THE GLOBAL EXPORT BLUEPRINT: WILL UZBEKISTAN SUPPLY EUROPE WITH GREEN HYDROGEN?

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Abstract. This article provides a comprehensive scientific assessment of Uzbekistan's potential to emerge as a strategic exporter of green hydrogen to the European Union within the framework of the global energy transition and decarbonization agenda. The study examines the European Union's commitment to achieving climate neutrality by 2050 and the growing role of Central Asian countries as prospective suppliers of renewable-based energy carriers. Uzbekistan possesses substantial renewable energy potential, particularly solar irradiation exceeding 300 kWh/m² annually, which is nearly twice the average level observed across many European countries.

The research applies an integrated methodological approach combining comparative analysis, institutional evaluation, and techno-economic assessment. Particular attention is devoted to hydrogen production capacity, electrolysis technologies, renewable electricity generation, export infrastructure, investment mechanisms, and public-private partnership models. The study also evaluates potential export corridors to Europe, including pipeline modernization and hydrogen transportation logistics.

A comparative benchmarking analysis of the hydrogen development strategies adopted by Germany, Saudi Arabia, Australia, the United Arab Emirates, and Kazakhstan is conducted to identify Uzbekistan's competitive advantages and structural limitations in the emerging hydrogen economy. The findings demonstrate that Uzbekistan has significant opportunities to become an important participant in the global green hydrogen market; however, achieving this objective requires substantial regulatory reforms, infrastructure modernization, technological innovation, international cooperation, and long-term investment support.

The article concludes with evidence-based strategic recommendations aimed at strengthening Uzbekistan's competitiveness in the international green hydrogen value chain and enhancing its integration into future European clean energy markets.

Keywords: green hydrogen, renewable energy, European Union, export strategy, solar energy, electrolysis, Central Asia, energy transition, Uzbekistan, decarbonization, hydrogen economy.

INTRODUCTION

The global energy system is currently undergoing a historic structural transformation driven by the urgent necessity to mitigate climate change and reduce greenhouse gas emissions. The objective of limiting global warming to 1.5°C above pre-industrial levels - established under the 2015 Paris Agreement and reaffirmed during subsequent United Nations Climate Change Conferences (COP summits) - requires a profound transition away from fossil fuel dependency across all sectors of the global economy [1]. Within this context, green hydrogen, produced through water electrolysis powered entirely by renewable electricity sources, has emerged as a strategically important energy carrier capable of decarbonising hard-to-abate industries, supporting long-duration energy storage, and facilitating international renewable energy trade [2]. According to projections by the International Energy Agency (IEA), clean hydrogen could account for nearly 10% of global final energy consumption and contribute up to 17% of cumulative CO_2 emission reductions under the global net-zero scenario by 2050 [3].

Simultaneously, the European Union has intensified its commitment to green hydrogen as a central pillar of its long-term energy transition strategy. This shift has been accelerated not only by climate objectives but also by energy security concerns arising from the geopolitical disruptions of Russian natural gas supplies in 2022. In response, the European Commission adopted the REPowerEU Plan in May 2022, which established a target of importing ten million tonnes of renewable hydrogen annually by 2030 in addition to achieving an equivalent level of domestic production [4]. These developments have

created substantial opportunities for renewable energy-rich regions capable of supplying low-carbon hydrogen to European markets.

Within this evolving geopolitical and economic environment, Uzbekistan occupies a strategically significant position. The country benefits from exceptionally high solar irradiation levels, substantial wind energy potential, geographic proximity to major Eurasian transport corridors, and access to existing regional gas pipeline infrastructure. Furthermore, Uzbekistan has implemented broad economic reforms since 2017 aimed at improving the investment climate, liberalising energy markets, and attracting foreign direct investment into renewable energy projects [5]. The adoption of a national hydrogen development roadmap in 2022, the expansion of cooperation with international financial institutions such as the European Bank for Reconstruction and Development (EBRD), and the integration of hydrogen priorities into the country's updated Nationally Determined Contributions (NDCs) under the Paris Agreement collectively demonstrate a growing institutional commitment to developing a domestic green hydrogen economy [6].

Despite these advantages, significant structural and economic challenges remain. Uzbekistan is a doubly landlocked country with limited direct access to international maritime trade routes. Water scarcity - exacerbated by climate change and intensive agricultural consumption - presents an additional constraint for large-scale electrolysis projects. Moreover, the domestic hydrogen sector remains at an early stage of development, while the financial requirements for renewable electricity generation, electrolyser deployment, storage facilities, and export infrastructure amount to several tens of billions of dollars. Consequently, the transition from theoretical export potential to commercially viable hydrogen supply chains will require substantial institutional coordination, technological modernization, and international cooperation.

Against this background, the present study aims to provide a comprehensive and evidence-based assessment of whether - and under what conditions - Uzbekistan could become a competitive exporter of green hydrogen to the European Union within the emerging global hydrogen economy.

The remainder of the article is structured as follows. Section 2 reviews the existing academic and policy literature concerning green hydrogen economics, renewable energy transitions, and the export potential of Central Asian countries. Section 3 outlines the research methodology and analytical framework employed in the study. Section 4 presents the principal findings across five thematic dimensions: renewable energy resource assessment, hydrogen production economics, export logistics and infrastructure, investment and financing mechanisms, and comparative international benchmarking. Finally, Section 5 concludes with strategic policy recommendations and future development perspectives for Uzbekistan's participation in the global green hydrogen market.

LITERATURE REVIEW

2.1 Green Hydrogen in the Global Energy Transition

Scholarly interest in green hydrogen has expanded significantly over the past decade, driven by rapid technological progress in electrolysis systems and increasing international commitment to decarbonization. Staffell et al. [7] provided one of the earliest comprehensive analyses of the global hydrogen economy, identifying declining renewable energy costs as the principal factor enhancing the competitiveness of green hydrogen production. Their modelling indicated that reductions in solar photovoltaic (PV) costs could enable green hydrogen production below USD 2/kg in regions with high solar irradiation by the early 2030s. This projection was later reinforced by the International Renewable Energy Agency (IRENA) in its *Global Hydrogen Trade Potential* report [8], which estimated that delivered green hydrogen costs from optimal production regions could decline to approximately USD 1.5–2.5/kg by 2030.

The International Energy Agency's (IEA) *Global Hydrogen Review* [3] established a widely recognised framework for categorising hydrogen production pathways and evaluating their economic viability. The report noted that green hydrogen currently represents less than 1% of global hydrogen output; however, its projected cost trajectory is expected to converge with grey hydrogen production costs within the current decade in regions possessing superior renewable energy resources. In this regard, the role of electrolyser technologies — particularly alkaline electrolysers and proton exchange membrane

(PEM) systems — has attracted substantial academic attention. Buttler and Spliethoff [9] demonstrated that electrolyser capital costs must decline from nearly USD 1,000/kW to below USD 300/kW in order for large-scale green hydrogen production to achieve market competitiveness without extensive subsidy mechanisms.

The Hydrogen Council [10] has also made a substantial contribution to the global policy discourse by forecasting that worldwide hydrogen demand could reach approximately 660 million tonnes annually by 2050. According to their analysis, the primary sources of demand will originate from industrial decarbonisation, heavy transportation, and electricity generation sectors. Furthermore, the report highlights the structural imbalance between regions with abundant renewable energy resources and regions with concentrated hydrogen demand. This asymmetry creates significant export opportunities for countries with high renewable energy potential, including Uzbekistan.

2.2 European Hydrogen Policy and Import Demand

The European Union has emerged as one of the global leaders in hydrogen policy development. The EU Hydrogen Strategy, introduced in July 2020 and significantly expanded through the REPowerEU framework in 2022 [4], constitutes one of the most comprehensive governmental hydrogen policy frameworks currently in operation. Schüth et al. [11] critically evaluated the technical and economic feasibility of the EU's hydrogen import objectives, concluding that achieving the target of importing 10 million tonnes of renewable hydrogen annually by 2030 would require unprecedented coordination among production, transportation, storage, and consumption sectors.

An important contribution to the European hydrogen infrastructure debate has been made by the European Hydrogen Backbone initiative [12], a consortium of 31 European gas infrastructure operators. The initiative proposed the conversion and expansion of approximately 53,000 kilometres of gas pipeline infrastructure by 2040 to establish a continent-wide hydrogen transportation network. Such infrastructure development would significantly strengthen Europe's capacity to absorb imported hydrogen from external supplier countries.

Olczak and Piebalgs [13] further analysed the geopolitical implications of European hydrogen imports, arguing that diversification of supply sources represents a strategic priority equal to import volume itself. Their research identified North Africa, the Middle East, Australia, and Central Asia as the most promising regions for future commercially viable hydrogen exports to Europe. Consequently, hydrogen diplomacy has become an increasingly important component of the European Union's external energy policy, leading to the establishment of strategic cooperation agreements with countries such as Chile, Namibia, Egypt, and Kazakhstan.

2.3 Central Asian Renewable Energy and Hydrogen Potential

Academic research concerning Central Asia's renewable energy and hydrogen export potential has accelerated considerably since 2021. Overland et al. [14] conducted one of the earliest systematic assessments of the region's hydrogen prospects, concluding that Kazakhstan and Uzbekistan collectively possess renewable electricity generation potential substantially exceeding regional domestic demand. In particular, the Aral Sea basin was identified as an area with exceptional wind energy potential extending across the territories of both countries. However, the authors emphasized that inadequate export infrastructure and the absence of supportive regulatory frameworks remain the primary obstacles to realizing this potential.

Zhakupova et al. [15] examined Kazakhstan's emerging hydrogen strategy from a comparative perspective and concluded that Kazakhstan currently possesses relatively stronger institutional readiness and more established international energy export relations than Uzbekistan. Nevertheless, the study also highlighted Uzbekistan's accelerating economic reform agenda and increasingly diversified international partnerships as important comparative advantages that may enhance its long-term competitiveness in the hydrogen sector.

The World Bank's assessment of renewable energy export corridors in Central Asia [16] identified two strategically important infrastructure options for future exports to Europe: the Trans-Caspian electricity interconnection system and the modernization or repurposing of existing natural gas pipeline networks. These export corridors were considered among the most economically feasible long-term solutions for integrating Central Asian renewable energy resources into European energy markets.

Buriev [17] specifically analysed Uzbekistan's energy sector reforms in relation to the development of a domestic hydrogen economy. His study noted that the government's New Development Strategy for 2022–2026 explicitly recognised green hydrogen development as a national strategic priority. At the same time, the analysis identified several institutional and structural constraints limiting investment mobilisation, including fragmented regulatory governance, underdeveloped domestic financial markets, limited technological capacity, and the persistence of energy subsidy mechanisms within the national energy system.

METHODOLOGY

This study employs an integrated methodological approach combining quantitative, techno-economic, institutional, and comparative analyses to evaluate Uzbekistan's potential as a green hydrogen exporter to Europe.

First, a quantitative resource assessment was conducted using solar and wind energy data from the Global Solar Atlas and Global Wind Atlas. The obtained renewable energy potential was converted into estimated green hydrogen production capacity based on standard electrolyser efficiency indicators [9].

Second, a techno-economic model was applied to estimate the Levelized Cost of Hydrogen (LCOH) under three scenarios: baseline, moderate, and optimistic. The model incorporates capital expenditure (CAPEX), operational costs (OPEX), renewable energy capacity factors, financing costs, and projected technology cost reductions through 2035, following the IRENA methodological framework [8].

Third, a qualitative institutional analysis was carried out to assess Uzbekistan's regulatory environment, investment climate, infrastructure readiness, and geopolitical position in the emerging hydrogen economy. The analysis is based on government strategies, international organisation reports, and energy sector assessments.

Finally, a comparative benchmarking approach was used to compare Uzbekistan with Germany, Saudi Arabia, Australia, the United Arab Emirates, and Kazakhstan across key indicators such as renewable resource potential, institutional capacity, infrastructure development, international cooperation, and production competitiveness.

The study relies on data and reports from the IEA, IRENA, World Bank, EBRD, European Commission, Hydrogen Council, Uzbekistan's Ministry of Energy, and peer-reviewed academic literature published between 2018 and 2024.

DISCUSSION AND RESULTS

4.1 Uzbekistan's Renewable Energy Resource Endowment

Uzbekistan possesses highly favorable natural conditions for the development of green hydrogen production based on renewable energy resources. The country receives an average global horizontal irradiation (GHI) of approximately 1,700-2,200 kWh/m²/year, while some southern regions, particularly Kashkadarya and Surkhandarya, exceed 2,500 kWh/m²/year [18]. These indicators are significantly higher than the average solar irradiation levels observed in most European countries, which generally range between 1,000 and 1,300 kWh/m²/year [19].

This substantial solar resource advantage creates important economic opportunities for green hydrogen production. Higher solar irradiation increases the operational efficiency and electricity generation capacity of photovoltaic systems, thereby reducing the overall cost of renewable electricity supplied to electrolysers. As a result, hydrogen production facilities located in Uzbekistan could potentially generate 60-80% more hydrogen annually compared to equivalent installations operating under average European climatic conditions.

In addition to solar energy, Uzbekistan also possesses promising wind energy potential, especially in the Aral Sea region and northwestern territories. These areas demonstrate favorable wind speeds suitable for utility-scale renewable electricity generation projects. The combination of solar and wind resources provides an opportunity to establish hybrid renewable energy systems capable of improving electrolyser utilization rates and ensuring more stable hydrogen production throughout the year.

Furthermore, Uzbekistan has considerable land availability for large-scale renewable energy projects, relatively low population density in desert regions, and existing energy infrastructure inherited

from the Soviet-era gas network. These factors collectively strengthen the country's long-term competitiveness in the emerging green hydrogen economy.

Table 1 presents a comparative overview of renewable energy indicators relevant to green hydrogen production in Uzbekistan and selected reference countries.

Country	Avg. GHI (kWh/m²/yr)	Wind Potential (GW)	LCOH 2024 ($/kg)	H_2 Export Target (Mt/yr)
Uzbekistan	1,700–2,200	~40 (est.)	2.8–4.5	No formal target
Saudi Arabia	2,200–2,600	~120	1.5–2.5	4.0 by 2030
Australia	1,900–2,400	~4,000	1.8–2.8	No cap
UAE	2,100–2,500	~20	1.6–2.4	N/A
Kazakhstan	1,600–2,100	~920	3.0–4.8	0.3 by 2030
Germany	950–1,200	~380	4.5–7.0	N/A (import)
Morocco	2,000–2,400	~200	2.0–3.0	10 TWh by 2030

Note: LCOH estimates reflect delivered production cost at plant gate under 2024 conditions; export delivery costs are additional. Sources: IRENA [8], IEA [3], Hydrogen Council [10], author calculations.

In addition to solar energy, Uzbekistan possesses considerable wind energy potential, although these resources are geographically concentrated in specific regions. The Aral Sea basin, jointly shared with Kazakhstan, demonstrates average wind speeds exceeding 7 m/s at a 100-meter hub height, making it suitable for large-scale wind power generation projects [20]. According to a 2023 technical assessment by IRENA, Uzbekistan's technically exploitable wind energy potential is estimated at nearly 40 GW [8]. When combined with solar energy resources, this capacity could support the establishment of a large-scale green hydrogen industry.

The seasonal complementarity between solar and wind resources represents an additional strategic advantage. Solar generation reaches peak levels during summer months, whereas wind intensity is generally stronger during autumn and spring periods. This combination can improve electrolyser utilization rates and increase annual operating efficiency, potentially reducing the levelized cost of hydrogen (LCOH) by approximately 15-20% compared to systems relying on a single renewable energy source [9].

Despite these advantages, water availability remains one of the most critical constraints for green hydrogen development in Uzbekistan. Electrolysis requires approximately 9 liters of purified water to produce one kilogram of hydrogen [21]. Uzbekistan already experiences significant water stress due to intensive agricultural irrigation, climate change impacts, glacier retreat, and regional water management challenges [22]. For example, producing one million tonnes of green hydrogen annually would require nearly 9 billion liters of demineralized water each year.

Therefore, sustainable hydrogen development in Uzbekistan will require the implementation of advanced water management solutions, including wastewater recycling technologies, atmospheric water extraction systems, and efficient desalination infrastructure connected through regional transport

networks such as the Caspian Sea corridor. Strategic placement of hydrogen production facilities in areas with strong renewable energy resources and relatively stable water access will also be essential.

4.2 Green Hydrogen Production Cost Trajectory

Under current market conditions, green hydrogen production costs in Uzbekistan are estimated to range between USD 2.8 and USD 4.5 per kilogram, depending on renewable electricity prices, electrolyser efficiency, and financing conditions. This relatively competitive cost structure is primarily supported by rapidly declining solar photovoltaic costs, which have decreased by nearly 90% since 2010 [19]. However, high electrolyser capital costs continue to represent a major economic challenge.

Nevertheless, long-term cost projections remain highly favorable. According to IRENA forecasts, alkaline electrolyser capital expenditure is expected to decline from approximately USD 800-1,000/kW in 2023 to below USD 300/kW by 2030 due to technological innovation, industrial scale expansion, and manufacturing learning effects [8]. Simultaneously, utility-scale solar PV investment costs in high-irradiation regions such as Uzbekistan are projected to fall below USD 300/kWp.

Based on the moderate development scenario applied in this study, the Levelized Cost of Hydrogen (LCOH) in Uzbekistan could decrease to approximately USD 1.5-2.2/kg by 2030. Achieving this level would significantly improve the country's competitiveness within the international green hydrogen market and increase the commercial feasibility of exporting hydrogen to European markets.

Scenario	Solar CAPEX ($/kWp)	Electrolyser CAPEX ($/kW)	WACC (%)	LCOH ($/kg)	Year
Conservative (Baseline)	380	900	8.0	3.8–4.5	2024
Moderate (Blended Finance)	300	450	6.0	2.2–2.8	2028
Optimistic (DFI-backed)	250	280	5.0	1.5–2.0	2032

Note: LCOH calculated for utility-scale solar PV + alkaline electrolyser system in southern Uzbekistan; 25-year project life; assumes no carbon price premium. Sources: IRENA [8], IEA [3], author calculations.

These production cost projections must be evaluated within the broader framework of hydrogen transportation and delivery costs to European markets. Transport infrastructure remains one of the largest economic barriers for Uzbekistan's potential hydrogen exports. Current estimates suggest that liquefied hydrogen transportation through the Caspian–Black Sea–Mediterranean route could add approximately USD 1.5-3.0/kg to production costs, whereas pipeline-based transport systems may reduce this figure to around USD 0.8-1.5/kg if dedicated hydrogen infrastructure is developed in the future [12]. Consequently, even under optimistic assumptions, the delivered cost of Uzbek green hydrogen to European industrial markets is unlikely to fall below USD 3/kg before 2035 [11].

4.3 Export Logistics and Transportation Corridors

Uzbekistan's double landlocked geographical position represents one of the most significant structural challenges for hydrogen exports. Unlike countries such as Saudi Arabia, Australia, or Morocco, Uzbekistan lacks direct maritime access and depends on regional transit corridors to reach international markets.

Several potential export routes have been identified for future hydrogen transportation to Europe [16]. The first option is the Trans-Caspian corridor, which would connect Uzbekistan to Azerbaijan through the Caspian Sea and further integrate with the South Caucasus and Trans-Adriatic Pipeline (TAP) systems. This route partially benefits from existing natural gas infrastructure but requires substantial modernization and legal coordination among participating countries.

The second option is the Middle Corridor, also known as the Trans-Caspian International Transport Route, passing through Kazakhstan, Azerbaijan, Georgia, and Turkey. This corridor has gained increasing strategic importance after the geopolitical disruptions of 2022 and is currently considered one

of the most realistic alternatives for future hydrogen and ammonia transportation without reliance on Russian territory.

A third alternative involves the export of renewable electricity through high-voltage direct current (HVDC) transmission systems, with hydrogen production occurring inside Europe. Although technically feasible, this option would require large-scale infrastructure investments and involve additional energy conversion losses.

4.4 Investment Architecture and Financial Mechanisms

The development of a commercially viable green hydrogen export industry in Uzbekistan requires extremely high levels of capital investment. According to existing estimates, producing approximately 500,000 tonnes of green hydrogen annually for export could require total investments ranging between USD 28 billion and USD 42 billion, including renewable energy facilities, electrolyser systems, storage infrastructure, and transportation networks [17].

Given these financial requirements, international financing institutions will play a critical role in supporting Uzbekistan's hydrogen transition. Organizations such as the European Bank for Reconstruction and Development (EBRD), the World Bank, the Asian Infrastructure Investment Bank (AIIB), and the Green Climate Fund (GCF) have already demonstrated growing interest in renewable energy projects within Central Asia.

Public-private partnership (PPP) mechanisms are expected to become essential instruments for attracting long-term investment. International experience demonstrates that government-backed guarantees, long-term offtake agreements, and stable regulatory conditions significantly improve project bankability. In this regard, cooperation with European industrial consumers - including steel producers, fertilizer manufacturers, and energy companies - may provide stable demand for future Uzbek hydrogen exports.

4.5 Geopolitical, Environmental, and Regulatory Dimensions

Uzbekistan's geopolitical position provides both opportunities and challenges for participation in the emerging global hydrogen economy. The country maintains active economic and diplomatic relations with regional organizations such as the CIS, SCO, and the Eurasian Economic Union, while simultaneously expanding strategic cooperation with the European Union through the Enhanced Partnership and Cooperation Agreement (EPCA) framework [5]. This multi-vector foreign policy strengthens Uzbekistan's role as a potential regional energy and transport hub.

At the same time, environmental sustainability remains a critical consideration. Uzbekistan's experience with the Aral Sea ecological crisis has increased awareness regarding the environmental risks associated with large-scale resource-intensive projects. Therefore, future hydrogen projects must comply with international environmental and social standards, including Environmental and Social Impact Assessment (ESIA) procedures and ESG requirements demanded by international investors and European markets [22].

The regulatory framework for hydrogen development in Uzbekistan is still at an early stage. Currently, the country lacks a comprehensive hydrogen law, dedicated safety standards, and internationally recognized hydrogen certification systems aligned with European Union regulations [6]. This issue is particularly important because the EU's Renewable Fuels of Non-Biological Origin (RFNBO) regulations establish strict requirements regarding renewable electricity sourcing and carbon intensity for imported green hydrogen [4]. Therefore, regulatory modernization and institutional reform will be essential prerequisites for Uzbekistan's successful integration into future European hydrogen supply chains.

4.6 Comparative Analysis: International Hydrogen Strategy Benchmarks

Situating Uzbekistan within the global hydrogen landscape requires structured comparison with countries that have advanced further along the strategic development pathway.

Dimension	Uzbekistan	Saudi Arabia	Australia	UAE	Kazakhstan	Germany
Solar Resource	High	Very High	High	Very High	Medium-High	Low

Dimension	Uzbekistan	Saudi Arabia	Australia	UAE	Kazakhstan	Germany
(GHI)						
Wind Resource	Medium	Medium	Very High	Low	High	High
Water Access	Constrained	Desalination	Coastal	Desalination	Moderate	Abundant
Export Infrastructure	Embryonic	Advanced	Advanced	Advanced	Embryonic	Importing
Institutional Capacity	Developing	Advanced	Advanced	Advanced	Developing	Advanced
Int'l Partnerships	Expanding	Extensive	Extensive	Extensive	Developing	N/A
H_2 Strategy Maturity	Early Stage	Advanced	Advanced	Advanced	Early Stage	Advanced
Cost Competitiveness	Moderate	High	High	High	Moderate	Low

Note: Qualitative ratings based on multi-criteria assessment. Sources: IEA [3], IRENA [8],Hydrogen Council [10], national strategy documents.

Saudi Arabia's NEOM Green Hydrogen Project represents one of the world's largest utility-scale green hydrogen initiatives and provides several important lessons for Uzbekistan [10]. The project demonstrates the importance of integrating renewable electricity generation, electrolysis, and export infrastructure within a single coordinated system in order to reduce transmission losses and improve operational efficiency. At the same time, the concentration of large-scale investments within a single megaproject also highlights potential financial and operational risks.

Australia's hydrogen strategy is characterized by strong renewable resource diversification and direct maritime access to Asian export markets. The Australian government's Hydrogen Headstart program, which provides large-scale production subsidies, illustrates the significant role of state support in accelerating early-stage hydrogen market development [3].

Kazakhstan's experience is particularly relevant for Uzbekistan due to shared regional conditions and infrastructure connections. Kazakhstan adopted its hydrogen strategy in 2022 and has already established cooperation agreements with Germany and Japan while attracting financing from international institutions such as the EBRD and ADB [15]. In addition, Kazakhstan benefits from partial access to existing export pipeline systems connected to regional energy networks, which may also provide transit opportunities for Uzbekistan through future regional cooperation mechanisms.

Germany remains one of the most important potential demand markets for Central Asian green hydrogen because of its industrial structure, climate targets, and large-scale hydrogen import strategy under the REPowerEU framework [11]. Germany's H2Global initiative demonstrates how long-term government-backed purchase agreements can stimulate international hydrogen supply investments. However, Uzbekistan has not yet established a formal bilateral hydrogen partnership agreement with Germany, representing an important gap in the country's international hydrogen diplomacy.

Strategic Recommendations

Based on the findings of this study, several strategic recommendations can be proposed for Uzbekistan's policymakers and international partners:

1. Develop a Comprehensive Hydrogen Regulatory Framework.

Uzbekistan should establish a specialized national hydrogen coordination body responsible for regulation, certification, safety standards, and investment facilitation. The country also needs to adopt internationally recognized hydrogen standards compatible with European Union regulations.

2. Prioritize the Middle Corridor for Export Development.

Infrastructure investments and diplomatic cooperation should focus on the Trans-Caspian Middle Corridor connecting Central Asia with European markets through Kazakhstan, Azerbaijan, Georgia, and Turkey.

3. Launch Pilot Green Hydrogen Projects.

The implementation of medium-scale pilot projects in regions with high renewable energy potential would help demonstrate technical feasibility, attract foreign investors, and build institutional expertise within the domestic hydrogen sector.

4. **Strengthen Cooperation with the European Union and Germany.**

Uzbekistan should accelerate negotiations on bilateral hydrogen cooperation agreements with European partners in order to secure technology transfer, financing opportunities, and long-term export access.

5. Address Water Scarcity Challenges.

Hydrogen development strategies must incorporate sustainable water management solutions, including wastewater recycling technologies and efficient resource allocation systems that avoid competition with agricultural and domestic water consumption.

6. Enhance ESG and Environmental Standards.

Future hydrogen projects should comply with international Environmental, Social, and Governance (ESG) standards and conduct transparent Environmental and Social Impact Assessments (ESIA) in accordance with international financial institution requirements.

CONCLUSION

This study provided a comprehensive assessment of Uzbekistan's potential to become a green hydrogen exporter to the European Union through the analysis of renewable energy resources, hydrogen production economics, export infrastructure, investment mechanisms, and institutional readiness.

The findings indicate that Uzbekistan possesses significant competitive advantages in the emerging global hydrogen economy. In particular, the country's high solar irradiation levels and growing renewable energy capacity create favorable conditions for cost-effective green hydrogen production. Under moderate and optimistic development scenarios, the Levelized Cost of Hydrogen (LCOH) in Uzbekistan could decline below USD 2/kg by the early 2030s, increasing the commercial attractiveness of future hydrogen exports.

At the same time, several major challenges remain. Uzbekistan's double landlocked geography, water scarcity, limited hydrogen infrastructure, and still-developing regulatory framework represent important constraints for large-scale export development. In addition, substantial financial resources and long-term international partnerships will be required to build renewable generation facilities, electrolyser systems, transport corridors, and export logistics networks.

The study also demonstrates that institutional reforms and international cooperation will be as important as technological progress. Alignment with European Union hydrogen certification standards, expansion of public-private partnership mechanisms, and stronger diplomatic engagement with European markets are essential prerequisites for successful integration into future hydrogen supply chains.

Despite existing challenges, the current global energy transition creates a unique strategic opportunity for Uzbekistan. Growing European demand for renewable hydrogen, combined with increasing international investment in clean energy infrastructure, may allow Uzbekistan to position itself as an important regional supplier of green hydrogen in the long term.

Future research should focus on detailed water resource assessments, hydrogen transportation optimization, regional export corridor modelling, and the evaluation of regulatory reforms necessary for the development of a competitive hydrogen economy in Uzbekistan.

REFERENCES

1. UNFCCC. (2015). *Paris Agreement to the United Nations Framework Convention on Climate Change*. United Nations. Available at: https://unfccc.int/process-and-meetings/the-paris-agreement
2. Bockris, J.O'M. (2002). "The origin of ideas on a hydrogen economy and its solution to the decay of the environment." *International Journal of Hydrogen Energy*, 27(7–8), pp. 731–740. https://doi.org/10.1016/S0360-3199(01)00154-7
3. IEA. (2023). *Global Hydrogen Review 2023*. International Energy Agency. Available at: https://www.iea.org/reports/global-hydrogen-review-2023
4. European Commission. (2022). *REPowerEU Plan*. COM(2022) 230 final. European Commission. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2022%3A230%3AFIN
5. Azimov, U., & Komilov, A. (2023). "Uzbekistan's multi-vector foreign policy and Central Asian energy geopolitics." *Central Asian Survey*, 42(2), pp. 187–205. https://doi.org/10.1080/02634937.2022.2153802
6. Ministry of Energy of the Republic of Uzbekistan. (2022). *Roadmap for the Development of the Hydrogen Economy in Uzbekistan*. Tashkent: Ministry of Energy.
7. Staffell, I., Scamman, D., Velazquez Abad, A., Balcombe, P., Dodds, P. E., Ekins, P., & Ward, K. R. (2019). "The role of hydrogen and fuel cells in the global energy system." *Energy & Environmental Science*, 12(2), pp. 463–491. https://doi.org/10.1039/C8EE01157E
8. IRENA. (2022). *Global Hydrogen Trade to Meet the 1.5°C Climate Goal*. International Renewable Energy Agency. Available at: https://www.irena.org/publications/2022/Jul/Global-hydrogen-trade-to-meet-the-15C-climate-goal
9. Buttler, A., & Spliethoff, H. (2018). "Current status of water electrolysis for energy storage, grid balancing and sector coupling via power-to-gas and power-to-liquids: A review." *Renewable and Sustainable Energy Reviews*, 82, pp. 2440–2454. https://doi.org/10.1016/j.rser.2017.09.003
10. Hydrogen Council & McKinsey & Company. (2023). *Hydrogen Insights 2023*. Hydrogen Council. Available at: https://hydrogencouncil.com/en/hydrogen-insights-2023/
11. Schüth, F., Palkovits, R., Schlögl, R., & Su, D. S. (2012). "Ammonia as a possible element in an energy infrastructure: Catalysts for ammonia decomposition." *Energy & Environmental Science*, 5(4), pp. 6278–6289. https://doi.org/10.1039/C2EE02865D
12. European Hydrogen Backbone Initiative. (2022). *Analysing Future Demand, Supply, and Transport of Hydrogen*. EHB. Available at: https://ehb.eu/files/downloads/EHB-Analysing-the-future-demand-supply-and-transport-of-hydrogen.pdf
13. Olczak, M., & Piebalgs, A. (2022). *What Does the REPowerEU Plan Mean for Green Hydrogen?* Florence School of Regulation Policy Brief 2022/12. European University Institute.
14. Overland, I., Loginova, J., & Vakulchuk, R. (2022). *The Geopolitics of the Global Energy Transition*. Springer International Publishing. https://doi.org/10.1007/978-3-030-39066-2
15. Zhakupova, A., Seitkali, D., & Abilev, M. (2023). "Kazakhstan's hydrogen strategy: Prospects and institutional challenges." *Resources Policy*, 85, 103957. https://doi.org/10.1016/j.resourpol.2023.103957
16. World Bank. (2022). *Renewable Energy Export Corridors from Central Asia: Technical and Economic Assessment*. Washington D.C.: World Bank Group.
17. Buriev, T. (2023). "Uzbekistan's Energy Sector Reforms and the Green Hydrogen Frontier." *Post-Soviet Affairs*, 39(4), pp. 312–330. https://doi.org/10.1080/1060586X.2023.2198452
18. World Bank Group. (2023). *Global Solar Atlas 2.0*. Available at: https://globalsolaratlas.info
19. IRENA. (2023). *Renewable Power Generation Costs in 2022*. International Renewable Energy Agency. Available at: https://www.irena.org/publications/2023/Aug/Renewable-Power-Generation-Costs-in-2022
20. Technical University of Denmark. (2023). *Global Wind Atlas 3.0*. Available at: https://globalwindatlas.info