entity, it is also a supranational organization with nearly three decades of experience, a high degree of harmonized national legislation, and unified parliamentary and executive institutions. Additionally, the EU is one of the most ambitious players in the global hydrogen market, with concrete plans for the production, consumption, and importation of renewable hydrogen by 2030. It also leads globally in the number of adopted national hydrogen strategies (IRENA 2024a). Consequently, the EU's example may not be fully applicable to regions such as Southeast Asia, Central Asia, the South Caucasus, Eastern Europe, MENA, Sub-Saharan Africa, North America, or Latin America and the Caribbean.

Some of the most apparent barriers to creating regional hydrogen certification schemes include the varying levels of importance assigned to hydrogen within the energy policies of different countries. If hydrogen does not rank as a priority within a country's energy strategy, stakeholders are unlikely to actively engage in the development of its certification framework. Additionally, a significant obstacle is the high cost associated with establishing such systems, which often requires the support of international organizations and development banks.

As of early 2025, only Latin America and the Caribbean are actively developing a regional initiative for hydrogen certification. In contrast, the vast majority of countries in other regions listed above either adopt a wait-and-see approach or focus on the advancement of national certification systems. Examples of countries pursuing national initiatives include those geographically and economically close to Central Asia, such as China, Japan, South Korea, and the UAE (IEA 2024a).

2.3 CertHILAC: The Hydrogen Certification System in Latin America and the Caribbean

Latin America and the Caribbean (LAC) is one of the largest regions globally, with a combined GDP of USD 7.1 trillion (current prices), spanning an area of 20.5 million km², and home to 660 million people (World Bank 2024). Only two countries in the region - Paraguay and Bolivia - are landlocked, while the major seaports of other nations are integral components of the global logistics network.

The CertHiLAC initiative represents a unique and pioneering effort to establish a regional hydrogen certification system. It was launched in 2023 through a ministerial declaration signed by 14 countries: Argentina, Bolivia, Chile, Colombia, Ecuador, El Salvador, Guatemala, Honduras, Mexico, Panama, Paraguay, the Dominican Republic, Trinidad and Tobago, and Uruguay. This project is supported by the Energy Division of the Inter-American Development Bank (IDB) as part of its broader initiative, "Regional Integration of the Green Hydrogen Value Chain" (RG-T3395). Furthermore, CertHiLAC is a key component of the energy cooperation agenda within the framework of OLADE, the Latin American Energy Organization, established in 1973 to promote energy policy integration and collaboration among LAC countries (OLADE 2023).

As of mid-2024, nine of the 14 countries involved in CertHiLAC had either published or were in the process of developing national hydrogen strategies or roadmaps (IRENA 2024a). This underscores the pivotal role hydrogen plays in the energy and climate policies of these nations, making regional certification cooperation a logical extension of their strategies.

Argentina and Chile are Participating Members, while Bolivia is an Observing Member of ISO/TC 197 Hydrogen Technologies, the international technical committee focused on standardization for hydrogen technologies (ISO 2024). Additionally, Chile and Uruguay are members of the International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE), actively contributing to the harmonization of international hydrogen certification systems (IPHE 2024).

The CertHiLAC system aims to ensure product traceability by providing detailed information on carbon intensity, production technologies, and attributes of environmental and social sustainability. Its overarching goal is to facilitate the export of clean hydrogen to other regions while supporting sustainable practices. To ensure the effective implementation of CertHiLAC, a System Representative Group has been established, comprising two representatives from each participating government. This group will be responsible for developing recommendations, shaping regional and national governance frameworks, and identifying key stakeholders for the system. According to the initiative's architects, the creation of a regional certification system will help avoid duplication of efforts across different countries, establish a unified standard, and enhance the region's competitiveness in the global hydrogen market.

Key Features of CertHILAC (Hartmann et al. 2023):

- *Voluntary Nature*. The system is not mandatory and is designed for producers who wish to certify the quality of their product and its compliance with international standards. Countries remain free to develop their own national certification systems, while CertHILAC can serve as a foundation for such national systems.
- *Technological Openness*. CertHILAC is not tied to specific hydrogen production technologies, thereby accommodating the diversity of energy sources in the region, including both renewable and fossil-based sources.
- *Focus on Precision over "Colours".* The system provides a detailed description of hydrogen characteristics to avoid confusion and ensure transparency. The use of "colours" for hydrogen classification is not employed.
- *Commitment to Sustainability.* The system integrates social and environmental factors important to the region, such as the positive social impact of projects on neighbouring communities and indigenous peoples, sustainable water sourcing and use, measures to minimize environmental impacts, wastewater treatment (including brine, where applicable), compliance with international labour standards, and sustainable, socially and environmentally harmonious land use (excluding lands with conflicts).

CertHILAC is structured around two certification formats: H2 Certification for the LAC Region and H2 Certification for EU Markets. The first format is designed for the regional market in Latin America and the Caribbean (LAC) and for exports outside the European Union. It incorporates regional specificities such as water scarcity and impacts on local communities, focusing on "Well-to-Gate" emissions. The second format is tailored specifically for export to the EU, aligned with the requirements of the Renewable Energy Directive (RED II), and includes additional attributes such as temporal and geographic correlation between hydrogen production and electricity generation.

Consequently, the H2 Certification for EU Markets represents a stricter category, building upon the H2 Certification for the LAC Region while meeting the specific demands of the European market.

Key Steps in the CertHILAC Implementation Plan:

- *Establishment of a Governing Body*: Formation of the System Representative Group composed of experts from LAC countries who will define system rules and standards.
- *Governance Design:* Development of protocols for interaction among system participants, including decision-making and voting mechanisms.
- *Assessment of Investment Costs:* Determination of the costs associated with the development and implementation of CertHILAC, and identification of funding sources.
- *Capacity Building:* Conducting training sessions for representatives from LAC countries on hydrogen certification processes.
- *Stakeholder Identification:* Formation of a group comprising representatives from the public and private sectors for consultations and technical support.
- *System Design Definition:* Approval of attributes, characteristics, and emission calculation methodologies within the CertHILAC framework.
- *Data Collection:* Compilation of required data from LAC countries to establish a comprehensive certification database.
- *Certification Costing:* Development of a fee structure for hydrogen certification to be applied to producers.
- *Pilot Testing:* Conducting pilot tests of CertHILAC in various countries to validate its functionality and scalability.

According to the system's designers, participating countries are expected to appoint national representatives to the unified governing body of CertHILAC, engage in educational programs, develop national certification management systems aligned with CertHILAC, collect necessary information, involve stakeholders, study international best practices, and standardise certification processes at the national level.

Once operational, CertHILAC is envisioned to function as a comprehensive ecosystem involving a variety of new stakeholders interconnected through a system of interactions (Figure 2).

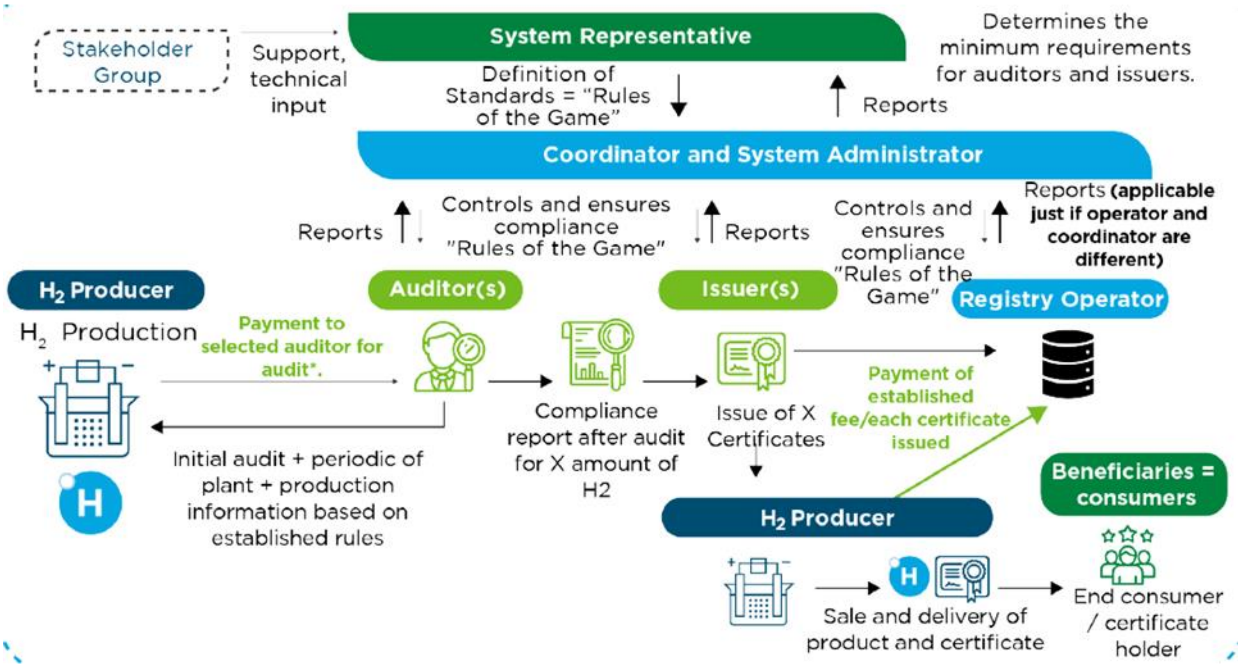

Figure 2: Certification Process Cycle and Interactions of Governance Players for Each Step. Source: Hartmann et al. 2023.

The key components of this ecosystem include:

- *System Representative:* Responsible for defining system rules and ensuring CertHILAC's functionality. This role requires a technical expert from the public or private sector with a permanent position and deep knowledge of their country's and region's hydrogen ecosystems (e.g., from energy ministries, national development agencies, or electricity market operators).
- *Coordinator and System Administrator:* Oversees system operations, ensures transparency, and provides support to participants. It is proposed that this role be undertaken by a coordinating organization, such as OLADE, which already has experience with certification systems.
- *Registry Operator*: Maintains the certification registry and supports the technical infrastructure while preventing double accounting. The registry operator works under the system administrator's supervision. It is suggested that this role be assigned to an experienced IT company or integrated into the system administrator's responsibilities.
- *Certificate Issuer:* Issues certifications based on the rules established by the System Representative, interacts with hydrogen producers, and trains certification bodies and auditors. To ensure cost efficiency and support local market development, it is recommended that issuers operate nationally.
- *Auditors:* Verify compliance of hydrogen producers with system criteria and attributes through standardized audit procedures. To maintain efficiency and competitiveness, multiple accredited auditors should be appointed.
- *Trade Platform Operator:* Facilitates the creation of a marketplace for certificate trading (this role may be introduced at a later stage).

The authors of CertHILAC estimate development costs to range between USD 300,000 and 2,000,000 or less, depending on lessons learned from similar projects. The preferred financing model involves funding from development banks, particularly the Inter-American Development Bank (IDB), complemented by partial contributions from participating countries (Hartmann et al 2023).

2.4 Conclusions and Recommendations for Central Asia

This chapter draws key lessons from international best practices in hydrogen certification and contextualizes them for Central Asia. The region's unique geographic, economic, and political characteristics shape both the opportunities and challenges in developing a regional hydrogen certification system.

1. Geographical and Socio-Economic Characteristics.

Central Asia comprises five countries with a total area of 4 million km², a population of 77 million, and a combined GDP of approximately USD 0.45 trillion. None of these countries have direct access to the open sea. These characteristics position Central Asia as a vital part of the Eurasian continent, particularly in the context of intracontinental connections between East, West, and the Middle East and North Africa (MENA). However, the region's current capacities and opportunities are not yet on the same scale as those of Latin America and the Caribbean (LAC) or the European Union, though there is potential for significant development in the future. This also applies to the limited resources that Central Asian countries can allocate to hydrogen deployment and certification systems.

2. Status of Hydrogen Strategic Planning.

Kazakhstan is the only Central Asian country that has published a medium-term strategic document on hydrogen (at the level of a concept or roadmap, as defined by IRENA 2024a). Uzbekistan is the only country in the region where a green hydrogen project is under construction (Chirchik, green ammonia). Hydrogen, in general, has not yet become a priority in the energy and climate policies of the region's countries. Stakeholder attention to hydrogen emerged significantly later than in regions such as Europe or LAC (IRENA forthcoming 2025)..

3. Objectives in Hydrogen Deployment.

Most national hydrogen strategies in the LAC region are oriented towards export, including to the European Union, supported by the region's significant role in global maritime energy transportation, including ammonia. In contrast, the objectives of Central Asian countries regarding hydrogen deployment are still at an early stage of development and may not necessarily focus only on exports to the European Union. This is due to the region's remoteness from the EU market and lack of access to maritime transport routes. The approaches to hydrogen certification demonstrated by China, Japan, and South Korea could have an equally significant, if not greater, influence on the countries of Central Asia.

4. Formats of Multilateral Energy Cooperation in Central Asia.

The countries of Central Asia share decades of collaboration in energy-related areas. In the electricity sector, for instance, the so-called Central Asian Energy System was developed between the 1950s and 1980s, aimed at the rational joint utilization of the region's water and energy resources. However, this system became politically and technologically fragmented by 2010. Other existing high-level cooperation formats, such as the CIS Electric Power Council, the Shanghai Cooperation Organization, and the Eurasian Economic Union, generally involve neighboring countries (China, Russia, South Caucasus countries, etc.) and broader agendas. There is no equivalent of OLADE in Central Asia—a dedicated international organization with a permanent secretariat, long-term strategy, and clear institutional structure (27 member countries), focusing on sustainable development and renewable energy deployment.

5. Participation in International Hydrogen Standardization and Certification Discussions.

Kazakhstan is the only Central Asian country with Observing Member status in ISO/TC 197 (ISO 2024). None of the region's countries currently hold membership in the International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE 2024a).

Based on the analysis of these fundamental differences and lessons from best practices, the following recommendations can be proposed to support the development of a regional hydrogen certification system in Central Asia:

- Establish a Regular Intergovernmental Platform for Discussions on Sustainable Energy and Hydrogen: Create a platform at the level of relevant ministries from Central Asian countries to facilitate joint research and coordinate positions on a wide range of topics.
- Attract External Financing for Activities: Seek funding from regional development banks (such as the Asian Development Bank and the Eurasian Development Bank) and international and national industrial and energy companies to support this initiative.
- Accelerate the Development of National Hydrogen Strategies: Draft strategies to define the scale, strategic priorities, objectives, and immediate steps for hydrogen deployment. These strategies should also outline the framework for hydrogen certification at both national and regional levels.
- Conduct a Comprehensive Study of Hydrogen Certification Systems in Partner Countries: Examine systems in countries such as Japan, China, South Korea, the European Union, Germany, and the UAE. This will maximize the use of existing frameworks, saving time and costs in creating a regional system. Apply the principle of modularity. Based on the study's results, determine whether to establish a proprietary regional certification system or join existing ones.

03. Green Value Chains and Local Content

3.1 Analysis of Regional Value Chains and Export Sectors with Potential for Green Hydrogen Integration

The value chains for green hydrogen are extensive and encompass the downstream (end-use products), midstream (transport and storage), and upstream (green hydrogen production) segments. They also involve interlinked sectors such as renewable electricity generation, advanced water purification, equipment manufacturing, workforce training, and research and development (R&D) (IRENA, UNIDO and IDOS 2024).

At present, green hydrogen is not yet produced in the region, and the locations for the production of grey hydrogen are co-located with its consumption points. As a result, a significant portion of the green hydrogen value chain, particularly related to upstream and midstream activities, will need to be built from scratch in all countries of the region. Furthermore, the downstream segment must be substantially expanded to transition from the use of grey hydrogen to green hydrogen.

Local content plays a pivotal role in ensuring sustainable economic opportunities and enhancing the global competitiveness of national industries. Thoughtfully implemented localization requirements can drive the development of domestic industries, create green jobs, and stimulate innovation. Local content also facilitates the integration of green technologies into national economies, reducing dependency on imported solutions and strengthening energy security. Moreover, it establishes a foundation for participation in global trade of environmentally friendly products and ensures equitable distribution of benefits to local communities.

Green hydrogen can be integrated into green value chains across several key industries, including:

- Chemical industry (e.g., production of green ammonia and methanol)
- Green steel and fertilizers
- Oil refining
- High-temperature industrial heating
- Long-haul heavy transportation (aviation, maritime sector)

In the longer term, hydrogen and its derivatives could become critical for seasonal energy storage, providing a sustainable solution for long-term energy balancing. Currently, such seasonal storage is supported by reserves of coal, oil, petroleum products, and underground gas storage.

In this chapter, each Central Asian country will be analysed to assess the presence of value chains and their potential for integrating green hydrogen. This analysis will be based on the Economic Complexity Index (Hausmann et al. 2014) and publicly available information on existing production chains in each country.

Kazakhstan

Kazakhstan is the largest economy in the region, with an economic complexity ranking[1] of 73 out of 133 and total exports amounting to $86.6 billion in 2022. The key export categories are mineral-related products (Fig.3) - Crude Petroleum ($47.6B), Gold ($9.73B), Refined Copper ($3.8B), Ferroalloys ($3.29B), and Radioactive Chemicals ($2.85B).

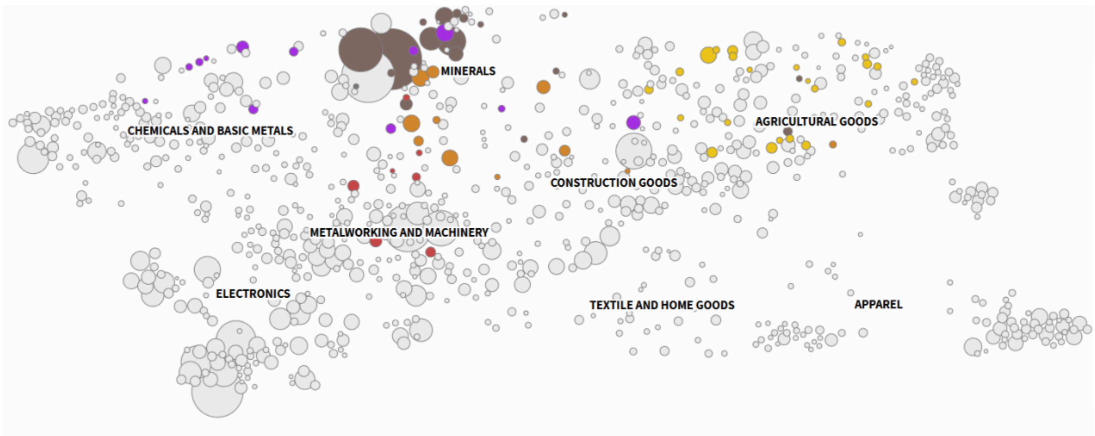

Figure 3: Kazakhstan in the Product Space, 2022

Based on this economic structure, the largest opportunities for the integration of green hydrogen in Kazakhstan can be found in the refining and metallurgy sectors. The production of ammonia and fertilizers plays a smaller role today but may become the next major sector. Additionally, Kazakhstan's vast logistical routes (as the largest country in the region), the important role of heavy-duty long-haul transport, and relatively low average annual outdoor temperatures may create opportunities for hydrogen mobility based on Fuel Cell Electric Vehicles (FCEV) (Melnikov 2023).

The concept of hydrogen energy development in Kazakhstan up to 2030 mentions the planning of a pilot project using hydrogen in gas-turbine power plants (by 2026), the introduction of hydrogen-fueled buses in three cities (by 2027), the implementation of pilot hydrogen projects in industry (by 2028), and the initiation of pilot projects for hydrogen export (by 2028-30).

[1] The Economic Complexity Index (ECI) measures and ranks countries according to the diversity and complexity of their export portfolios. It reflects the breadth and specialization of a nation's productive capabilities, with a low ECI value indicating advanced and diverse production capacity, enabling the creation of a wide array of goods. Conversely, a high ECI value signifies dependence on a limited range of simpler exports, often primary commodities or basic manufactured products.

Kyrgyzstan

Kyrgyzstan is a country with an economic complexity ranking of 70 out of 133 and total exports amounting to $3.77 billion in 2022. The key export categories are minerals and agricultural products (Fig. 4) - Refined Petroleum ($145M), Gold ($139M), Precious Metal Ore ($135M), Dried Legumes ($100M), and Scrap Copper ($87.7M).

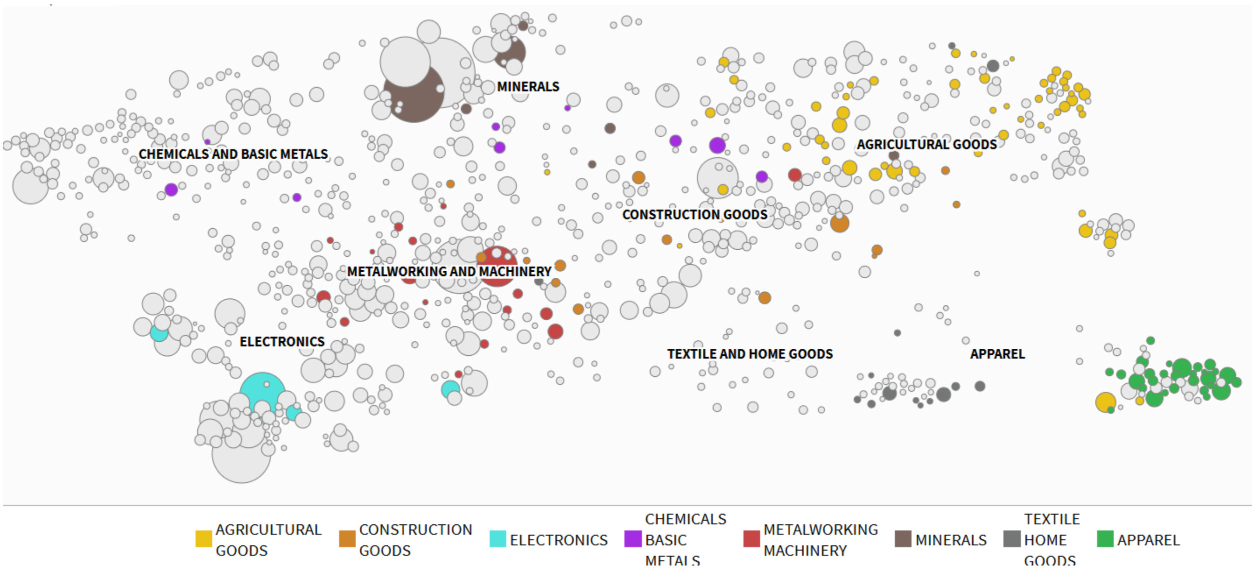

Figure 4: Kyrgyzstan in the Product Space, 2022

Based on this economic structure, the largest opportunities for green hydrogen integration in Kyrgyzstan can be found in the oil refining sector. Due to the significant role of agriculture in the economy, the development of the green fertilizer sector could play a role in further decarbonizing this sector. In the long term, hydrogen-based seasonal energy storage may open up opportunities for balancing the intermittency of electricity generation from hydropower, the country's primary energy source.

Tajikistan

Tajikistan is a country with an economic complexity ranking of 108 out of 133 and total exports amounting to $2.2 billion in 2022. The key export categories are minerals and agricultural products (Fig. 5) - Gold ($644M), Precious Metal Ore ($249M), Raw Cotton ($212M), Copper Ore ($203M), and Raw Aluminium ($174M).

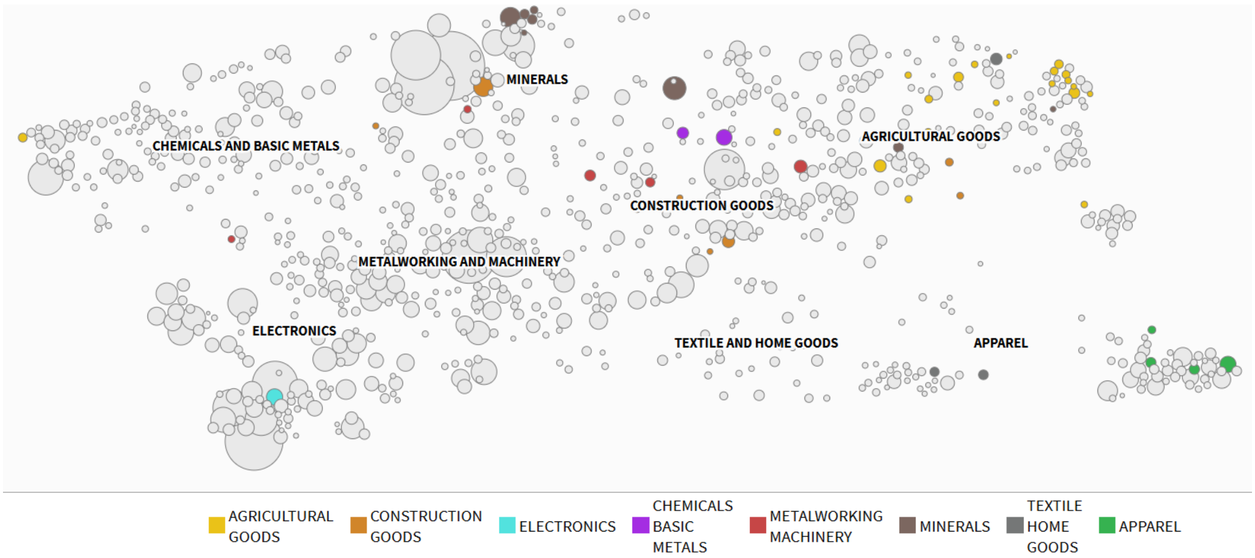

Figure 5: Tajikistan in the Product Space, 2022

Based on this economic structure, the largest opportunities for the integration of green hydrogen in Tajikistan can be found in the metallurgy sector, where hydrogen could be used as a reducing agent and a source of high-temperature heat. Given the significant role of agriculture in the economy, the development of the green fertilizer sector could play a role in further decarbonizing this sector. In the long term, hydrogen-based seasonal energy storage could help balance the intermittency of electricity generation from hydropower, which is the country's main energy source.

Turkmenistan

Turkmenistan is a country with an economic complexity ranking of 90 out of 133 and total exports amounting to $12 billion in 2022. It is the largest producer and exporter of natural gas in the region. The key export categories are hydrocarbons and nitrogen fertilizers - Petroleum Gas ($9.21B), Refined Petroleum ($1.28B), Nitrogenous Fertilizers ($585M), Crude Petroleum ($394M), and Electricity ($165M).

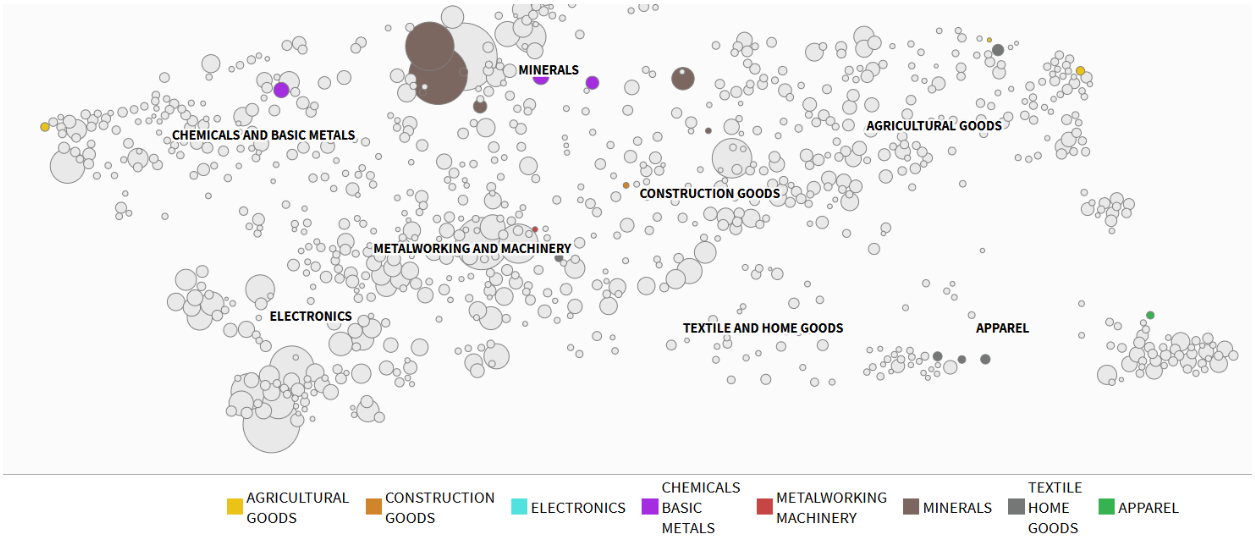

Figure 6: Turkmenistan in the Product Space, 2022

Based on this economic structure, the largest opportunities for the integration of green hydrogen in Turkmenistan are in the oil refining and new green fertilizer production sectors. The latter will be especially important for agriculture, which makes a significant contribution to GDP.

Uzbekistan

Uzbekistan is the most populous country in the region, with an economic complexity ranking of 79 out of 133 and total exports amounting to $19 billion in 2022. The key export categories are cotton and textiles, agriculture, and minerals (Fig.7) - Gold ($5.18B), Non-Retail Pure Cotton Yarn ($1.39B), Petroleum Gas ($934M), Refined Copper ($596M), and Silver ($339M). The country is an important exporter of nitrogen fertilizers, having developed its chemical industry based on natural gas for decades.

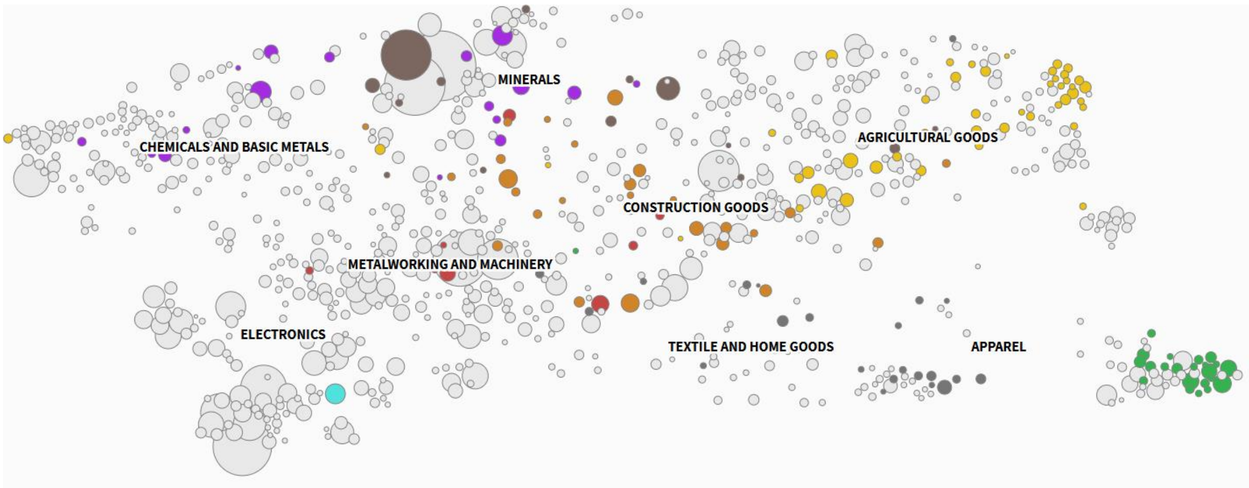

Figure 7: Uzbekistan in the Product Space, 2022

Based on this economic structure, the largest opportunities for the integration of green hydrogen in Uzbekistan can be found in the chemical and fertilizer production sectors. The integration of green hydrogen into these value chains could help decarbonize not only the chemical industry but also agriculture, which relies on its products (fertilizers). Notably, the first pilot green hydrogen project in Central Asia, now under construction, is taking place in Uzbekistan's ammonia production sector. ACWA Power (Saudi Arabia) is developing it in the city of Chirchik in partnership with the Uzbek chemical company Uzkimyosanoat. The first phase of the project, upon completion, is expected to produce 3 kt of green hydrogen annually. The second phase, which will produce 500 kt of green ammonia per year, is currently in the feasibility study stage (ACWA Power 2023).

Longer-term prospects for the integration of green hydrogen into Uzbekistan's value chains are related to the production of green steel using Direct Reduced Iron (DRI) technology, based on the country's abundant iron ore, and green hydrogen. In addition to green steel production, green hydrogen could also be used in copper production.

Central Asia at a glance

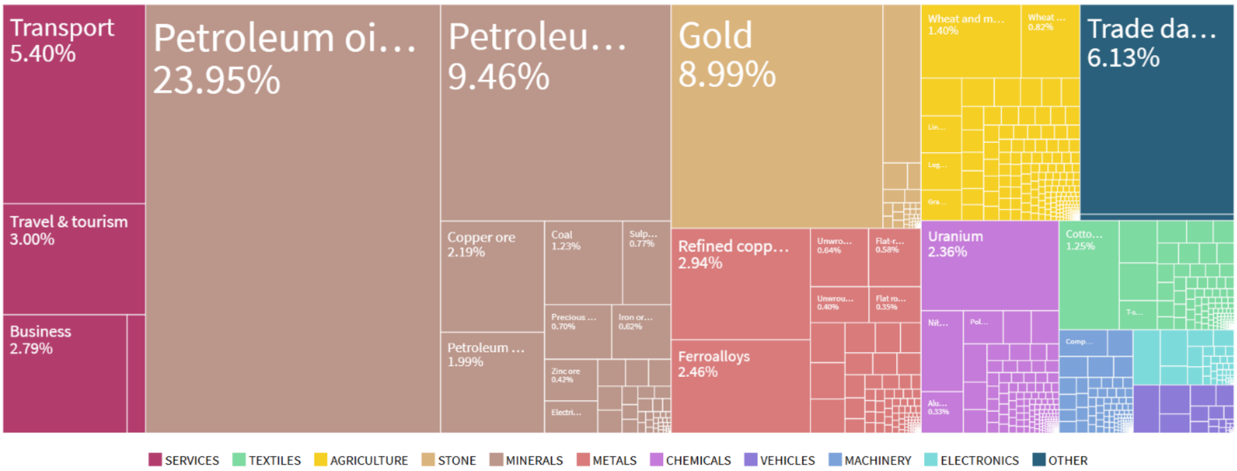

Figure 8: Export Products Mix of Central Asia, 2022

In total, the countries of Central Asia exported $123 billion in 2022, with key export commodities (more than 50% of the export basket) being products from the extraction and processing of minerals – oil, gas, coal, copper, iron, and ferroalloys (see Fig. 8).

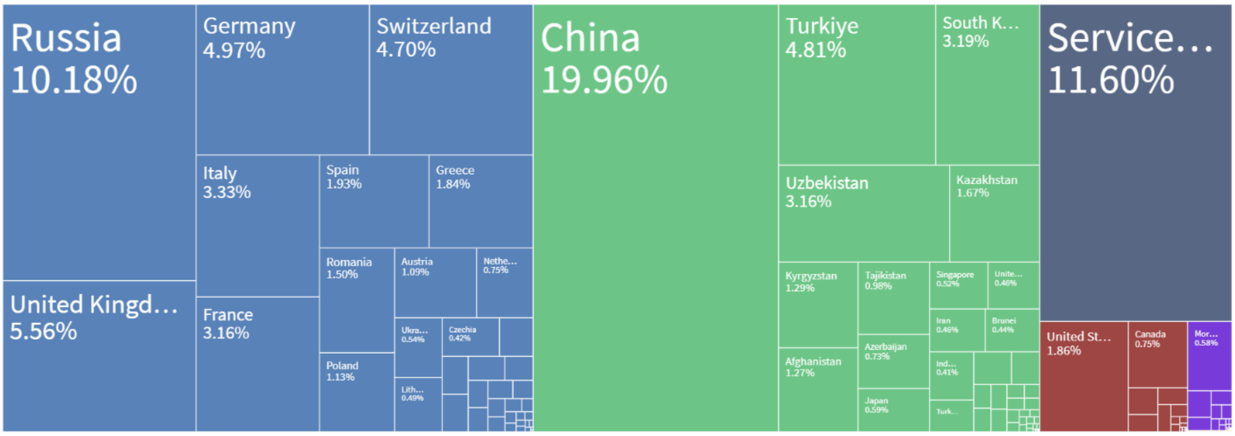

Figure 9: Export Destinations Mix from Central Asia, 2022

The main export markets for Central Asian countries are Europe, China, and Russia (Fig. 9). The roles of China and Europe are especially significant for the markets of oil, coal, iron, steel, copper, and fertilizers.

The dominant role of fossil energy exports in the economies of Central Asian countries (particularly Kazakhstan, Turkmenistan, and Uzbekistan) creates a foundation for stakeholders in the region to carefully consider hydrogen export projects (and occasionally derivatives) to the European Union and other export markets. These initiatives are discussed both at the level of individual projects within specific countries and within the framework of intergovernmental cooperation. They share a common idea – positioning Central Asian countries as key players in the future global trade of PtX, leveraging the region's abundant renewable energy resources.

Some of the most notable initiatives include:

- The Hyrasia One Project (Kazakhstan) has currently completed the pre-FEED phase, with detailed engineering (the FEED phase) expected to begin in mid-2025. The project aims to establish 20 GW of electrolyser capacity, powered by 27 GW of wind and 13 GW of PV. Once operational, the project is expected to achieve a total production capacity of 2 million tons per annum (Mtpa) of hydrogen or 11 Mtpa of green ammonia annually (Hyrasia One 2024). According to the project's website, green hydrogen or ammonia could already today be transported in large quantities to Asia, the Gulf region, or Europe via ship and rail.
- The Green Energy Corridor between the countries of Central Asia via the South Caucasus to the European Union is often discussed in the context of exporting renewable electricity to the EU, but hydrogen is less frequently mentioned. In 2024, Uzbekistan, Kazakhstan, and Azerbaijan formed a joint venture headquartered in Baku and signed an agreement to study this project. Initially, its parameters were estimated at 10-15 TWh per year, with a CAPEX of $2 billion. The project is currently in the feasibility study phase.
- Kazakhstan's Hydrogen Energy Development Concept by 2030 aims to export from 5,000 tons of green hydrogen in 2028 to 15,000 tons by 2030 (with an estimated production volume of 25,000 tons by 2030).
- The Minister of Energy and Water Resources of Tajikistan stated in 2023 that the country intends to produce 500,000 tons of green hydrogen by 2030, with 75% of this volume potentially directed toward export to other Central Asian countries (Neftegaz.RU 2023).
- The idea of decarbonizing the South Gas Corridor (Margvelashvili 2024) envisions the export of 30 billion cubic meters of natural gas per year through the Trans-Caspian Gas Pipeline (TCGP), and at a later stage, repurposing this pipeline to transport 4-5 Mtpa of green hydrogen (equivalent to 150 billion cubic meters of natural gas previously supplied by Russia to the EU until 2022). According to the project's authors, producing this amount of hydrogen would require around 140 GW of wind or 330 GW of solar power plants. The project would involve countries such as Kazakhstan, Turkmenistan, Uzbekistan, Azerbaijan, Georgia, and Turkey.

For both participation in export initiatives and the development of local green value chains, Central Asian countries will require corresponding infrastructure. The analysis of this infrastructure is the focus of the following section.

3.2 Evaluation of Existing Infrastructure, Technologies and its Potential for Supporting Local Production and Export

Renewable energy potential

A key component of the infrastructure for green value chains is the power generation infrastructure, particularly renewable energy production. Central Asia possesses vast renewable energy potential, which, according to various estimates, can range from 0.3 to 30 GW (small hydropower), from 195 to 3,760 GW (solar energy), from 1.5 to 354 GW (wind energy), up to 54 GW (geothermal energy), and from 0.2 to 0.8 GW (bioenergy) (Laldjebaev et al 2024).

The distribution of renewable energy potential across the Central Asian countries is uneven and varies depending on the type of energy:

- Kazakhstan has the largest potential for solar and wind energy (3,760,000 MW and 354,000 MW, respectively), as well as geothermal energy (54,000 MW).
- Tajikistan leads in small hydropower potential (30,000 MW).
- Uzbekistan has the second-largest potential for solar energy (593,000 MW) and bioenergy (800 MW).
- Kyrgyzstan ranks second in small hydropower potential (900 MW).
- Turkmenistan stands out with substantial potential for solar (655,000 MW) and wind energy (10,000 MW).

Power Generation Infrastructure, Including Renewables

Despite the vast renewable energy potential in the region described above, its utilization is still relatively limited. As of 2023, Central Asian countries have 61.6 GW of installed capacity from all types of power stations, of which 28.3% are renewable (including 4.9% wind and solar). Electricity production in 2022 amounted to 254.1 TWh, with 25% from renewables (including 2.1% from wind and solar). The majority of renewable electricity is generated by large hydropower stations, commissioned decades ago, with Kyrgyzstan and Tajikistan accounting for more than half of the total renewable electricity production in the region (Table 1).

Table 1: Renewable Electricity Capacity and Generation Statistics in Central Asia (2022-2023). Source: IRENA 2024b.

Country	Electricity Production in 2022 (TWh)	Share of Renewables in Electricity Production, % (incl. solar + wind)	Installed Power Capacity in 2023 (GW)	Share of Renewables in Installed Capacity, % (incl. solar + wind)
Kazakhstan	112.9	12 (4)	26	22 (10.6)
Kyrgyzstan	13.9	86 (0)	4.1	78 (0)
Tajikistan	21.4	93 (0)	6.5	89 (0)
Turkmenistan	31.6	0 (0)	7.0	0 (0)
Uzbekistan	74.3	9 (1)	18	15 (1.35)

This infrastructure currently provides electricity to the existing consumers in Central Asian countries (with some seasonal limitations, especially in Kyrgyzstan and Tajikistan, which face chronic electricity shortages in the winter). To significantly scale up green value chains and, particularly, implement export initiatives for green electricity and hydrogen, this infrastructure will need to be rapidly expanded. It is roughly estimated that to produce 1 Mtpa of green hydrogen, 20 GW of new renewables will need to be deployed. For example, implementing the Hyrasia project will require the commissioning of renewable energy capacity greater than all the power stations in Kazakhstan. Similarly, the decarbonization project of the Southern Gas Corridor will require the addition of renewables with greater capacity than all the power stations in Central Asia.

Thus, the existing electricity generation infrastructure in the region can facilitate small-scale pilot projects in green value chains (such as in Chirchik, Uzbekistan), but scaling up will depend on quickly deploying renewables through the establishment of an optimal regulatory framework, setting ambitious targets, reducing costs through economies of scale, and developing human resources.

Electricity Grid Infrastructure in the Context of Scaling Green Hydrogen Value Chains

Electricity grids are important for transmitting electricity from renewable power plants to electrolysers in the green hydrogen value chains. Historically, the electrical grids of the five Central Asian countries were closely interconnected, operating in synchronous mode within a single energy system during the Soviet era. However, after the collapse of the USSR, this interconnection weakened. Turkmenistan withdrew from the system in 2003, and Tajikistan’s energy system was temporarily disconnected. By 2025, it is expected to start operating synchronously with the systems of Uzbekistan, Kyrgyzstan, and Kazakhstan. The issue of insufficient interconnection also exists at the level of individual countries. For example, in Kazakhstan, the bottleneck is the 500 kV North-South transit section, which creates risks for the stability of the energy system during emergency disturbances (UNECE 2023a).

The problem of insufficient interconnection is further exacerbated by the high wear and tear of the electrical grids - both trunk (for example, connecting Turkmenistan and Uzbekistan) and distribution grids. For instance, the average wear of Kazakhstan’s distribution grids exceeds 65%. High wear increases electricity losses, reduces the reliability of electricity supply, and increases the risk of failures (Kazenergy 2023).

The growth of renewables in electricity generation, including the introduction of new renewables specifically intended for hydrogen production, will require addressing these accumulated problems, including by building additional transmission lines, digitalizing grids, and modernizing emergency control systems. For a balanced development of electricity infrastructure with the increasing share of renewables and considering the interaction between the dominant hydropower dams in the region with water scarcity and its importance for agriculture, regional cooperation will be necessary.

Electrolysers

Electrolysers, which produce hydrogen and oxygen from demineralized water using electricity, are a key element of the green hydrogen value chains. As of the end of 2024, there are no large-scale electrolysers in operational status in Central Asia (IEA 2024b). This infrastructure will need to be built from scratch in the region. A rough estimate suggests that to produce 1 Mtpa of green hydrogen, electrolysers with a capacity of 10 GW will need to be deployed. One electrolyser project in the region is under construction (ACWA Power, Chirchik, Uzbekistan), and a second has completed the pre-FEED phase, with detailed engineering (the so-called FEED phase) expected to begin in mid-2025. (Hyrasia One, Mangistau, Kazakhstan).

Pipeline Infrastructure

For transporting hydrogen over land on a medium to large scale, the most optimal option is pipeline infrastructure. Currently, there is no significant hydrogen pipeline system in Central Asia, as existing grey hydrogen production sites align with consumption areas. As green hydrogen supply chains are developed, this infrastructure will be crucial for large-scale hydrogen use within the countries and for export projects.

Part of the existing natural gas pipeline system in Central Asia could be repurposed for hydrogen transportation after necessary modernization. The gas transport system in Central Asia, built over decades, is a complex network of interconnected pipelines that serves both the internal needs of each country and exports gas to Russia and China (UNECE 2023b). Kazakhstan plays a key role in the transit of gas from Uzbekistan and Turkmenistan. Gas consumption in Kazakhstan is growing, with the household gasification rate increasing from 30% to 55% over the last decade. QazaqGas manages the gas infrastructure, which includes pipelines such as the “Soyuz”, “Middle Asia-Centre”, “Bukhara-Urals”, “Tashkent-Bishkek-Almaty”, “Gazli-Shymkent”, “Beineu-Bozoy-Shymkent”, and “Central Asia-China”. However, the infrastructure built during the Soviet period is 70% worn out, thus requiring modernisation. QazaqGaz plans to reduce this figure to 25% by 2030 (Kazenergy 2023).

Kyrgyzstan imports gas from Uzbekistan and transits it to Kazakhstan via the “Bukhara-Tashkent-Bishkek-Almaty” pipeline. The infrastructure managed by “Gazprom Kyrgyzstan” requires modernization, as it is over 35 years old.

Tajikistan imports gas from Uzbekistan to meet the needs of the Dushanbe power station and the TALCO aluminium plant. The state company “Tajiktransgaz” manages this infrastructure. Plans include building the “Line D” transit pipeline as part of the Central Asian gas pipeline to China.

Turkmenistan, a major gas producer, has a developed infrastructure, including new gas pipelines. The "Turkmenistan-Uzbekistan-Kazakhstan-China" pipeline, over 9,000 km long, supplies gas to China. Other operational pipelines include "Dovletabad-Deryalyk", "Korpedje-Kurtkui", and "Dovletabad-Serahs-Hangaran" for export to Iran, and "Vostok-Zapad" for domestic supplies. Among the prospective projects are the "Turkmenistan-Afghanistan-Pakistan-India" pipeline, the Trans-Caspian underwater pipeline, and the "Fourth Line (D)" of the "Turkmenistan-China" pipeline (UNECE 2023b).

Uzbekistan has a gas transport infrastructure of 13,500 km, managed by "Uztransgaz". The "Bukhara-Tashkent-Bishkek-Almaty" pipeline supplies gas to Kyrgyzstan and Kazakhstan, while the "Mubarek-Shurabad-Dushanbe" pipeline supplies gas to Tajikistan. Uzbekistan also transits gas from Turkmenistan to China and Russia via pipelines passing through Kazakhstan.

Kazakhstan plays a central role in the gas transit sector, connecting Turkmenistan and Uzbekistan to Russia and China. The "Central Asia-Centre" and "Central Asia-China" pipelines are critical for gas exports. Uzbekistan and Turkmenistan supply gas to the southern regions of Kazakhstan. Kyrgyzstan imports gas from Uzbekistan and transits it through its territory to Kazakhstan.

A significant portion of the gas transportation infrastructure in Central Asia was built during the Soviet era and is in need of modernisation. This is especially pertinent for Kazakhstan and Kyrgyzstan. In recent years, Turkmenistan has been actively constructing new pipelines.

Hydrogen export projects to the European Union could require multimodal logistics - creating new hydrogen pipelines, modernizing existing pipelines in the South Caucasus countries, and utilizing rail and sea transport from Black Sea ports in Georgia. According to a study published by GIZ, (Fichtner 2023), large-scale hydrogen exports from western Kazakhstan would entail substantial development of pipelines and maritime infrastructure from scratch, as well as the significant expansion and adaptation of existing railway and port capacities in several countries. The route involves pipelines, railways, and maritime transportation via the Caspian and Black Seas. The main options pass through the ports of Aktau or Kuryk in Kazakhstan to the port of Alat in Azerbaijan, and then to the ports of Poti or Batumi in Georgia, and onward to Constanța (Romania) or Burgas (Bulgaria), or overland transport from Alat to Kipoi at the Turkey-Greece border. The scale of export is expected to be at 2 Mtpa by 2040 and 0.18 Mtpa by 2030. The existing NH3 railway infrastructure in the region requires expansion by a factor of 2 to 22, and there are currently no tankers for NH3 in the Caspian Sea. For large-scale export, a hydrogen pipeline through the Caspian Sea is the most cost-effective ($1/kg H2). For smaller scales, the cost would be $4/kg H2, still cheaper than alternatives.

Water Resources and Their Role in Supporting Green Hydrogen Production

Central Asia possesses significant water resources for hydrogen production, largely unrelated to seawater desalination, although these resources are unevenly distributed among the five countries, and there is significant competition among water consumers (particularly from agriculture, which forms a major part of the economies of many countries, and hydropower, which depends on the flow of mountain rivers and simultaneously defines the electricity mix in countries such as Kyrgyzstan and Tajikistan).

Most of the major rivers in Central Asia originate in high mountain ranges where snow and glaciers feed the water supply: the Tian Shan (Kyrgyzstan: Naryn, Syr Darya rivers, Kazakhstan: Ili, Chu rivers), and the Pamirs (Tajikistan: Panj, Vakhsh rivers, tributaries of the Amu Darya). Tajikistan has a large area of glaciers, which are the main source of water for the region's rivers. Tajikistan is also home to the highest mountain ranges in Central Asia, such as the Pamirs, where the flow of major rivers, including the Amu Darya, originates. Therefore, Tajikistan (and to a lesser extent Kyrgyzstan) plays a crucial role in the freshwater supply of Central Asia and, if economically viable, could support large-scale green hydrogen projects by providing sources of high-quality freshwater. Regional cooperation becomes essential in the context of implementing large-scale green hydrogen projects.

Regarding Turkmenistan, Kazakhstan, and Uzbekistan, the situation is more challenging. Regions such as the Caspian Depression (Kazakhstan, Turkmenistan), the Ustyurt Plateau (Kazakhstan, Uzbekistan), South and Central Kazakhstan (including the Betpak-Dala semi-desert), the Kyzylkum Desert (Uzbekistan), South Uzbekistan, and the Karakum Desert (Turkmenistan), as well as the Kopet Dag and Paropamiz mountain systems (Turkmenistan), require special attention due to water stress and the distribution of available freshwater resources.

Desalination of Caspian Sea water is most developed in Aktau (Kazakhstan) using reverse osmosis and multi-effect distillation (MED) technologies. Projects aimed at significantly increasing water consumption in regions like Aktau (including for hydrogen production) may need to address the challenges of providing drinking water to the local population.

In general, average water consumption and withdrawal levels for hydrogen electrolysis are 17.5 litres/kg H2 and 25.7 litres/kg H2, respectively (IRENA and Bluerisk 2023).

04. Political Cooperation and Geopolitics

4.1 Analysis of Current Political Cooperation Frameworks and Geopolitical Dynamics Impacting Green Hydrogen

Russia – Centuries of Close Ties and Focus on Fossil Fuels

Throughout the 19th and 20th centuries, the countries that now make up Central Asia were part of the Russian Empire and the Soviet Union, during which time they developed strong relations with Russia. The highly centralized governance structure of the Soviet Union left a significant imprint on the political relationships within the republics and the rapid development of the energy sector, with strong interconnections in electricity, oil, gas, and coal industries. A key legacy of this period, which will influence the future development of green hydrogen value chains, is the harmonized (within the five countries) system of technical regulations, based on Soviet-era standards. The decision-making processes in energy strategy remain highly centralized in these countries, traditionally shaped by the decisions of top officials, with significantly less influence from local authorities or municipalities, which contrasts with European norms. Notably, Russian remains a widely spoken language in the region, and in countries like Kazakhstan, it holds the status of an official language in governmental and local administration documentation.

Energy ties with Russia remain robust, with various formats of collaboration between governments and companies, and Russian investors are active across all five countries. Russia shares the second-longest land border in the world with Kazakhstan and leverages its proximity and cheap energy resources to exert influence in the region, while increasing the transit of its energy resources to China, especially amid social tensions and infrastructure challenges in the region (Mitrova 2024). However, while these geopolitical factors predominantly concern fossil fuels (including uranium and the potential deployment of Russian-designed nuclear power plants), they have minimal impact on renewable energy sources, which remain largely outside the scope of Russia's energy strategy. Russia’s hydrogen strategy is focused on developing its own hydrogen technologies, setting a modest target of producing 0.55 Mtpa of hydrogen by 2030, with an emphasis on the domestic market rather than exports (Bashmakov et al, 2023). Consequently, collaboration on hydrogen is unlikely to be a significant part of the cooperation agenda between Central Asian countries and Russia, at least in the medium term.

1990s-2002: Emergence of Nationhood and the Rise of New Global Players

Following the collapse of the Soviet Union, many Central Asian countries focused more on establishing and consolidating their statehood than on developing political ties with neighbouring states. This was reflected in the energy sector (disagreements over the shared use of hydro resources and water, suspension of the unified energy system of Central Asia, etc.), and in the trade relations among the five countries, whose economies were not as complementary as those of other regions. In contrast, bilateral relations with countries outside Central Asia rapidly developed, directly impacting the energy sector. The United States became a key investor in Kazakhstan's oil and gas sector as early as the 1990s, while China emerged as an active player in Turkmenistan's gas sector in the 2000s. The European Union (including companies like Shell, TotalEnergies, and Eni) has been involved in Kazakhstan's oil and gas sector since the mid-1990s. During this period, cooperation was focused on fossil fuels, with little involvement of hydrogen. Nevertheless, the United States, the European Union, and China remain pivotal geopolitical partners for Central Asian countries, expanding their presence through investments in electricity, including renewable energy projects.

A New Era: Renewed Leadership and Repositioning Central Asia in Global Sustainable Development and Changing Geopolitical Landscape

The period beginning in the mid-2010s and continuing today has introduced several new geopolitical trends that will have direct implications for the energy sector and the future development of green hydrogen value chains.

Firstly, between 2016 and 2022, new political leaders emerged in all the region's countries except Tajikistan, with leaders less tied to the Soviet past and more open to the outside world, ready for political and economic reforms. They have focused on strengthening regional ties, developing new international relationships, and increasing attention to social issues. During this period, the relatively new C5 format was developed to expand regional cooperation among Central Asian countries and strengthen ties with the United States, with a focus on economics, the environment, and security.

Secondly, by the mid-2010s, there was a growing global consensus on the challenges posed by climate change and the need to transition to sustainable development. This was reflected in the adoption of the Paris Agreement and the UN Sustainable Development Goals. All Central Asian countries joined the Paris Agreement by January 2020 (most of them before the end of 2017). Led by the new elites, Kazakhstan, Kyrgyzstan, and Uzbekistan publicly committed to carbon neutrality and the transition to a green economy, with Kazakhstan being the only country in the region to adopt a long-term low-carbon development strategy and a short-term hydrogen roadmap.

Thirdly, the war in Ukraine, which began in early 2022, and the resulting destruction of long-standing energy and broader economic ties between Russia and the European Union, have prompted a global reassessment of Central Asia's role on the continent. This has acted as a catalyst for the long-term shift and diversification of energy, trade, migration, and logistical flow, leading to both the emergence of new geopolitical contacts and the strengthening of existing ones, including those related to energy.

Between 2022 and 2024, there was, for example, an unprecedented intensification of high-level contacts between Central Asian countries and the member states of the Gulf Cooperation Council (GCC), especially with Saudi Arabia and the United Arab Emirates. Historically significant cultural and religious ties have been complemented by specific new energy-related joint projects, including the first green hydrogen project in Central Asia, in Chirchik (Uzbekistan), being developed by Saudi company ACWA Power (Ward 2024). The European Union has increased its attention to Central Asia, prioritizing cooperation on topics such as the “Middle Corridor” (TITR), critical minerals, green energy, and hydrogen (Mikovic 2024). The EU aims to maintain its role as the largest trade and investment partner for countries like Kazakhstan, the largest economy in the region. Kazakhstan is the only country in the region where Germany opened a Hydrogen Diplomacy Office.

With support from Germany, a wide range of activities is being carried out to strengthen cooperation with Kazakhstan and the broader Central Asian region in the field of green hydrogen. This includes publication of studies, policy advisory and capacity-building efforts. The German-Kazakh Energy Dialogue, supported by dena and AHK, serves as an important platform for this cooperation, addressing topics from climate policy to the development of hydrogen value chains (dena 2025). In addition, the Hydrogen Diplomacy Office in Astana supports hydrogen cooperation across the whole of Central Asia, including advisory services, stakeholder engagement, and educational initiatives. Notably, the Hydrogen Diplomacy Office is working with regional universities to build teaching capacity on hydrogen, including the training of professors and lecturers and the development of educational content to integrate hydrogen into curricula. The Kazakh-German University (DKU) and its KINI institute in Aktau are also contributing to education and training efforts in this field.

At the same time, despite these efforts, the rapid deepening of cooperation between Central Asia and the European Union may be hindered by political and cultural differences, as well as Russian influence (Meister 2024[2])

Meanwhile, China is diversifying its areas of cooperation, traditionally focused on natural gas and pipelines, toward solar and wind energy. Its large-scale "Green Silk Road" initiative (Belt and Road) could promote the development of clean technologies and infrastructure in Central Asia. Critical minerals are also a significant area of collaboration, and China’s global leadership as the manufacturing hub for green technologies (photovoltaics, wind energy, energy storage, electrolysers) makes it a key partner for Central Asian countries in the future development of green supply chains (Umarov 2024).

The United States has increased its support for renewable energy projects in the region through various initiatives led by USAID. A direct focus on hydrogen was seen in the creation of the Green Hydrogen Centre, led by TetraTech and funded by USAID. The project assessed the potential of renewable energy, water availability, methods for producing clean hydrogen, and export possibilities. As a result of the study, Navoi was recommended as a pilot site for the Green Hydrogen Centre due to its proximity to key consumers (fertilizer producers, refineries). Moving forward, the project was supposed to be focused on research and regulatory development, as well as education – with the University of Delaware and Tashkent State Technical University developing a master’s program in green hydrogen. However, the future of USAID's initiatives in Central Asia became uncertain following the launch of a review of the agency's funding priorities at the end of January 2025, initiated by the new US presidential administration.

[2] Meister, 2024. Upgrading -EU-Central Asia Cooperation: How to Leverage Common -Interests Amid Geopolitical Turmoil. https://dgap.org/en/research/publications/upgrading-eu-central-asia-cooperation

4.2 Key Stakeholders and their Roles in Discussions and Negotiations

Based on the above analysis, the following key stakeholders can be identified in the geopolitical context, who will play a critical role in the development of green hydrogen value chains in Central Asia:

Intergovernmental and Interministerial Bodies

- *Eurasian Economic Union (EEU)*: Including Kazakhstan, Kyrgyzstan, Belarus, Russia, and Armenia, with Uzbekistan holding observer status. Russia is considered the most influential member. Within the EEU, there are permanent formats for interaction among the heads of states, governments, and ministries. Energy occupies an important place in the EEU's agenda, being one of the key sectors for the economic development and integration of member states. Among the topics discussed are the formation of common energy markets (oil, gas, oil products, electricity), energy efficiency improvements, and the development of green energy sources. In July 2024, EEU representatives discussed the role of hydrogen mobility (EEC 2024).
- *Shanghai Cooperation Organization (SCO)*: Another influential regional organization, founded in 2001 by China, Russia, and all Central Asian countries except Turkmenistan, which includes energy cooperation in its agenda. In recent years, China's Belt and Road Initiative has strengthened within the SCO, although hydrogen is not yet a central topic of discussion.
- *C5:* A relatively new format of cooperation among Central Asian countries, first established in the context of a summit with the United States, but gradually expanding to joint summits with other international bodies. The GCC-C5 summit in July 2023 was an important step in enhancing cooperation, with a focus on energy security and investment, including in green energy.
- *United Nations Economic Commission for Europe (UNECE):* The UNECE, with its office in Geneva and consisting of 56 member states, including all Central Asian countries, supports regional cooperation through the release of analytical reports and the organization of dialogues, including those related to clean energy and hydrogen.
- An example of high-level multilateral cooperation formats is the strategic agreement on the interconnection of the energy systems of Kazakhstan, Azerbaijan, and Uzbekistan, which was signed by the Presidents of these countries in November 2024. This agreement laid the foundation for subsequent agreements and collaborative work at the ministerial level, including in areas related to green energy and hydrogen (President of the Republic of Kazakhstan 2024).

The Ministries and Government Funds

The role of sector-specific ministries in the development and implementation of energy strategies in Central Asia is pivotal, reflecting the management traditions in these countries.

Key ministries involved in this process include:

- Ministry of Energy of the Republic of Kazakhstan
- Ministry of Energy of the Republic of Uzbekistan

- Ministry of Energy of Turkmenistan, Ministry of Oil and Gas of Turkmenistan, Turkmengas State Concern
- Ministry of Energy and Water Resources of the Republic of Tajikistan
- Ministry of Energy of the Kyrgyz Republic.

Additionally, ministries responsible for economic development, ecology, investment, education, and foreign affairs may also play a role in energy strategy implementation.

Government agencies or quasi-governmental funds, such as Samruk-Kazyna and the Development Bank of Kazakhstan (Kazakhstan), the Green Energy Fund and the State Fund for Economic Development (Kyrgyzstan), the State Committee for Investments and Management of State Property of the Republic of Tajikistan, the Entrepreneurship Support Fund under the Government of Tajikistan, the State Fund for the Development of Turkmenistan, the Turkmenistan Entrepreneurship Development Fund, and the Reconstruction and Development Fund of Uzbekistan, also hold significant influence. These funds can facilitate subsidies and investments in the development of value chains and promote regional cooperation.

Corporations, Development Banks, and International Agencies

Influential corporations in Central Asia traditionally have a considerable impact on the development and implementation of energy strategies, sometimes even influencing geopolitical dynamics.

Key stakeholders include:

- *In Kazakhstan*: KazMunayGas, QazaqGaz, KEGOC, EuroChem-Fertilizers, Karachaganak Petroleum Operating, Tengizchevroil
- *In Uzbekistan*: Uzbekneftegaz, UzTransGaz, Uzkimyosanoat, Shurtan Gas Chemical Complex
- *In Turkmenistan*: Türkmengaz, Türkmennebit, Türkmenenergo, Maryazot, Garabogazkarbamid
- *In Kyrgyzstan*: Kyrgyzneftegaz, Electric Stations OJSC
- *In Tajikistan*: Barki Tojik, Tajiktransgaz

International agencies play a key role as well, including GIZ (Germany), USAID (USA), UNIDO, UNDP, and IRENA. Development banks, such as the Asian Development Bank and the Eurasian Development Bank, are also key players in the energy landscape.

05. Human Capacities and Education System

The development of hydrogen value chains requires the establishment of a strong workforce and the adaptation of education systems. Existing educational programs in Central Asia related to chemical engineering, oil and gas, and electrical energy can facilitate this process. This section presents an overview of the most significant and relevant existing educational programs, as well as identifies key gaps and opportunities for their further development.

5.1 Existing Education Systems

Kazakhstan

Kazakhstan leads the region in the number of universities offering programs potentially directly or indirectly related to hydrogen value chains.

Key examples include:

- Satbayev University: As the leading technical university in Kazakhstan, it offers programs in the following areas:
    - 18.03.01 / 18.04.01 "Chemical Technology" (electrochemistry, petrochemistry, processes and apparatus of chemical technologies);
    - 13.03.02 / 13.04.02 "Electrical Engineering" (including renewable energy sources);
    - 15.03.01 / 15.04.01 "Mechanical Engineering" (pipelines, compressors, equipment for high-pressure operations).
- Nazarbayev University conducts research on green hydrogen as part of the Chemical and Materials Engineering program, focusing on interdisciplinary studies in materials science and renewable energy. Specifically, projects are underway to develop new catalysts for water electrolysis. The Renewable Energy Laboratory also studies materials for hydrogen storage, such as metal hydrides, carbon composites, and metal-organic frameworks (MOFs), aimed at improving the efficiency of hydrogen storage and transport.
- Al-Farabi Kazakh National University (KazNU) offers programs in:
    - Chemical Technology (18.03.01 / 18.04.01) – covering processes and apparatus of chemical technologies, including electrochemistry and petrochemistry, which are related to hydrogen production and use.
    - Chemistry (04.03.01 / 04.04.01) – includes courses on electrochemistry, which are beneficial for studying electrolysis and fuel cell technologies.

- Physics (03.03.02 / 03.04.02) – in this program, students can study the fundamentals of materials and technologies applied in hydrogen value chains. The university also conducts research in biohydrogen production using solar energy.

- Atyrau University of Oil and Gas (AUNiG) offers programs such as 21.03.01 "Oil and Gas Engineering" and 18.03.01 "Chemical Technology," which focus on hydrocarbon processing and transportation systems. The knowledge gained by students is relevant to the development of hydrogen value chains.
- Kazakh-German University in Almaty offers a unique two-year program, "Strategic Management of Renewable Energy and Energy Efficiency," developed with the support of the German Ministry of Foreign Affairs, USAID, and OSCE. In 2023, the Kazakh-German University, in partnership with the Caspian University of Technology and Engineering, launched the Kazakh-German Institute of Sustainable Engineering. The new institute aims to enroll 30 students annually in two educational programs – "Energy and Environmental Engineering" and "Transport Logistics." The programs consist of 9 semesters, with students spending 2 semesters at KNU and 3 semesters at technical universities in Germany. Eight bachelor's and six master's programs are planned for launch in the 2023-2024 academic years.

Uzbekistan

Uzbekistan is taking initial steps in developing educational programs related to hydrogen technologies. Focus is placed on the oil and gas sector and chemical engineering.

- Tashkent Chemical-Technological Institute (THTI): A leading university in chemical technology, offering courses in gas processing and the design of chemical industry equipment, with programs in chemical technology (covering electrolysis and catalysis) and process automation. In 2024, the institute hosted a "Sustainable Development and Green Economy" week, which, while not directly addressing hydrogen, demonstrated the institute's potential to develop related programs.
- Tashkent State Technical University (TSTU) offers programs in electrical engineering and oil and gas, which include studying gas transportation. Key programs: 13.03.02 "Electrical Engineering" and 21.03.01 "Oil and Gas Engineering" (pipeline management). In 2023-24, a master's program in green hydrogen was introduced at TSTU in collaboration with the University of Delaware (USA), supported by USAID and Tetratech. The first department for renewable energy sources was established at TSTU in 2016. New programs focusing on hydrogen technologies may emerge through TSTU's partnership with the St. Petersburg Polytechnic University (Russia).
- National University of Uzbekistan (NUUz) offers programs in chemistry and physics, including the study of new materials for hydrogen production and storage.
- Other notable institutions offering programs for energy specialists include Andijan Machine-building Institute, Bukhara Institute of Engineering and Technology, Fergana Polytechnic Institute, and Karshi State University.
- The Tashkent branch of the Moscow Institute of Physics and Technology, established in 2019 as part of Uzbekistan-Russia cooperation, offers bachelor's programs in thermal and electrical power engineering, with a focus on nuclear energy. A similar program is offered by the branch of the Moscow Power Engineering Institute in Tashkent, although the licensing status is unclear.

Students at the Turin Polytechnic University in Tashkent (a branch of the renowned Politecnico di Torino) are involved in research on solar energy and electromobility.

- For master's and bachelor's students interested in renewable energy, particularly solar energy, with a focus on scientific research, opportunities are available at the Physical-Technical Institute and the Institute of Materials Science at the Academy of Sciences of Uzbekistan.
- The Central Asian University for Environmental Studies and Climate Change (Green University), established in 2023, offers undergraduate and graduate programs in sustainable development.

Kyrgyzstan

The education system in Kyrgyzstan is less developed in terms of green hydrogen education compared to Kazakhstan and Uzbekistan. However, several universities offer general engineering programs that are important for secondary components of the value chain.

Key institutions include:

- Kyrgyz State Technical University (KSTU) named after Razakov offers programs in electrical engineering and mechanical engineering. Research in catalysis and gas storage processes is conducted in the university's laboratories.
- Kyrgyz-Russian Slavic University (KRSU) offers programs in chemical technology and process automation, which could be adapted for green hydrogen.

Tajikistan

Local universities provide basic knowledge in chemistry and physics, such as:

- Tajik Technical University named after M. Osimi (TTU) offers programs in chemical technology and process automation.
- Tajik National University (TNU) offers programs in chemistry and physics.

Turkmenistan

Turkmenistan places a strong emphasis on hydrocarbon technologies, but hydrogen-related topics could be integrated into educational programs.

Key institutions include:

- International University of Oil and Gas: Courses on gas processing and the design of hydrocarbon transportation and storage systems (programs 21.03.01 "Oil and Gas Engineering" and 18.03.01 "Chemical Technology").
- Turkmen State Energy Institute: Programs in electrical engineering, electrical technology, and automation of energy processes.

Regional and International Initiatives

Support from international organizations and initiatives plays a critical role in the development of hydrogen technologies in Central Asia. Such projects contribute to research funding, infrastructure development, and workforce training. The development of these initiatives also helps universities in the region become more internationally competitive and accelerate the transition to green energy.

Besides the aforementioned USAID project in Uzbekistan, notable initiatives include GIZ (Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH), which cooperates with universities in Central Asia to create and complement educational courses, and foster inter-country dialogue in the field of green hydrogen for education.

The EU implements the Erasmus+ program in Central Asia, promoting university cooperation and organizing internships.

5.2 Gaps and Opportunities for Development

The brief overview indicates that while the education systems of Central Asian countries possess significant potential for developing programs related to hydrogen technologies, the current infrastructure and curriculum are still limited.

In general, most universities lack dedicated hydrogen technology courses and master's programs. Due to funding shortages, universities lack modern specialized laboratory equipment such as electrolysers, fuel cells, and hydrogen storage systems. Many faculty members have limited experience in working with hydrogen technologies or contemporary knowledge in this field. Additionally, weak integration between universities and industry hampers the practical focus of educational programs.

Kazakhstan stands out among the other countries due to its greater number of universities with relevant educational tracks and strong support from international organizations. Uzbekistan is taking important initial steps to adapt its programs for new technologies, while Kyrgyzstan and Tajikistan face challenges with both laboratory infrastructure and specialized courses. Key gaps include insufficient integration of hydrogen technologies into existing educational programs, weak interaction between universities and industry, and limited investment in research and technical infrastructure.

Nevertheless, the region presents opportunities to implement interdisciplinary programs, create specialized centres, and strengthen partnerships with international organizations.

Development opportunities include:

- Expanding the participation of Central Asian universities in international programs like Erasmus+ and others.
- Supporting academic exchanges between European and Central Asian universities.
- Establishing regional educational and research centres, for example, based at leading universities in Kazakhstan and Uzbekistan, funded by international organizations (as seen in the USAID project in Uzbekistan).
- Stimulating knowledge exchange through annual regional conferences and forums on hydrogen, featuring international experts.
- Developing grant support for students and faculty for international study and internships at global and regional companies.

- Strengthening industry cooperation by involving international companies in developing educational programs and providing internships for students.
- Developing online courses and distance learning programs on hydrogen technologies.

06. Regional Cooperation and Practices Comparison

Central Asia is one of the regions that encompasses countries with similar historical, cultural, industrial, and energy characteristics. Analysing best practices from other regions will allow for the identification of the most suitable approaches to be adapted and implemented in Central Asia.

6.1 Latin America

The Organization of Latin American and Caribbean States for Energy (OLADE) was established in 1973. Through its cooperation, the countries in this region are developing several initiatives aimed at improving energy infrastructure and fostering sustainable development:

- *SIEM (Sistema de Interconexión Eléctrica de los Países de América Central)*: The Electrical Interconnection System of Central American Countries plays a significant role in supporting regional electricity trade and the integration of renewable energy sources. Its advantages include enhancing supply reliability, reducing electricity costs, and promoting the development of renewable energy sources (RES).
- *Mercado Eléctrico Regional (MER)*: A regional electricity market that unites Central American countries and Mexico, which promotes market expansion, increases competition, and attracts investments in renewable energy sources.
- *CELAC Initiatives (Community of Latin American and Caribbean States):* Actively promote regional cooperation in sustainable energy. This includes the development of RES, energy efficiency, and actions to combat climate change. It also involves the creation of shared strategies, knowledge exchange, technological solutions, and participation in joint projects.
- *CERTHILAC:* The hydrogen certification system for Latin America and the Caribbean.
- The region is also known for its active collaboration with the European Union, the United States, and China, which contributes to investments in green energy projects.

Examples of specific projects include:

- The Itaipu power line connecting Brazil and Paraguay, which facilitates electricity transmission from the world's largest hydroelectric plant, Itaipu.
- The Orejana Wind Park in Uruguay, one of the largest wind farms in Latin America, built with European investment.

- The Aura Solar I photovoltaic plant in Mexico, a large solar power plant financed by Chinese companies.

Among the key regional conferences in the field of renewable energy are the Latin American Hydrogen Congress, Hydrogen Americas Summit, and Renewable Energy Latin America & Caribbean.

Latin America holds immense potential for the development of green energy. Regional and international partnerships play a key role in realizing this potential, contributing to investments, knowledge and technology exchange, and accelerating the transition to sustainable energy.

6.2 Gulf Countries

Gulf countries, endowed with vast reserves of hydrocarbons, have increasingly focused on green energy in recent years. This shift is driven by several factors: the desire to diversify their economies, reduce dependence on oil, improve environmental conditions, and position themselves as leaders in sustainable development.

Examples of relevant partnerships include:

- *The Gulf Cooperation Council (GCC):* This organization fosters coordination among member states, including in the energy sector, with a focus on the development of RES. Among its initiatives are the development of common strategies for RES, exchange of information and technology, and joint projects.
- *Joint RES Projects:* GCC countries are implementing joint projects in solar and wind energy, as well as exploring hydrogen potential. Companies from one GCC country may collaborate on projects in other countries, leading to the creation of Special Purpose Vehicles (SPVs), mixed financing models, and so on. Notable projects include the construction of large solar power plants in Saudi Arabia and the UAE, as well as the development of wind energy in Kuwait.
- *Cooperation with developed countries*: The Gulf countries are actively collaborating with the United States, the European Union, Japan, and South Korea in the development of green energy. This cooperation involves attracting investments and technologies for RES development, as well as joint research and development efforts.
- *Partnerships with international organizations*: GCC countries collaborate closely with IRENA (International Renewable Energy Agency), whose headquarters is located in Abu Dhabi, UAE. It is noteworthy that this office is situated in Masdar City, an environmentally sustainable city powered entirely by renewable energy.

Among the largest industry conferences in the region are the World Hydrogen MENA, Middle East Energy, GCC Hydrogen Summit, and ADIPEC.

6.3 Southeast Asia

Southeast Asia also demonstrates interesting examples of partnerships in the field of green energy, driven by growing energy demand, the pursuit of energy security, and the need to combat climate change.

Some examples include:

- *ASEAN (Association of Southeast Asian Nations)*: ASEAN is actively promoting regional cooperation in energy, focusing on the development of RES, energy efficiency, and sustainable development. The ASEAN Plan of Action for Energy Cooperation (APAEC) sets ambitious targets for the share of RES in total primary energy resources.
- *Cross-border electricity trade*: There is an increasing trend in cross-border electricity trade within ASEAN countries, such as between Laos and Thailand, and Malaysia and Singapore. This trade optimises the use of energy resources, enhances supply reliability, and supports RES development.
- *Joint projects*: ASEAN countries are implementing joint projects in solar, wind, and hydro energy, such as hydroelectric projects in the Mekong River Basin and solar power plants in Vietnam and Thailand.
- *International cooperation*: ASEAN countries are actively engaged in joint projects with Japan (geothermal energy in Indonesia, solar power plants in Vietnam), Australia (technology exchange programs, joint RES research), the Asian Development Bank, and the World Bank.

Among the key projects in the region is the Mekong River Basin energy infrastructure development program, which includes the construction of hydroelectric plants and transmission lines. Notable projects also include the Cordillera Hydroelectric Power Plant (Philippines) with Japanese investment and Vietnam's RES development strategy, supported by international partners.

Key conferences in Southeast Asia include the Asia Hydrogen Summit, ASEAN Energy Business Forum, and Hydrogen Technology Conference & Exhibition (Malaysia).

07. Conclusion

The analysis highlights that regional cooperation will play a critical role in advancing green hydrogen deployment and green value chains in Central Asia. This is due to decades of collaboration between countries in the energy sector, strong political, economic, and ethnocultural ties. To unlock this potential, countries are encouraged to establish a regular intergovernmental platform for discussions on sustainable energy and hydrogen. Such a platform would help elevate the topic to the highest political level, define joint objectives, address barriers, and mobilize financial support from multilateral development banks and international organizations.

Accelerating the development of national long-term strategies, including energy and hydrogen strategies, will help to define priorities, scale, objectives, and immediate actions. Joint research could also focus on the certification of hydrogen and its derivatives, which will be essential for future regional and international trade. Considering the current economic structure of Central Asian countries, green hydrogen integration should prioritize sectors such as refining, steelmaking, and ammonia and fertilizer production, which are closely linked to agriculture, an important economic pillar in the region.

Export-oriented projects are likely to face significant infrastructure bottlenecks, such as insufficient renewable electricity generation capacity, underdeveloped grids, gaps in pipeline networks, and water management challenges. Addressing these bottlenecks proactively should become a priority task for the proposed intergovernmental platform, as these infrastructure challenges are not only critical for hydrogen development but also for the overall sustainable development of the region.

Rapid deployment of renewable energy will require the creation of an enabling regulatory environment, the setting of ambitious deployment targets, cost reduction through economies of scale, and the development of skilled human capital. In the evolving geopolitical landscape, Central Asian countries could also enhance cooperation with international partners that are already investing in the region's renewable energy sector and offering technologies, expertise, and educational initiatives - such as the European Union, Gulf Cooperation Council countries, China, and the United States.

In particular, strengthening the education sector through expanded international partnerships, academic exchanges, and industry collaborations, alongside the creation of regional training centres and targeted grant programs, could help close existing gaps such as weak industry-academia linkages, low research funding, and the insufficient integration of renewables and hydrogen topics into educational curricula.

Ultimately, enhanced regional cooperation can enable the countries of Central Asia to make better use of limited resources, while achieving common goals more effectively. To that end, Central Asia could also benefit from studying the experiences of regional cooperation platforms in Latin America and the Caribbean, the Gulf Cooperation Council, and ASEAN.

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