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COUNTRY RISK ANALYSIS FOR THE DEVELOPMENT OF GREEN HYDROGEN ECOSYSTEM: CASE STUDY OF LANDLOCKED COUNTRIES

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Abstract
The global pursuit of decarbonization has elevated green hydrogen as a critical component of the future energy mix. While many coastal nations are rapidly advancing green hydrogen projects, landlocked countries face a distinct set of barriers that hinder their participation in this emerging market. These include challenges related to transport logistics, infrastructure limitations, water scarcity, and geopolitical dependencies. This paper provides a country risk analysis for the development of green hydrogen ecosystems in landlocked nations, focusing on Central Asia and selected African states. Using a multi-criteria framework combining PESTLE and SWOT analysis, the study identifies key risk factors—political, economic, environmental, and technological—and proposes strategic pathways to mitigate these risks. The findings highlight the need for regional cooperation, tailored investment models, and integrated policy reforms to enable landlocked countries to harness the potential of green hydrogen for sustainable development.

Keywords: Green hydrogen, country risk analysis, landlocked countries, renewable energy, sustainable development, hydrogen infrastructure, energy policy, PESTLE analysis, Central Asia, water scarcity.

Introduction

The urgent global need to reduce greenhouse gas emissions has accelerated the search for clean and sustainable energy sources. Among these, green hydrogen—produced through the electrolysis of water using renewable energy—has emerged as a promising solution for decarbonizing various sectors, including industry, transport, and power generation. As countries seek to meet climate targets and transition to low-carbon economies, green hydrogen is increasingly recognized not only as an energy carrier but also as a strategic tool for energy security and economic diversification.

However, the development of green hydrogen ecosystems is highly dependent on geographical, infrastructural, political, and economic contexts. Landlocked countries, which lack direct access to international maritime trade routes, face unique constraints in participating in the global hydrogen economy. These constraints include high logistics costs, reliance on transit through

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neighboring countries, limited export infrastructure, and challenges related to water availability—an essential input for hydrogen production.

Despite these obstacles, many landlocked countries—especially in Central Asia and Sub-Saharan Africa—possess significant renewable energy potential (such as solar and wind), which positions them as future players in green hydrogen production if risks are properly managed. Yet, country-specific risks remain a major barrier to investment and implementation of hydrogen projects.

This paper aims to explore the country-level risks associated with developing green hydrogen ecosystems in landlocked countries. By applying a structured analytical framework, including PESTLE and SWOT analyses, the study identifies the key factors that influence the feasibility and sustainability of hydrogen development in these regions. Case studies from selected countries such as Uzbekistan, Kazakhstan, and Rwanda are used to illustrate common challenges and propose context-sensitive strategies.

Literature Review

The global momentum toward green hydrogen development has generated a growing body of academic and policy-focused literature. Green hydrogen is widely regarded as a key enabler of the global energy transition, particularly due to its potential to decarbonize hard-to-abate sectors and support long-term energy storage (IRENA, 2022; Hydrogen Council, 2023)[1]. Countries with abundant renewable energy resources are actively exploring hydrogen as an export commodity, while international agencies emphasize the need for coordinated policy, infrastructure investment, and innovation support.

However, most existing studies focus on coastal or industrialized nations with advanced infrastructure, leaving a gap in the literature concerning the specific risks and challenges faced by landlocked countries. These nations, despite often having vast solar and wind energy potential (especially in Central Asia and Sub-Saharan Africa), confront significant barriers in entering the green hydrogen market.

Several key themes emerge from the existing literature:

- Infrastructure and logistics constraints: According to the World Bank (2021), landlocked countries suffer from higher transport costs and greater dependence on transit countries, which complicates the export of green hydrogen or its derivatives (such as ammonia).
- Water resource challenges: Studies by the International Energy Agency (IEA, 2023)[2] highlight that green hydrogen production is water-intensive. Many landlocked countries face water scarcity or rely on shared water basins, adding a layer of environmental risk to hydrogen development.
- Policy and governance gaps: According to reports by UNCTAD (2022)[3] and the African Development Bank (2022)[4], inconsistent energy strategies, regulatory uncertainty, and lack of

[1] International Renewable Energy Agency (IRENA). (2022). *Green hydrogen: A guide to policy making*. Abu Dhabi: IRENA.
[2] International Energy Agency (IEA). (2023). *Global hydrogen review 2023*. Paris: IEA Publications. https://www.iea.org/reports/global-hydrogen-review-2023
[3] UNCTAD. (2022). *Trade and transport corridors in landlocked developing countries: Current issues and way forward*. Geneva: United Nations Conference on Trade and Development.
[4] African Development Bank. (2022). *Unlocking the potential of green hydrogen in Africa*. Abidjan: AfDB Publications.

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investment incentives in landlocked countries reduce their attractiveness to investors in clean energy sectors.

- Financial and technical capacity: Research also points to the limited availability of local expertise, weak research ecosystems, and underdeveloped green finance markets as key impediments (IRENA, 2022; ESCAP, 2021)[5].

Although some recent pilot projects—such as those in Uzbekistan and Namibia—show promise, there remains a need for more empirical research and risk-oriented analysis tailored to the geopolitical and economic realities of landlocked states.

This study seeks to address this gap by analyzing risks from a country-specific perspective and offering a comparative framework to assess green hydrogen readiness in landlocked regions.

Methodology

This study adopts a multi-method qualitative approach to assess the risks associated with the development of green hydrogen ecosystems in landlocked countries. Given the complex and multifaceted nature of the topic, the research combines descriptive analysis, comparative case study, and contextual risk evaluation tools.

The methodology is built on the premise that country-level risks for green hydrogen projects are influenced by a mix of political, economic, infrastructural, and environmental factors. To capture these dimensions, the study uses two complementary tools:

- PESTLE analysis, to systematically review macro-environmental conditions.
- SWOT analysis, to understand each country's internal strengths and vulnerabilities in the hydrogen sector.

This dual analysis enables a holistic understanding of both risks and opportunities specific to landlocked nations.

Each country was analyzed using a customized risk mapping approach, which included:

- Identifying and describing country-specific risk factors
- Assessing the severity and likelihood of each risk
- Evaluating the capacity of the government or private sector to manage or mitigate the risks
- Comparing countries based on their overall readiness to support green hydrogen development

This methodology allows the study to go beyond generalized discussion and offer policy-relevant insights tailored to landlocked countries' unique contexts.

Result and Discussion

This section presents the findings from the PESTLE and SWOT analyses for the selected landlocked countries—Uzbekistan, Kazakhstan, and Rwanda—and discusses the common and country-specific risks related to the development of a green hydrogen ecosystem.

Uzbekistan has demonstrated growing political interest in renewable energy and green hydrogen, with support from international partners such as ACWA Power and the European Bank for Reconstruction and Development (EBRD). Its strengths include abundant solar resources, a

[5] International Renewable Energy Agency (IRENA). (2022). *Green hydrogen: A guide to policy making*. Abu Dhabi: IRENA.

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centralized governance model that enables rapid policy implementation, and a relatively stable political environment.

However, the country faces major risks, such as:

- Water scarcity, especially in the arid regions where solar projects are located
- Limited hydrogen infrastructure, including lack of pipelines, storage, and transport facilities
- Regulatory uncertainty, due to the absence of specific laws or incentives for hydrogen projects

Despite these risks, Uzbekistan's integration into regional energy corridors and its interest in exporting to East Asia and Europe represent significant opportunities.

Kazakhstan is among the most resource-rich countries in Central Asia and has recently announced plans to become a hydrogen exporter. The country benefits from:

- Large wind and solar potential, particularly in the steppe regions
- Strong foreign investment ties, especially with the EU and China
- A relatively advanced energy infrastructure compared to other regional peers

Nonetheless, key threats include:

- Geopolitical risks due to dependence on Russian transport corridors
- Policy fragmentation, as hydrogen is not yet fully integrated into national energy planning
- Environmental concerns, such as water overuse in industrial zones

Kazakhstan's readiness to attract large-scale projects is evident, but long-term success will depend on coordinated planning and risk mitigation.

Rwanda is emerging as a leader in sustainable development in East Africa, with strong government commitment to green energy. Although its hydrogen potential is still in an exploratory phase, the country stands out for:

- Clear visionary leadership and political stability
- International cooperation and support from development partners
- Emphasis on innovation and digital energy management systems

However, Rwanda faces significant structural weaknesses:

- Very limited renewable capacity for large-scale hydrogen production
- Inadequate infrastructure, particularly in transport and energy storage
- High dependency on international financing

While hydrogen may not be immediately feasible at scale in Rwanda, the country can serve as a pilot model for decentralized or regional cooperation-based hydrogen projects in Sub-Saharan Africa.

Across all three countries, several common risk themes emerged:

- Infrastructure gaps: Lack of hydrogen-specific facilities hinders scalability
- Policy uncertainty: Absence of dedicated hydrogen frameworks reduces investor confidence
- Water resource constraints: All countries require water management strategies to support hydrogen production sustainably

At the same time, there are also shared opportunities:

- Abundant renewable energy potential
- Growing international interest in hydrogen investments
- The strategic value of positioning as regional energy hubs

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To address these risks, governments must:

- Develop clear, long-term hydrogen strategies
- Strengthen regional cooperation for trade, water, and infrastructure integration
- Create blended finance models to attract both public and private investment

Table 1: Comparative Risk Assessment for Green Hydrogen Development in Selected Landlocked Countries[6]

Risk Factor	Uzbekistan	Kazakhstan	Rwanda
Political Stability	Medium – centralized leadership, but reform process ongoing	Medium – stable but influenced by Russia-China dynamics	High – strong governance and investor-friendly environment
Energy Infrastructure	Low – under development for hydrogen	Medium – partially suitable for hydrogen	Low – limited infrastructure and grid access
Water Availability	Low – severe water stress in key regions	Low – water stress in industrial zones	Medium – seasonal limitations
Policy and Regulation	Low – lack of hydrogen-specific policy	Medium – partial integration in energy plans	Low – no defined hydrogen roadmap yet
Transport & Export	Medium – dependent on regional corridors	Low – reliant on Russian/Chinese access	Low – landlocked with poor connectivity
Renewable Resource Potential	High – strong solar radiation	High – wind and solar rich areas	Medium – limited large-scale solar/wind
Access to Finance	Medium – growing donor/investor interest	High – international project funding available	Low – dependent on aid, limited private sector
Technical Expertise	Low – early-stage R&D and training	Medium – improving, but still limited	Low – emerging innovation base

This table provides a structured comparison of critical risk factors affecting the development of a green hydrogen ecosystem in three landlocked countries: Uzbekistan, Kazakhstan, and Rwanda. Each factor is assessed based on country-specific conditions and categorized as High, Medium, or Low depending on its potential impact.

Key Insights:

- Uzbekistan faces challenges in water availability and regulatory frameworks but has excellent solar potential and growing regional integration.
- Kazakhstan shows moderate political risk and strong international investment appeal but is vulnerable to export dependence and fragmented energy policies.

[6] Author created

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- Rwanda offers a politically stable and innovation-driven environment, yet it struggles with infrastructure and financing barriers.

Risk Level Legend:

- High = Advantageous / Low Risk
- Medium = Moderate Risk
- Low = High Risk / Constraint Present

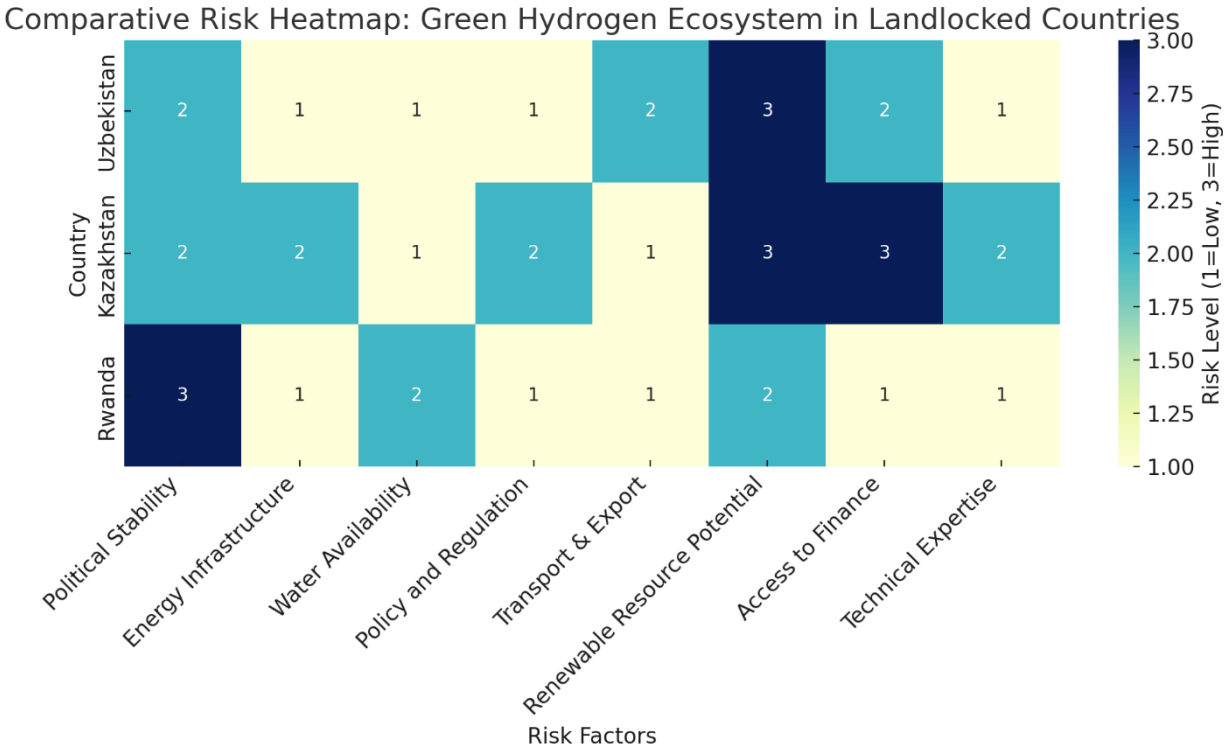

Figure 1: Comparative Risk Heatmap for Green Hydrogen Ecosystem Development in Landlocked Countries[7]

This heatmap illustrates the comparative country risk assessment for developing a green hydrogen ecosystem in three selected landlocked countries: Uzbekistan, Kazakhstan, and Rwanda. The analysis evaluates each country across eight key risk factors, with values normalized on a 1-to-3 scale:

- 1 = Low Risk / Strong Performance (shown in dark blue)
- 2 = Medium Risk / Moderate Performance (shown in light green-blue)
- 3 = High Risk / Weak Performance (shown in yellow-green)

Risk Factors Evaluated:

1. Political Stability – Governance continuity and policy risk
2. Energy Infrastructure – Grid, storage, and production readiness
3. Water Availability – Access to sustainable water resources
4. Policy and Regulation – Existence of hydrogen-specific legal frameworks

[7] Author created

5. Transport & Export Capacity – Connectivity and export corridor access
6. Renewable Energy Potential – Solar and wind resource availability
7. Access to Finance – Availability of public and private investment
8. Technical Expertise – Local knowledge, R&D, and labor skills

Insights:

- Kazakhstan shows strong renewable potential and finance access but faces geopolitical and policy integration risks.
- Uzbekistan benefits from high solar availability but is challenged by water scarcity and regulatory uncertainty.
- Rwanda demonstrates strong political will and innovation capacity but lacks infrastructure and investment depth.

The heatmap helps visualize which risk areas dominate in each country, guiding policymakers, investors, and international partners in strategic planning, capacity-building, and risk mitigation efforts for green hydrogen development in landlocked contexts.

Conclusion

The global transition toward decarbonized energy systems has accelerated the strategic interest in green hydrogen as a clean, versatile, and scalable energy carrier. For landlocked countries, where geographical constraints often translate into economic and energy vulnerabilities, the development of a green hydrogen ecosystem offers a unique opportunity to reduce carbon emissions, improve energy independence, and participate in emerging global energy markets. This study conducted a multidimensional country risk analysis focusing on Uzbekistan, Kazakhstan, and Rwanda, aiming to uncover the enabling and inhibiting factors for green hydrogen development within landlocked contexts.

The comparative assessment revealed that although landlocked countries face structural and logistical disadvantages, they are not homogenous in their risk exposure. Each country possesses distinct comparative advantages:

- Uzbekistan benefits from exceptional solar irradiation and growing political commitment to renewable energy, but suffers from water scarcity and underdeveloped hydrogen policy frameworks.
- Kazakhstan holds vast wind and solar resources and enjoys better access to international capital, yet remains exposed to political fluctuations and a heavy reliance on fossil fuel infrastructure.
- Rwanda has made notable progress in governance, innovation, and institutional reform but faces acute limitations in infrastructure, export logistics, and technical workforce readiness.

The heatmap analysis and SWOT framework provided a visual and analytical synthesis of these risks, enabling a nuanced understanding of how various factors intersect across political, technical, environmental, and financial dimensions. The findings suggest that while no country is risk-free, targeted policy interventions, regional cooperation, and international financing mechanisms can significantly lower the barriers to entry for green hydrogen development in landlocked regions.

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To unlock the full potential of green hydrogen in these countries, several strategic priorities are recommended:

- Develop national hydrogen roadmaps aligned with climate goals and industrial strategies;
- Invest in cross-border infrastructure and logistics, especially for transport and export corridors;
- Enhance regional water management cooperation to ensure resource sustainability;
- Promote technology transfer and workforce development through public-private-academic partnerships;
- Create enabling investment climates, leveraging multilateral institutions and green finance instruments such as climate funds and green bonds.

In conclusion, landlocked status should not be viewed as a limiting factor but as a planning parameter that can be effectively managed with the right mix of innovation, governance, and international collaboration. With coordinated action and a long-term vision, countries like Uzbekistan, Kazakhstan, and Rwanda have the potential to become regional leaders in the green hydrogen transition—contributing not only to their own sustainable development but also to global decarbonization efforts.

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